Managing an urban forest:
Have street tree populations of
Acer platanoides invaded forested parks?

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This study examined the existing, or potential, risk of invasion by street trees into an urban forested park (Breithaupt Park, a 32.5 hectare semi-forested park, and its surrounding residential neighbourhood in the City of Kitchener.). The primary research question is: What are the spatial distribution and dispersal patterns of street trees and park trees in urban areas? For street populations, height, crown spread, diameter at breast height (DBH), tree condition, trunk condition and foliage transparency were measured. Qualitative tree health indicators were used to gauge the condition of the street tree population only. For trees in Breithaupt Park, a point-quarter sampling method combined with a line-plot sampling method was used. There were 33 identified (and several unidentified) species of street trees and 24 identified species of forest trees. *Acer platanoides* was the most abundant street tree species, while *Acer saccharum* was the most abundant forest tree species. 52% of the street tree population and 9% of the forest tree population were exotic species; however, the exotics were mainly species not originating from the nearby streets (i.e. *Rhamnus cathartica*). Despite the well-established population of exotic invasive species such as *Acer platanoides* on the streets, spatial assessment of the nearby forested park revealed that relatively few exotic species had actually established there. *Acer platanoides* composed 1.9% of all trees, 3.2% of all saplings and 2.7% of all seedlings in the forest sample. The four possible sources of *Acer platanoides* seeds were trees planted on the street, trees planted in backyards, the leaf drop site in the parking lot of Breithaupt Park (only in the fall) and trees potentially planted directly in the forest. Explanations for the lack of invasion by *Acer platanoides* (in particular) include: 1) houses located between *Acer platanoides* street trees and Breithaupt Park functioning as a barrier to seed dispersal; 2) the highway traversing the northeast corner of the park; 3) the short length of time since *Acer platanoides* street trees reached their age of maturity to produce enough viable seeds to invade the forest and the lag time in the establishment phase; 4) unique park characteristics; and 5) opposing predominant wind directions. While *Acer platanoides* may be more invasive under different circumstances, it was concluded that *Acer platanoides* is not currently invading the park at a considerable rate but may be tending towards a future invasion. The main recommendations are: 1) to not cut down the *Acer platanoides* currently growing as street trees as they do not pose a high risk of invasion (though this is specific to the current study); 2) to manage the forest for invasive species and remove and restore the ecology of the forest as necessary; 3) to remove *Acer platanoides* currently growing in the forest; and 4) to replace dead street trees with non-invasive, hardy native trees instead of the historical planting of *Acer platanoides* and other exotics, in case the risk of invasion changes because of climate or urban design changes.

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Chapter 1 - Introduction

1.1. Background

As urban development increased considerably at the beginning of the twentieth century and again after the Second World War, a substantial number of trees were planted in urban subdivisions throughout Canada (CBC News Online, 2005a; Moll and Urban, 1989). This phenomenon occurred in the cities of Kitchener and Waterloo, where currently, many trees as old as fifty to seventy-five years (some even older) can be seen lining residential streets (CBC News Online, 2005a; Grand River Conservation Authority (GRCA), 2004a). Both native and exotic trees were planted and are currently found on the streets of these residential neighbourhoods and in more 'natural' areas such as forested parks and habitat corridors in urban areas (GRCA, 2004a). These trees together form the urban forest, defined as "the street trees, park and cemetery trees, and yard trees in cities, towns and suburbs" (United States Department of Agriculture Forest Service (USDA Forest Service), 2005, p. 1). It is thought that street tree populations can function as an entry point for invasive species as these species of trees are often horticultural cultivars or introduced exotic species planted in gardens and yards and on streets (Farr, 2004). From there, invasive species can disperse into local natural forests, changing the forest structure (Farr, 2004). This potential problem is demonstrated by the twentieth century's most commonly planted street tree, *Acer platanoides* (Norway maple), as there are indications that *Acer platanoides* is capable of invading local forested parks from residential streets, resulting in a decrease in the ecological integrity of the urban forest as a whole (Lanken, 1992; Webb and Kaunzinger, 1993). Invasive species are native or exotic species that have a high reproductive capability and proliferate within certain environments to such an extent that they begin to have significant, negative ecological effects on other species in that environment (Kendle and Rose, 2000; Raloff, 2003). For all ecosystems, it is imperative that the extent of invasion be established, and that it is determined whether it is necessary to remove the source of the invasive species. This source includes both street trees and trees planted on private property, which produce seeds that can ultimately disperse into forested parks.

The purpose of this study is to examine the spatial distribution and dispersal of the trees in the urban forest. This study will utilize the theories of urban forest ecology and its associated theories to inform a methodological approach based on quantitative and qualitative observations of the urban forest ecosystem. It will specifically examine the question of whether exotic trees which are planted as street trees are successfully establishing themselves in nearby urban forested parks. A further aim of this research is to determine whether other species of trees should be planted on the residential streets and in the forested parks of the case study site, an urban forest in the city of Kitchener, instead of the current abundant planting of exotic species such as *Acer platanoide*s The main ecological benefit this would provide would be to reduce the potential for invasive exotic species to invade nearby urban forested parks, if this is indeed occurring. The methodology, results and conclusions of this study will be beneficial to the urban ecology academic community and urban foresters in all municipalities where forested areas and streets meet. It will be especially useful for the urban foresters of Kitchener who are currently drafting an urban forest management plan.

1.2. Research Questions

The primary research question for this study is:

> What are the spatial distribution and dispersal patterns of street trees and forested park trees in urban areas?

The secondary research questions for this study are the following:

- What is the relationship, if any, of exotic tree species planted on the residential streets with those found in the nearby forested parks?
- Has the study site notably changed since the last forest study?
- What is the condition of the street tree population and the forest tree population?
- How transferable are the results of this study to similar urban areas?
- What recommendations can be made for Kitchener’s urban forest management policies to improve the long-term viability of Kitchener’s residential street trees and forested parks?
- Are there ecological benefits in replacing exotic species of trees with native species in Kitchener’s urban forest?

1.3. Research Objectives

The research objectives of this study are the following:

1) to perform an inventory of the various types of tree species found in a case study area of Kitchener's urban forest;
2) to determine the general condition of Kitchener's street trees;
3) to examine the spatial dispersal of exotic street trees into nearby forested areas;
4) to ascertain whether there are negative ecological effects in having *Acer platanoides* as the most predominantly planted street tree in Kitchener;
5) to develop baseline tree inventory data which can be used for future research; and
6) to make recommendations to the City of Kitchener concerning their urban forest management plans.

Chapter 2 – Literature Review

2.1. Conceptual Framework

The concept of ecological integrity is the perceptual lens through which the underlying theoretical framework for this research will be examined (Figure 1). This theoretical framework is based on the theory of urban forest ecology and its associated theories: landscape ecology, invasive species ecology, tree biology and urban environmental planning. Urban forest ecology and its associated theories will guide the methodological approach used in this study to effectively answer the research questions. An ecological assessment will be performed, involving qualitative and quantitative measurements of the urban forest and spatial and statistical analyses of the collected data. Recommendations for urban forest management plans, such as that drafted by the City of Kitchener, will be informed by an evaluation of the results of the ecological assessment.

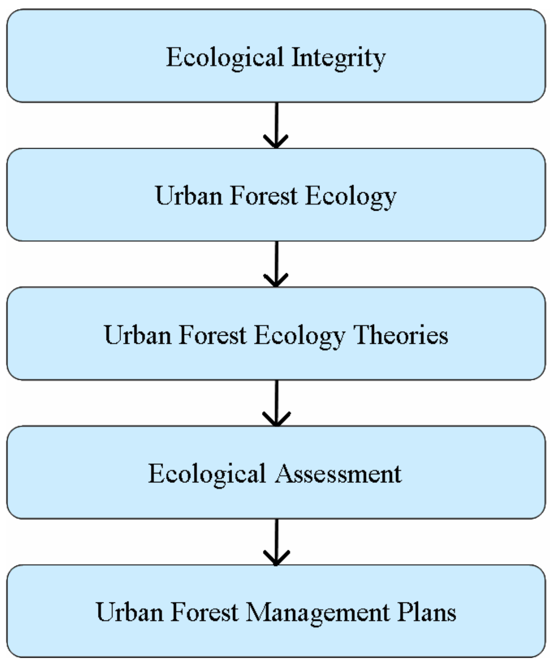


Figure 1. Conceptual Framework

2.2. Ecological Integrity

Parks Canada (2007) defines ecological integrity as “a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes”. Ecosystems with high ecological integrity are those that have high biodiversity in combination with sustainable normal ecosystem functioning and ideally, strong components such as healthy trees (Society for Ecological Restoration International Science and Policy Working Group (SER), 2004). Thus, ecological integrity can be evaluated by comparing the condition of the study site with that of the past and the standard of the natural region that it is in, and assessing the presence and abundance of native species and the structure and function of the ecosystem as a whole. Interpretation of Parks Canada's (2007) definition means that the presence of exotic species does not necessarily represent a system with less ecological integrity, unless these species alter key structure, function and processes. This is important for urban forests as very few can be expected to be pristine, native-only communities without the direct influence of humans.

2.3. Urban Forest Ecology

The theory of urban forest ecology is a relatively recent theory which has effectively united the theories of forestry and ecology in the consideration of an urban setting (Rowntree, 1988). It has advanced through a growing recognition and appreciation of the benefits and values of the urban ecosystem and has evolved from a focus on pure management of tree growth to a science in which the ecological benefits of vegetation in urban areas are recognized and integrated into environmental planning and management plans (Konijnendijk, 2003). Urban forest ecology incorporates social values and scientific information in an attempt to manage ecosystems in urban areas such that they are as productive and ecologically and socially valuable as possible. In addition to using unique methods that are not utilized in the traditional field of forestry, urban forest ecologists also tend to focus on improving the structure and function of the urban forest for their ecological, social and non-traditional economic values (Nowak et al., 2002b). Many of the problems encountered by urban forest ecologists are related to the degradation of the urban forest due to the unique stresses of it being in an urban environment (Quigley, 2004). Ecologists are often guided by the theories of restoration ecology in the mitigation of these problems (Hobbs and Harris, 2001; Kuuluvainen et al., 2002).

The urban forest is a unique ecosystem experiencing different combinations of stressors than many other ecosystems. It therefore requires site-specific research in addition to special strategies and policies to govern its management and design. The four major problems that are currently encountered in the field of urban forest ecology are: 1) mass urban tree death; 2) invasive species; 3) management plans lacking scientific justification; and 4) lack of appreciation of the ecological, social and economic values of the urban forest (CBC News Online, 2005a; Duncan, 2005; Kendle and Rose, 2000; Miller, 2005). Trees in the urban forest also encounter many stressors that their rural conspecifics are either not subjected to at all, or are subjected to at a lower frequency or magnitude (Table 1). Although there are many hardships encountered by the typical tree in an urban setting that are often not conducive to healthy growth, it can also provide numerous ecological, social and economic benefits to the urban population (Table 2).

Table 1. Stressors of Urban Trees

Type of Stressor	**Examples**
Directly Anthropogenic	pollution, urbanization, paving, winter salting, pruning, construction, vandalism, recreational use, impervious surfaces, poor planting, plowing, snow loading, planting of exotic species
Ecological	effects of urban animals and invasive species, disturbed soil profiles, disease, insect infestations, fragmentation
Chemical	soil, water and air pollution
Hydrological	increased runoff, increased evaporation from pavement, restricted water infiltration and deep infiltration, inadequate drainage, drought
Climatological	urban heat island effect, climate change

(Duncan. 2005; Langdon, 2005; MacDonald, 1996; Miller, 2005; Ministry of Natural Resources, 2002; Moll and Urban, 1989; Perkins, 2004; Quigley, 2002; Quigley, 2004; Raloff, 2003)

Table 2. Benefits of Trees

Type of Benefit	**Examples**
Ecological	improving air and water quality, preventing erosion, moderating air temperatures, removing air pollutants, sequestering carbon dioxide, producing oxygen, filtering groundwater, cycling minerals and nutrients, absorbing chemicals, reducing wind velocity, providing wildlife habitat, reducing runoff, reducing stormwater flow, mitigating the urban heat island effect
Economic	increasing property values, reducing the need for heating and air conditioning, developing the local economy, increasing tourism
Social	providing shade, providing areas for recreation, controlling urban reflection, improving the aesthetic value of the urban landscape, reducing noise pollution, maintaining a sustainable city, contributing to better mental health

(Brack, 2002; Chiesura, 2004; Davis, 1995; Dwyer et al., 1992; Kenney and Rusak, 2005; MacDonald, 1996; McLean, 2002; McPherson et al., 1994; Miller, 1997; Moll, 1989; Rowntree, 1988; Schroeder, 1989; Tagtow, 1990; Ulrich, 1981; Wong, 1999)

2.4. Associated Theories of Urban Ecology

Landscape Ecology

Landscape ecology is concerned with the interactions and connections of stands or patches of forest with each other. Examples of these interactions may include connection via the dispersal of seeds or via habitat corridors (Silva Ecosystem Consultants, 1992). Landscape ecology is defined by Bell et al. (1997) as being the "study of processes occurring across spatially defined mosaics (landscapes), and the abiotic and biotic responses to those processes" (p. 318). Landscape ecology is based on the concept that spatial relationships have an effect on the structure and function of individual ecosystems. The three most important principles of landscape ecology are: 1) time and space; 2) heterogeneity; and 3) connectivity (Silva Ecosystem Consultants, 1992).

The theories of fragmentation and connectivity are closely related in the study of landscape metrics as they are both forms of conservation strategies involving spatial analysis (Tischendorf and Fahrig, 2000). A study of fragmentation involves an examination of the processes whereby a fragmented landscape is created and quantification and spatial analyses of the fragmented habitats occurs (Ministry of Natural Resources, 2002). Connectivity examines how connected the patches of a landscape are to each other and how these patches can be ideally connected to each other through habitat corridors (Ministry of Natural Resources, 2002). Connectivity can be defined as "the degree to which the landscape facilitates or impedes movement among resource patches" (Tischendorf and Fahrig, 2000, p. 633). In essence, fragmentation and connectivity are not inversely related, as a landscape with high fragmentation can be considered to have high connectivity (Tischendorf and Fahrig, 2000). Both fragmentation and connectivity theories involve a spatial analysis of the patches of different land types in a landscape and the effects that these have on movement, dispersal and habitat condition of local flora and fauna (Tischendorf and Fahrig, 2000). At a regional scale, the study of the fragmentation and connectivity between urban forests is important as they influence the ecological integrity of the urban forest, and often determine the viability of certain species being planted on the edges of these patches or being planted to provide functional habitat corridors (Neel et al., 2004).

The creation of forest edges and the formation of patches are a result of fragmentation. This edge is a transitional zone where biotic and abiotic properties such as different microclimatic conditions than that of the interior of the patch or that of the surrounding land (Meffe and Carroll, 1997). Edge effects, such as differences in the amount of wind, direct sunlight, shade, air temperature and humidity, that exist between the edge of a forested area and its interior will influence the type of species found in edge habitats (Bell et al., 1997; Murphy and Martin, 2001). Different tree species and unique understory species not found in the interior of forested areas may be found at this edge. The empirical determination of an edge is complicated as it is a zone of transition and it is difficult to decisively ascertain where the edge of a habitat patch ends and the interior patch begins (Fernandez et al., 2002). Area to perimeter ratio is often used as a quantitative indicator of the effect of the edge (Fernandez et al., 2002). Another term, boundary, is used both in reference to a sharp edge, and in reference to a wider, more gradual edge in which there is a more substantial zone of transition allowed between two different habitat types (Cadenasso et al., 2003; Fagan et al., 2003). Edge effects must be considered in the analysis of species survival in a certain location as the influences of urban stresses (e.g. salting, pavement, high winds) may be higher at these edges. Edge habitat is often more conducive to establishment by invasive and exotic species (either plant or animal) and thus edge effects can have a considerable impact on the species composition of the forest (Harper et al., 2005). Edge conditions and their characteristics ideal for invasion by exotic species must be considered in urban forest management strategies.

Invasive Species Ecology

An exotic species is a plant or animal “that was introduced into an area where it did not previously occur through relatively recent human activities” (SER, 2004). An exotic species is also known as an alien species, a non-indigenous species or an introduced species (Kendle and Rose, 2000). Ecological benefits of exotic species may include “structural diversification and niche creation, food supply, facilitation of regeneration of natives (nurse species), modification of disturbance (e.g., reducing erosion or fires) and directly compensating for the loss of a native that was important for ecosystem function” (Kendle and Rose, 2000, p. 23). While some of these traits may be necessary for providing healthy urban forests that are able to contribute many ecological benefits to the urban environment while being resilient to its stresses, exotic species have a higher likelihood of being invasive than do native species (Kendle and Rose, 2000). However, scientific evidence does show that only 10 introduced species out of 1000 will become aggressively invasive (Raloff, 2003).

Invasive species can be native or exotic, floral or faunal, and can have many negative effects on their surrounding ecosystem including displacement of native species and potentially negative effects on productivity and ecological processes (Davies and Sheley, 2007; Martin, 1999). Their traits include: having an ability to grow in a wide variety of environments, being a hardy species, having even greater and more rapid reproduction and growth than they would in their native territories and negatively affecting the growth of native species, often because they have fewer natural enemies in a new particular environment (Martin, 1999; Sanford et al., 2003). Invasive species place a large amount of stress on an ecosystem by changing its local micro-climate to conditions not optimal for other species' growth (Martin, 1999). They can do this by changing the pH of the soil, shading the understory and by increasing competition for natural resources (Metsger, 2000). For example, the invasive exotic *Acer platanoides* not only has a high reproductive ability in its introduced environments, but also shades native trees such as *Acer saccharum*, preventing their growth as well (Sanford et al., 2003). Examples of invasive flora and fauna in Southern Ontario include: *Dreissena polymorpha* (zebra mussel), *Rhamnus frangula* (glossy buckthorn), *Elaeagnus angustifolia* (Russian olive), *Betula pendula* (silver birch), *Ailanthus altissima* (tree of heaven), *Lythrum salicaria* (purple loosestrife), *Morus alba* (white mulberry) and *Hedera helix* (English ivy) (Claudi et al., 2002; Duncan, 2005; Sanford et al., 2003; Waldron, 2003). Invasive species also include disease and insects which have negatively affected the forests of Southern Ontario. Examples of these include Chestnut blight fungus (*Cryphonectria parasitica*); Dutch elm disease (*Ophiostoma ulmi*); emerald ash borer (*Agrilus planipennis*); gypsy moth (*Lymantria dispar*) and the Asian long-horned beetle (*Anoplophora glabripennis)* (Ontario Forestry Association (OFA), 2000; OFA, 2004; Farr, 2004; Pain, 2004; Langdon, 2005).

Tree Biology

Acer platanoides is often described as a majestic tree, which can grow to an average of 12-30m in height at maturity, with a crown spread of 15m and a diameter at breast height (DBH) that has the potential to reach 190cm (Miller, 1997; Munger, 2003). This species, with over 100 cultivars, has an expected lifespan in urban areas of 100 years, but often only lives 55-70 years (CBC News Online, 2005b; Lanken, 1992; Munger, 2003). *Acer platanoides* is a species native to Europe and western Asia, and was introduced to the United States in the late 18th century (Munger, 2003; Nowak and Rowntree, 1990). *Acer platanoides* is often stated as being a congener of the native *Acer saccharum* (sugar maple), but is distinguishable by its milky juice, the regular diamond pattern found on its grey trunk, its samaras with wings at an obtuse angle and its plump purplish-green or reddish-purple terminal buds (Farrar, 2005; Munger, 2003). It is a late successional, monoecious and insect-pollinated species whose fruit (samaras) germinate in the spring, and mature and disperse in late summer or fall (Farrar, 2005; Munger, 2003). Its age of maturity is 25 to 30 years old, and at this age, viable seed production begins (Wangen and Webster, 2006). The wind-dispersed samaras which carry its seeds can travel an average of 50m from the parent tree in a 10km/hr wind (Matlack, 1987).

In the twentieth century, *Acer platanoides* was a favourite tree for planting on streetscapes due to its aesthetic appeal, rapid growth and its hardiness to the major stressors of urban areas such as pollution, disease and compacted soils (Lanken, 1992; Munger, 2003; Metsger, 2000; Meiners, 2005). It has been widely planted in North America and is credited as being the most commonly planted street tree in the twentieth century (Munger, 2003; Lanken, 1992). In forests, *Acer platanoides* establishes in canopy gaps, in edge habitat and in the interior (Munger, 2003). *Acer platanoides* has proven to be a successful invasive species in North America due to its ability to shade out other forest species, precluding the growth especially of shade intolerant native species, which quickly allows it to become dominant (GRCA, 2004a). *Acer platanoides* produces many seeds which have the opportunity to establish, forming many shade-tolerant seedlings (Raloff, 2003; Munger, 2003; Meiners, 2005). Though seeds may establish themselves in the forest, a considerable lag time may exist between the dispersal of the seeds into the forest and range expansion, which is indicative of invasion (Wangen and Webster, 2006). The success of *Acer platanoides'* seedling establishment and growth in comparison to *Acer saccharum* may be explained by differences in seed physiology and predation (Meiners, 2005). *Acer platanoides* seeds are much larger (65% greater in mass) than those of *Acer saccharum* and have a much lower rate of predation (Meiners, 2005). *Acer platanoides* seedlings also tend to be 98% larger than those of *Acer saccharum* due to the larger seed size (Meiners, 2005). The larger seeds of *Acer platanoides* give it a competitive advantage as its larger seedlings produce more shade, are shade tolerant and tolerate herbivory (Meiners, 2005). Since many trees and groundcover are unable to grow under such dense shade, fewer species can grow, resulting in a lower biodiversity of the forest (GRCA, 2004b). Although *Acer platanoides* is credited with being an excellent urban tree, it does have its own limitations, including the tendency to girdle itself with its own roots, being highly sensitive to drought and that its trunk tends to rot around the age of 60 years (Lanken, 1992; Apple and Manion, 1986).

Acer saccharum is a medium to tall tree, which at maturity can measure 27-37m tall and have a DBH of 76-91cm (Farrar, 2005; Tirmenstein, 1991). In contrast to *Acer platanoides*, it has slender and pointed brown terminal buds, samaras with parallel wings and grey scaly bark with an irregular pattern (Farrar, 2005). It develops deep roots and grows in rich, fertile, upland, moist and well-drained soils, often with other broadleaf trees such as *Fagus grandifolia* (OFA, 2000; Metsger, 2000; Tirmenstein, 1991). While *Acer saccharum* has been known to live for up to 300 to 400 years, it has an expected lifespan of 75 years in urban areas as long as it is not growing in compacted soil, which considerably shortens its lifespan (CBC News Online, 2005b; Tirmenstein, 1991). *Acer saccharum* is no longer a strong street tree as it tends to be intolerant of soils with high sodium levels (often found with urban salted streets) and highly sensitive to other urban stressors such as air pollution, drought and disease (Farrar, 2005; Miller, 1997; OFA, 2000; Tirmenstein, 1991). *Acer saccharum* is a shade tolerant species that grow readily under other *Acer saccharum* trees; however, studies show that they do not grow well under *Acer platanoides* trees (Allen et al., 1992; Martin, 1999). In fact, Martin's (1999) study demonstrated that plots with an *Acer platanoides* canopy had 0% *Acer saccharum* regeneration. As *Acer saccharum* is a native species, it contributes to the ecological integrity of the forest by allowing spring wildflowers and other native ground cover to establish underneath it (GRCA, 2004a). Like *Acer platanoides*, its seeds are wind dispersed, but can travel as far as 100m from the parent tree (Tirmenstein, 1991). Their age of maturity for producing seeds is 30 to 40 years old and it can be monoecious or dioecious (Tirmenstein, 1991). In southern Ontario, *Acer saccharum* has been affected by the maple petiole borer (*Caulocampus acericaulis*) and *Anthracnose* (OFA, 2005b; Natural Resources Canada, 2003).

Fagus grandifolia (American beech) is a native climax species, often found in coexistence with *Acer saccharum* in *Acer saccharum- Fagus grandifolia* climax forests in Southwestern Ontario (Farrar, 2005). Its characteristic smooth grey bark and thick trunk allow for quick identification in the forest (Waldron, 2003; Farrar, 2005). *Fagus grandifolia* tends to be found on well-drained soils, can live up to 300 to 400 years old and can grow up to 25m tall and up to 200cm DBH (Waldron, 2003; Farrar, 2005). Its seeds are dispersed by both birds, such as blue jays, and mammals (Waldron, 2003; Farrar, 2005). When growing, seedlings require a site which has shade and protection, and rarely grows in open areas (Waldron, 2003). As such, a full grown *Fagus grandifolia* tree casts a deep shade beneath it, often shading out other potential species from growing, though it itself is very shade tolerant (Farrar, 2005; Waldron, 2003). *Fagus grandifolia* trees in Ontario have been severely affected by Beech Bark Disease, which is caused by interactions between a beech scale insect (*Cryptococcus fagisuga*) and a fungus (*Nectria coccinea)*. Beech bark disease has been affecting *Fagus grandifolia* in Ontario since 1999, and has resulted in the death of many *Fagus grandifolia* (Waldron, 2003).

Rhamnus cathartica (common buckthorn) is an invasive shrub that can grow as tall as 7m and has dark green, thick, smooth leaves with black fruits and grey-brown bark (Farrar, 2005; OFA, 2005a). In some forests of Southwestern Ontario, it is currently growing at an exponential rate (OFA, 2005a). Like *Acer platanoides, Rhamnus cathartica* densely shades the understory, not allowing ground fauna and shade intolerant seedlings to grow (Raloff, 2003; Duncan, 2005). It was introduced to Canada to act as a shelterbelt species, but became an effective invasive species as it can establish in a variety of environments, has an abundant seed production and grows rapidly (Duncan, 2005; OFA, 2005a). *Rhamnus cathartica* is also alleliotrophic which means that it secretes chemicals which can interfere with the growth of nearby plants (Waldron, 2003). *Rhamnus cathartica* seeds are dispersed by birds that ingest the seeds and then deposit them in other locations where they establish and grow (Duncan, 2005; OFA, 2005a). As *Rhamnus cathartica* can reproduce by sprouting, it is very difficult to control by mechanical means alone. Thus the Ontario Forestry Association recommends that *Rhamnus cathartica* found growing along fence lines and on the edge of forests, which tend to be the most prolific seed-producers, be eradicated first (OFA, 2005a).

Urban Environmental Planning

Though urban planning has traditionally focused on managing the built areas of a city, urban environmental planning is an endeavour to manage the interface between ecological areas and built areas, and to improve and fully integrate both (Marsh, 2005). Urban environmental planning is a reactionary theory, which has developed in response to the massive urbanization over the past few centuries (Marsh, 2005). It can refer to both planning the future growth of cities and to improving existing urban areas, but ultimately examines the relationship between the built and natural environments, and how this interface can be improved (Marsh, 2005). Urban planning may consider issues such as whether to plant a monoculture or a diverse selection of species; whether to allow for natural unaided growth or utilize high management strategies; whether it is even feasible to plant trees or other vegetation; and whether to allow exotic species or only plant native species (Kendle and Rose, 2000; Moll and Ebenreck, 1989; Miller, 1997). In terms of the field of urban forest ecology, urban environmental planning specifically involves the integration of the urban forest into the design and planning of future areas and improvement of existing built areas, with the purpose of creating an optimal relationship between these two elements such that both benefit as much as possible.

2.5. Ecological Assessment

Current ecological assessment methods are mainly the same methods that have been used in forestry and other similar fields, but have now been adapted, and modified, for use in urban areas. Therefore, most of the problems and limitations of the methods used in other fields have either been dealt with, or at a minimum, have been established such that these limitations are known and can be compensated for. There are a wide range of methods used to evaluate the urban forest, with varying objectives and uses (Table 3). For example, there are currently a diverse number of models with varying foci, such as economic valuation or ecological benefits (Brack, 2002; Moll, 1995; Nowak et al., 2002b). While all of these methods have their strengths, the methods used in this study were deemed to be the most appropriate and effective for fulfilling this study’s objectives.

Table 3. Alternative Methods Used in Urban Forest Ecology

Methods	**Types**	**Purpose**	**Research**
Modelling	Urban Forest Effects (UFORE) model, CityGreen	spatial analysis, analysis of economic value of urban forest, modeling of future ecological functions and effects of disturbance and change on the urban forest	Moll, 1995; Wong, 1999; MacDonald, 1996; Nowak et al., 2002b; USDA Forest Service, 2005
Remote sensing	Laser altimetry, Landsat Thematic Mapper (TM) / Enhanced TM (ETM)	measurement of canopy cover, vegetation types and leaf area, estimation of carbon storage	Jensen and Hardin, 2005; Myeong et al., 2006;
Spatial Analysis	Landscape Metrics	measurement of fragmentation and connectivity of the landscape	Tischendorf and Fahrig, 2000
Monitoring	TreesCount	inventory of trees involving collection of data and its analysis to establish the current condition of the urban forest and to create baseline data	McLean, 2002; Nowak et al., 2002a; Christensen et al., 1996
Statistical Analysis	Spatial Autocorrelation Analysis Methods	examination of spatial structure and spatial autocorrelation	Fortin et al., 1989; Houle, 2007; Liang et al., 2007
Tree Evaluation	Dendrochronology	determination of tree age and carbon dioxide content	Cair, 1978; Apple and Manion, 1986; Webb and Kaunzinger, 1993

Tree inventories are the primary method for determining the composition of urban street trees. A tree inventory involves a comprehensive, manual, on-the-ground survey of a population of trees (Kenney and Puric-Mladenovic, 2002). On-the-ground surveying has been found to be much more reliable and accurate than other tree inventory methods such as remote sensing. This is because determination of specific species of trees is difficult at the resolution that remote sensing is capable of producing (Lefsky et al., 2002). On-the-ground tree inventories involve recording tree condition parameters such as the species of tree, location, canopy condition and the presence or absence of disease or insects and measuring such variables as diameter at breast height, tree height and canopy spread (Kenney and Puric-Mladenovic, 2002; Quigley, 2002; Welch, 1994; Jim, 2005; Miller, 1997; Nowak et al., 2002a; Philips, 1993; Hopkin et al., 2001). A tree inventory performed recently in Scarborough, Ontario is the *Trees Count* program (McLean, 2002). This program utilized the *NeighbourWoods* method, which is a tree inventory program designed for community groups with limited training to perform an on-the-ground tree inventory (McLean, 2002; Kenney and Puric-Mladenovic, 2002).

One of the strengths of current tree evaluation methods is their simplicity. While complicated methods involving invasive procedures such as clipping of leaves, branches or removal of the entire tree have been attempted, studies have shown that less complicated methods involving both easily-performed qualitative and quantitative measurements are just as accurate at reflecting tree health (Nowak et al., 2002a). Researchers can qualitatively and quantitatively measure many different tree variables to determine the condition or health of a tree. The most commonly measured variables are: diameter at breast height (DBH), tree height, crown spread, crown condition, trunk condition and indications of disease or insect infestations (Kenney and Puric-Mladenovic, 2002; Quigley, 2002; Welch, 1994; Jim, 2005; Miller, 1997; Nowak et al., 2002a; Philips, 1993; Hopkin et al., 2001). Tree condition can also be used as a predictor of probability of future disease or insect infestations, as trees which are in poor condition either have latent disease or insect infestations, or have a higher susceptibility to them (Kenney and Puric-Mladenovic, 2002). The condition of certain parts of the tree, such as the trunk and the crown, or the tree's overall condition are usually ranked on a numerical scale (Miller, 1997; Nowak and O'Connor, 2001; Nowak et al., 2002a; Magasi et al., 1996; Philips, 1993; Grey and Deneke, 1986; Quigley, 2002). The results of the above measurements are analyzed to determine distributions of certain variables within the studied forested area, such as diameter class, species, natives versus exotic abundance and deciduous versus coniferous distributions (Kenney and Puric-Mladenovic, 2002; Martin, 1999, Welch, 1994). Certain variables of each tree, such as canopy density, DBH, canopy width and height, can also be compared against horticultural standards for that particular species to determine whether its growth is meeting horticultural norms (Schwets and Brown, 2000). By integrating the above information, the condition of a specific urban forest can be determined (Martin, 2005).

Geographic Information Systems (GIS) has become very popular over the past decade as a software tool for analyzing spatial data (MacDonald, 1996; Moll, 1995; Nowak et al., 2002b; Wong, 1999). One type of spatial analysis is density mapping, which can be done using several different techniques, including point density estimation and kriging (Fortin and Dale, 2005). Point density estimation is a method of point pattern analysis using either simple or kernel density estimates to create density maps (Fotheringham et al., 2005). Kernel density estimation is basically a smoothed version of simple density estimation, in which values within a specified area are summed and then divided by the area to create an overall density map (Theobald, 2003). Kernel density estimation is used in a variety of applications, such as examining the density of amphibians in relation to their breeding sites (Rittenhouse and Semlitsch, 2007) and determining hot spots of crime in national forests (Wing and Tynon, 2006). Kriging is a spatial interpolation method used for spatial analysis and mapping of environmental variables. It is a "weighted moving average technique" for mapping spatial patterns such that they can be visually analyzed (Fortin and Dale, 2005, p. 165). Other studies have utilized kriging in varying applications, from density mapping of animal species, such as moose surveys (Schmidt et al., 2005), to density mapping of vegetation, such as understory invasive plants (Davalos and Blossey, 2004).

2.6. Urban Forest Management Plans

Regionally, urban forest practices are often in the form of policy and legislation, or strategies concerning the conservation, preservation, maintenance or management practices of an entire region (Farr, 2004; Miller, 2005). At the city scale, urban forest management plans are often adopted and applied to the entire urban forest in a particular municipality as a whole (Miller, 2005). Though single tree management is decided upon and implemented at an individual level, these are often subjective decisions guided by broader municipal urban policies (Rhode Island Department of Administration Information Services, 1999).

Many municipalities are now focusing on creating urban forest management plans to address the growing importance of trees in urban areas. These are often developed by urban foresters who have training or education in ecology or forestry, in addition to arboriculture. Two urban forest management plans that are applicable to this study are the management plans of the cities of Kitchener and Waterloo. The City of Waterloo has an urban forest policy that came into effect in 2001. It addresses issues such as the vision of urban forestry, specifications and standards of new plantings, and design and planning of street trees (City of Waterloo, 2001). Kitchener also has a tree management policy which was implemented in 2002. It includes a vegetation plan and a tree preservation / enhancement plan (City of Kitchener, 2002). In general, urban forest management plans may address maintenance schedules, suggested species lists, planting priorities, urban tree policies, a decision to either employ heavy management or natural growth strategies, restoration strategies and monitoring programs (City of Kitchener, 2002; City of Waterloo, 2001; Rhode Island Department of Administration Information Services, 1999). In an attempt to control invasive species, urban tree policies have even been implemented that address nursery stocks (Pain, 2004). This legislation controls the types of species that nurseries are allowed to stock to prevent potentially invasive species, or species which may carry certain invasive fungi, such as *Phytophthora*, from establishing themselves in the community (Pain, 2004). To improve municipal legislation, the Environmental Commissioner of Ontario suggests that “municipalities updating tree by-laws could begin integrating biodiversity considerations, woodlands conservation and landscape-level issues into tree conservation policy” (Miller, 2005, p. 203).

One issue that has become increasingly important and necessary to include in urban forest management plants is biodiversity. A forest with high biodiversity is believed to be more resilient to hardships such as disease, insect infestations and climate changes which could potentially decimate the population, and provides a variety of habitats for wildlife (Kenney and Rusak, 2005). A diverse stand of trees is more resistant to disease and insect infestations as both usually specifically infect or target only certain species. If a forest has numerous species of trees, the disease may only decimate particular species and not the entire forest (Kenney and Rusak, 2005). In addition, as different species of trees have different tolerances of desiccation, solar radiation levels, air temperatures and general anthropogenic effects such as salting and pruning, some species may react poorly to changes in climate or microclimate, while others will thrive in the new conditions (Kenney and Rusak, 2005). Therefore, an urban forest will be more likely to survive these threats and situations if a diverse selection of species is found. Moll and Ebenreck (1989) suggest that an urban forest should be composed of a maximum of 5% of any specific species and a maximum of 10% of any specific genus. This is further supported by Kenney and Rusak (2005) who suggest that urban street tree populations be composed of a maximum of 10% of any specific species and 30% of any specific genus.

2.7. Critical Knowledge Gaps and Contributions of the Study

As the theories, methods and practices in the field of urban forest ecology are still evolving, quite a few critical knowledge gaps still remain. There is an overall lack of baseline data (Rowntree, 1988). Through tree inventories, such as those by Nowak et al. (2002a) in Brooklyn and Chicago, these baseline data are being continually developed but are still not complete. Baseline data are necessary for each urban area, as each city creates unique conditions for the survival of its urban forest (Nowak et al., 2002a). As evidenced by Rowntree (1988), the lack of baseline data was already a problem in 1988 and has yet to be rectified. This study will provide the necessary baseline data for future studies in the City of Kitchener, such that trends in the forest condition can be analyzed. Knowledge of the historical and present states and predictors of future state is critical for developing accurate goals and objectives in urban forest management policies.

The field of urban forest ecology is relatively young as a formally recognized field in academia. This has had implications for both urban forest ecology methods and practices. Few studies have utilized spatial analysis from an ecological perspective in their examination of urban forests. In addition, only within approximately the past two decades have urban municipalities begun to realize the benefits in using extensive scientific data and information to inform management policies of urban trees (Nowak et al., 2002a; Nowak, 1994). As such, incorporation of spatial analysis methods in the study of urban areas, and integration of urban forest ecology theories into urban forest management and planning are still relatively in their formative years. Through the evolving practice of ecosystem management, the value of ecological perspectives and scientifically justified information are being recognized and necessarily adapted into planning and management strategies and policies (Musacchio and Wu, 2004). This study will demonstrate how spatial analysis and statistics can be used in the study of urban forests, in addition to demonstrating how urban forest ecology and urban management policies can be synthesized, especially through the recommendations that this study will make for policymakers.

Though studies concerning the ecology of *Acer platanoides* have become much more prevalent in the last decade or so (Martin and Marks, 2006; Reinhart et al., 2006; Wangen and Webster, 2006; Webb et al., 2001), there is a need for further research concerning the ecology of invasive species such as *Acer platanoides* in North America. Specifically, more research is needed to understand the interactions between *Acer platanoides* and native North American species, as well as the impact of *Acer platanoides* invasions on understory species (Munger, 2003). One common practical question by urban foresters is whether there is a need to immediately replace the invasive exotic species of trees planted on streetscapes, such as *Acer platanoides*, with non-invasive native species, a question that has been inadequately answered thus far. This study will examine the possible impacts of *Acer platanoides* on urban forests and answer whether *Acer platanoides* currently planted on the streets should be immediately replaced.

Thus, this study will fill these critical knowledge and research gaps by:

a) creating baseline tree condition and species tree inventory data for the city of Kitchener;

b) demonstrating how urban forest ecology and urban management policies can be synthesized;

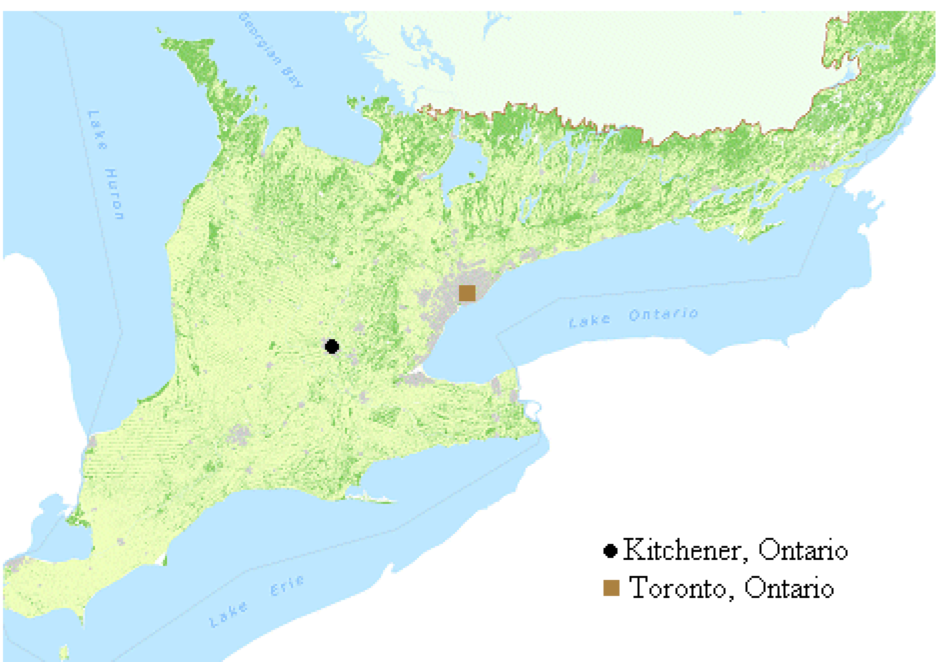
c) examining the possible impacts of *Acer platanoides* on urban forests;

d) determining whether *Acer platanoides* currently planted on the streets should be immediately replaced; and

e) making recommendations for urban forest management plans using scientific data.

Chapter 3 – Study Site

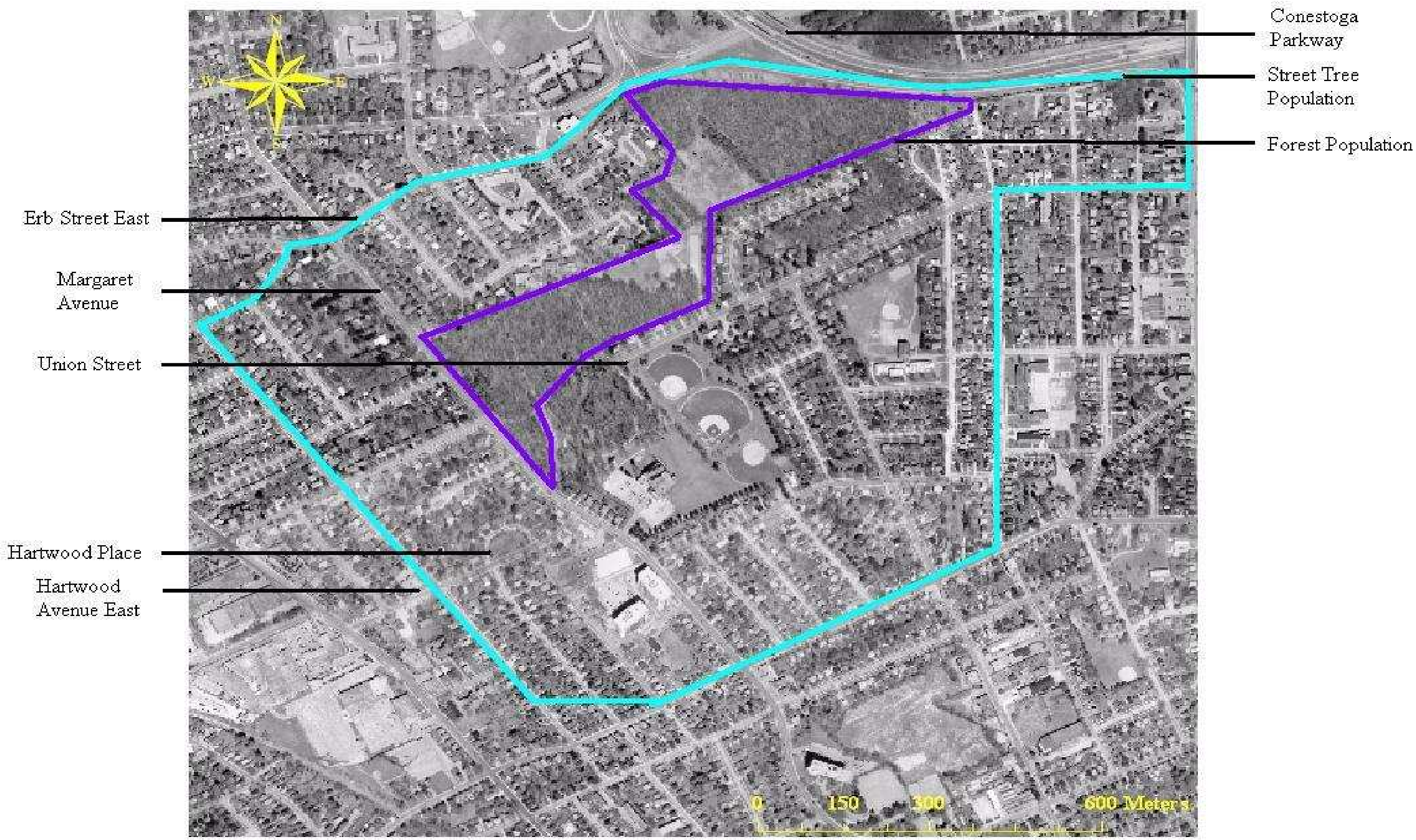
The city of Kitchener, located in Southwestern Ontario, was chosen as the case study for this research as it is a representative size and population of many cities in Southern Ontario (Figure 2) and it was near the University of Waterloo. The results, methodologies and recommendations stemming from this study are potentially applicable and certainly testable with other municipalities, especially ones where natural areas abut residential areas. The choice of Kitchener had an additional purpose as staff want to use the results of this research in their urban forest management plan, which is now being drafted. Currently, the City of Kitchener (1998) has 36,000 trees on its streets and an untallied, but significant, number of trees on its 1220 hectares of woodland and parkland. Some of the key problems of the street tree population, as noted by the City of Kitchener in their 1998 report, *The State of Kitchener's Street Trees*, were: it was estimated that 40% of the boulevard trees would die within five years, large cohorts of even-aged trees were dying concurrently due to old age, an appallingly low street tree species biodiversity, many mature *Acer platanoides* were being killed by their girdling roots, many tree species were exhibiting structural defects and evidence of disease and infestations, and construction activities were severely affecting many of the large street trees (City of Kitchener, 1998).



Imagery From: Ministry of Natural Resources Natural Spaces, 2006

Figure 2. The City of Kitchener

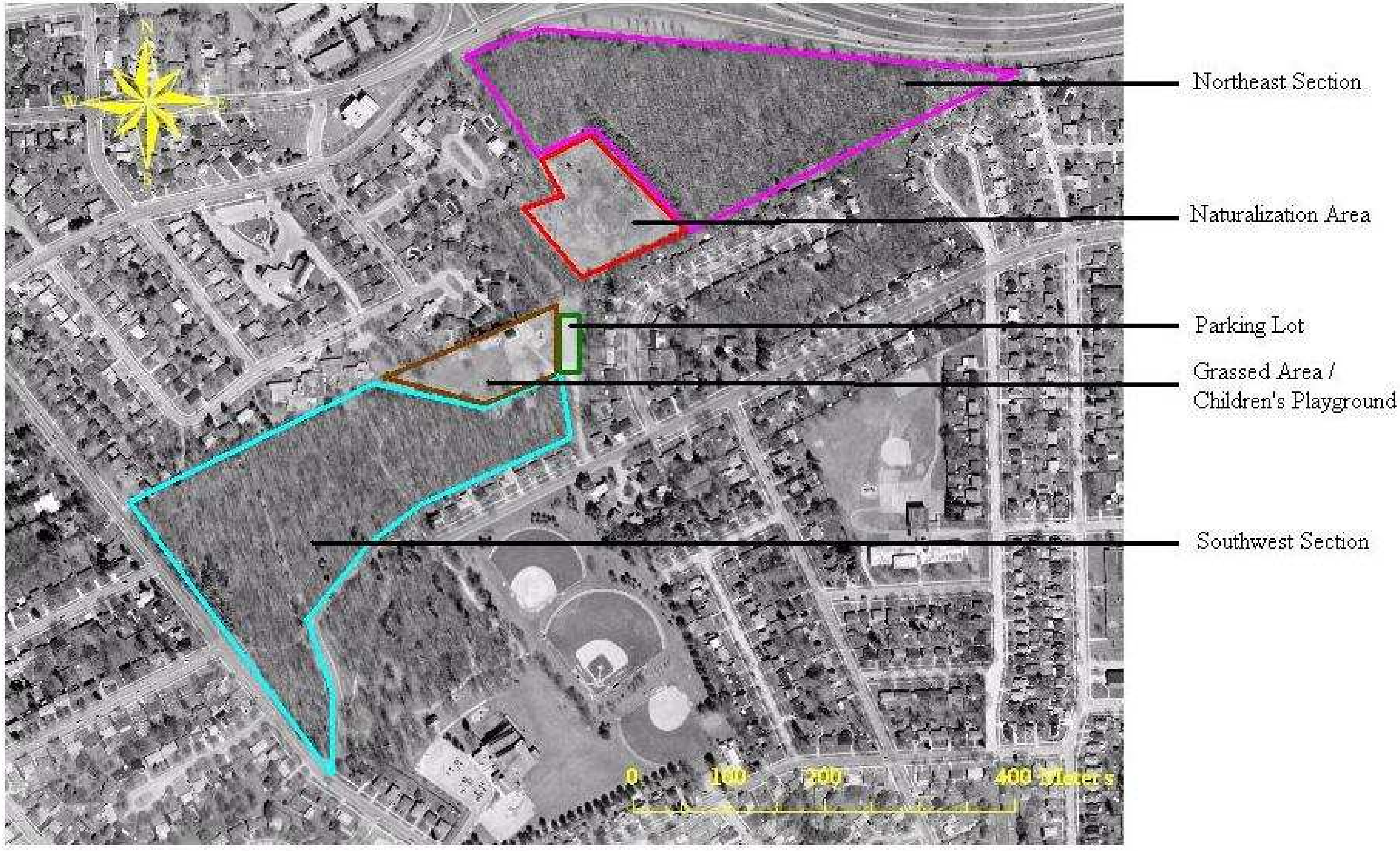
This study focused on a 127.5 hectare section of urban forest encompassing Breithaupt Park and its surrounding residential area. Within the city of Kitchener, this site was chosen for this research as it is a medium-sized park which has a forested park which directly interfaces with the surrounding residential neighbourhood. This allowed for a study of the interaction between the planted residential street trees and the natural or planted adjacent forested areas. Breithaupt Park itself is a 32.5 ha park that is on the border of the contiguous urban areas of the City of Kitchener and the City of Waterloo (Figure 3). Early pioneers recorded a plethora of *Acer sp.*, *Fagus sp. Pinus strobus*, *Fraxinus sp.*, *Quercus sp.*, and *Ulmus sp.* in the County of Waterloo (Schmidt, 1981). The site of Breithaupt Park likely remained relatively undisturbed until 1868 when a number of white pines were removed for sawmill activities (Schmidt, 1981). In 1913, the City of Berlin (Kitchener) purchased the 26.8 hectares of land and designated it as Breithaupt Park (Schmidt, 1981). By the late 1910s, the park had grown in size to 36.4 hectares and was reportedly the largest park in Kitchener as this time (Schmidt, 1981). From 1913 onward, the park was surrounded by urban development, though for all intents and purposes, it remained a natural area. Over time, modifications to the park occurred, including: the City of Kitchener supposedly removed much of the dead wood and debris for both aesthetic and practical purposes in 1913; the grassy area north of the current parking lot off Union Street was quarried for gravel to be used in Victoria Park in 1915; many *Pinus* sp. trees were cut down as Christmas tree by thieves in 1919; residential housing units were built around the park in the 1950's, the roads Maplewood Crescent and Valewood Crescent were both extended into the park in 1951, and in 1969, Conestoga Parkway was built at the North Eastern end of the park, effectively dividing it into two distinct parts, and decimating approximately 12% of the original woodlot (Schmidt, 1981; Schmitt, 1990; Anonymous, 1919). Examination of a city planning proposal illustrating the Adam-Seymour Plan for the city of Kitchener and the town of Waterloo in 1924 shows a piece of land labelled Breithaupt Park which is very similar to today's perimeter of the park, with the exception of Union Street and Conestoga Parkway which did not transverse the park at that time (English and McLaughlin, 1983). In terms of planting within the park throughout the past century, it is known that 1500 trees were planted between 1910 and 1912 (just before the park's acquisition), that the Park Board planted *Juglans cinerea*, *Juglans nigra* and *Ulmus* sp. trees throughout Breithaupt Park (exact location unknown) in 1932 and that there were many *Pinus strobus* trees replanted as part of Earth Day 2007 in the naturalization area just northeast of the parking lot, near the original plantation of *Pinus sylvestris* (Anonymous, 1912; Anonymous, 1919; Anonymous, 1932).



Imagery From: City of Kitchener, 2003

Figure 3. Breithaupt Park and its Surrounding Residential Area

Today, Breithaupt Park is a semi-forested park which interfaces with residential streets and is located near the major intersection of Erb Street East and Conestoga Parkway (Highway 85). The park is composed of baseball diamonds, a playground, splash pads, a community centre and walking trails, in addition to an extensive forested area. The natural forested area of Breithaupt Park currently covers an area of 20.2 hectares. The studied area of Breithaupt Park can be split into two primary sections, which are the northeast section and the southwest section (Figure 4). The northeast section covers an area of 5.8 hectares, while the southwest section is considerably larger and covers an area of 14.4 hectares. Like many of the forests in Southwestern Ontario, Breithaupt Park is an *Acer saccharum – Fagus grandifolia* climax forest (Schmitt, 1990). Limited management of the park currently occurs; mainly involving mowing of the grassed areas and removal of dead trees over trails. Though there are signs indicating *Vinca minor* and *Acer platanoides* management via removal, according to David Schmitt (Environmental & Urban Forest Project Manager) there has been only removal of dead trees and existing *Acer platanoides* have only had their trunks marked but not removed (Schmitt, personal communication, July 2007). The park is surrounded by single unit residences or institutions (comprising 2.8km of the edge of the park), city roads (0.6km) and Conestoga Parkway (1.0km), and there are many 7.6km (as of 1990) of trails running through the park, which occupy 1.2 hectares (Schmitt, 1990). The residential streets surrounding the park are single homes with front yards which often have one or more trees. Major native species found in this park include *Acer saccharum*, *Fagus grandifolia*, *Fraxinus americana*, *Fraxinus pennsylvanica*, *Actaea rubra* (baneberry), and *Solidago canadensis* (Canada goldenrod) (City of Kitchener, 2007). Major exotic (and invasive) species found in this park include *Acer platanoides*, *Alliaria petiolata* (garlic mustard), *Vinca minor* (periwinkle), *Cynanchum rossichum* (dog strangling vine) and *Rhamnus cathartica* (City of Kitchener, 2007). Overall, there are 34 known tree species in the park (12 exotic and 22 native), 12 known shrubs (4 exotic and 8 native) and 84 known herbaceous species (34 exotic and 50 native) (City of Kitchener, 2007).



Imagery From: City of Kitchener, 2003

Figure 4. Sections of Breithaupt Park

Chapter 4 - Methodology

A mensurative experiment was performed as any form of control would hinder the validity of the results. In this field research, there was limited replication ability and data collection was specific to the area studied. Though this research concentrated on one park within Kitchener, the methods and procedures utilized, as well as the overall results are assumed to be generalizable to similar parks (in size, species composition or similar forest-street interfaces) within other cities. Though comparing numerous sites would have been preferable, within the parameters of this research, it was essential to comprehensively study one site for the intensive and extensive data and measurements that were collected.

4.1. Field Measurements

Fieldwork commenced at the study site in May of 2006 and was completed in November of 2006. The fieldwork consisted of two key components: an examination of the street tree population and an examination of a sample of the forest tree population.

The first phase of fieldwork focused on the street trees that line the residential streets surrounding Breithaupt Park. A boundary of at least 250m from the park was delineated within which all street trees were measured. The width of this boundary was chosen based on the fact that all of the exotic species of street trees (revealed by a preliminary visual inspection), especially *Acer platanoides*, had an average seed wind-dispersal distance of 50m (Matlack, 1987). The boundary distance chosen was intentionally high to ensure that all trees that could possibly have any influence on the park were included. Any street trees within this boundary but on the other side of Conestoga Parkway, of which there were very few, were not included in this survey as it is highly likely that the parkway served as a barrier to samara transmission. Within this pre-determined boundary, all street trees which had their trunks on public property were measured. Street trees are trees planted between the road and the sidewalk on a particular street and which are within the street allowance and therefore under municipal jurisdiction (Welch, 1994; Nowak et al., 2002a). Residential trees in the backyards of homes and their front yards, inside of the sidewalk, were not included, as one of the objectives of this study is to make recommendations to the municipal forest practitioners concerning the management of their public urban forest and the trees that they have jurisdiction over. Residential trees, where possible, were counted as such, but no qualitative or quantitative measurements were taken. Although a concerted effort was made to positively identify each species of street tree, there were some rare or obscure species whose identity remained elusive. These trees were grouped together as ‘unknown horticultural species’.

An inventory was used to measure the street trees as it is a thorough and comprehensive method, useful in determining the spatial distribution and characteristics of the street tree population at a certain point in time (Fancy, 2000). During street tree sampling, the house number, tree species, height, diameter at breast height (DBH) and radius of crown spread were measured (Apple and Manion, 1986; Banks et al., 1999). Presence of disease or insects, other trees located on the property and miscellaneous notes about other abiotic or biotic conditions were also made. These variables were chosen for measurement as they were determined to be the most reliable, as well as the most commonly used in tree condition analysis (Hopkin et al., 2001; Schwets and Brown, 2000). Qualitative measurements of tree condition, trunk condition and crown condition were based on Kenney and Puric-Mladenovic’s (2002) *NeighbourWoods Tree Inventory Report*. Tree condition was quantified on a scale of 1 to 5 where 1 indicated a tree with extreme problems such as severe loss of limbs and thin crown, while 5 indicated a tree without any visible symptoms of damage, disease or broken limbs (Kenney and Puric-Mladenovic, 2002, p. B-1) (Table 4). These criteria were used to determine an individual tree’s condition and cumulatively determine the entire residential street tree population’s condition. These methods have been found to accurately reflect the overall condition of an individual tree, and have been used in numerous other tree condition evaluation studies (Kenney and Puric-Mladenovic, 2002; Quigley, 2002; Welch, 1994; Jim, 2005; Martin, 1999; Nowak et al., 2002a).

Table 4. Tree Condition Class and the Criteria for This Condition

Condition Class	Description
5 - Excellent	Tree is without any visible systems
4 - Good	No apparent problems
3 - Fair	Minor problems
2 - Poor	Major problems
1 - Very Poor	Extreme problems

(Source: Kenney and Puric-Mladenovic, 2002, p. B-1).

For both forest and street trees, approximate age was determined using the International Society of Arboriculture's (1988) table, for determining tree age which involved multiplying a pre-determined factor unique to each species by the DBH of the tree. These factors were determined from studies on different species in woodlands, timber woodlots and landscape plantings in Ohio (International Society of Arboriculture, 1988). Though the growth rate of a tree depends on a number of variables, including climate, the factors used here are still valuable as approximations of tree age (International Society of Arboriculture, 1988). DBH was measured using a measuring tape calibrated to convert circumference to diameter. Diameter of the trunk was measured at approximately 1.3m from the base of the trunk as this is the standard height considered to be 'breast height' (LandOwner Resource Centre et al., 1996). Tree height was measured by using an Abney Level which uses trigonometric functions to determine the height of a tree. Crown cover was measured using an estimate of the foliage transparency of the tree. This was out of a maximum value of 100%. Thus, a value of 100 indicated that one could not view any of the sky above and that the view was entirely of the crown (either leaves or branches), while a value of 0 indicated a transparent crown in which only the trunk and dead branches were present. The Universal Transverse Mercator (UTM) grid co-ordinates of each tree were determined by locating the associated house and its tree on the 2003 aerial photographs (UTM zone 17N, North American Datum 1983). These grey-scale aerial photographs had a resolution of 10cm, and are available on the City of Kitchener's website (City of Kitchener, 2003). On this website, it was possible to interactively retrieve the UTM co-ordinates for each tree.

The second phase of fieldwork involved systematic sampling of the forest. The objective of this inventory was to obtain a comprehensive survey of the types of species, their characteristics and their distribution within the forest without having to measure every tree. Shiver and Borders (1996), Husch et al., (1982) and Brack and Wood (1998) all note that systematic sampling is the preferred sampling method for forest inventories because it is a quick, inexpensive, unbiased and reliable method of ascertaining tree population means and general characteristics. In their comparison of the accuracy of random and systematic sampling when assessing residual stand damage, Han and Kellogg (2000) established that, for determining the composition of a forest, systematic plot sampling was nearly as accurate as a full inventory of every tree. The systematic sampling methods used in this research were point-quarter sampling and line-plot sampling. Point-quarter sampling was used to determine the relative abundance of each tree species and to systematically, but in an unbiased manner, choose individual trees for extensive measurement of their characteristics. A point-quarter sampling method was chosen instead of a wandering quarter sampling method as the important factor of distance to the edge is easily measurable using point-quarter sampling, while it would not have been if a wandering quarter sampling method was used. A point quarter sampling method has been used by Larson and Waldron (2000), Christopher and Barrett (2006), Collins et al., (2006), and Ehrenfeld (2004) in their studies of forests, while other methods, such as transects and quadrat or line-plot sampling have been used by Allen et al. (1992), Fortin et al. (1989), Martin (1999) and Wangen and Webster (2006). Many of these studies, such as that by Ehrenfeld (2004) and Christopher and Barrett (2006), utilized a combination of plot sampling and point quarter sampling, as was also used in this study. Utilizing line-plot sampling in the current study, the absolute number of each species of seedling, sapling and tree was counted per 3m radius ($28.3m^2$) plot.

The forest study site included both the southwest and northeast sections of Breithaupt Park but did not include the section of the park south of Union Street. This latter section was primarily composed of fields, baseball diamonds and a community centre. This part of the forest has few trees in relation to the rest of Breithaupt Park and is not really considered part of the natural forested area. The forested area south of Union Street is also much more disturbed, with picnic areas, picnic shelters and many trails and thus, it was not included in this study. Using the point-quarter sampling method, a series of lines were created transversing the study site. These lines were parallel, going from a compass direction of northwest to southeast, as this was the approximate direction of the prevailing winds at the study site. Points were systematically chosen along each line. A greater density of sample points were allocated near the edge (every 10m), while less were allocated to the interior (every 20m), to ensure that exotic species presence was detected in the event that it was very low overall (Fancy, 2000). These plots were located in 10-20m increments based on ground distances and not true horizontal sampling distances. While species such as *Acer platanoides* do not require edge habitat to establish, in this study the edge was hypothesized to be the area within which invasive exotic species would have the highest density and the location at which they would attempt to penetrate the forest, especially as *Acer platanoides* is primarily wind-dispersed and its source was likely primarily exterior to the forest (Matlack, 1987; Munger, 2003). Increasing the intensity of sampling at specific areas of interest throughout the sampling area is a method suggested by the National Parks guide, *Guidance for the Design of Sampling Schemes for Inventory and Monitoring of Biological Resources in National Parks* (Fancy, 2000). At each point along the created lines, the closest tree with a DBH of greater than 5cm and within a 3m radius was measured within each quadrant; these being north, west, east and south quadrants (Wangen and Webster, 2006). Tree species, location, groundcover, approximate age (successional status), diameter at breast height (DBH), crown cover and tree height were recorded for every forest tree (Allen et al., 1992; Eastern Ontario Model Forest, 1997; Millard, 2000). A true point-quarter sampling method would involve measuring the closest tree within each of the specified quadrants (north, south, east or west) no matter how far away the particular tree was. Within this site, it was not always possible to measure the closest tree within a specific quadrant, as often this tree was a substantial distance away. A distance limit of 3m was placed on each quadrant, and if no tree was within this threshold, a designation of null was assigned. Temporal changes in the composition or structure of the transects were not directly studied as an inadequate amount of time elapsed over the course of the study to observe any major natural (not human-initiated) change in the structure of the forest or in the individual tree conditions.

The field methodology also incorporated line-plot sampling which utilized the same points that were used in the point-quarter sampling. Each point was used as the centre of a 3m radius circle plot in which all seedlings, saplings, trees, and groundcover were recorded. The number and type of saplings and seedlings within each fixed 3m radius plot, though their specific characteristics were not measured, were recorded such that an estimate of the future overstory canopy type could be ascertained by indicating the current viability of understory exotic or native species. Though of a drastically smaller size and much more frequent than that suggested by the Eastern Ontario Model Forest for plot sampling, the setup and layout of the plots followed that suggested by the Eastern Ontario Model Forest (1997). Within each plot, groundcover and seedling data were also collected; however, their accuracy is questionable as they were collected over a five month period in the forest, and were collected mainly to provide additional context.

4.2. Spatial Analysis

All forest plots and individual street trees were overlaid on an aerial photograph of the site using the Geographic Information Systems program *ArcGIS*. Plotting of the site, the trees, their conditions, the species and the type of species (exotic vs. native) were completed using this GIS software. These plots were geo-located by using the aerial photograph and ground distances along the sampling line (heading in a compass direction of southeast) from the edge. For each plot, the mean distance to the closest visual edge of the forest was measured, in addition to summing the number of trees, saplings and seedlings per species per plot. Density maps of tree and sapling densities of all species, as well as solely *Acer platanoides* and solely *Rhamnus cathartica* were interpolated from plot-scale raw densities using ordinary kriging. The parameters of this procedure included an autocorrelation range of 70 m, and a so-called nugget variance of 30% of the overall variance (or sill). This combination of parameters produces a smoothed density map that reduces the impact of local random variation and highlighted the general patterns and trends of tree density.

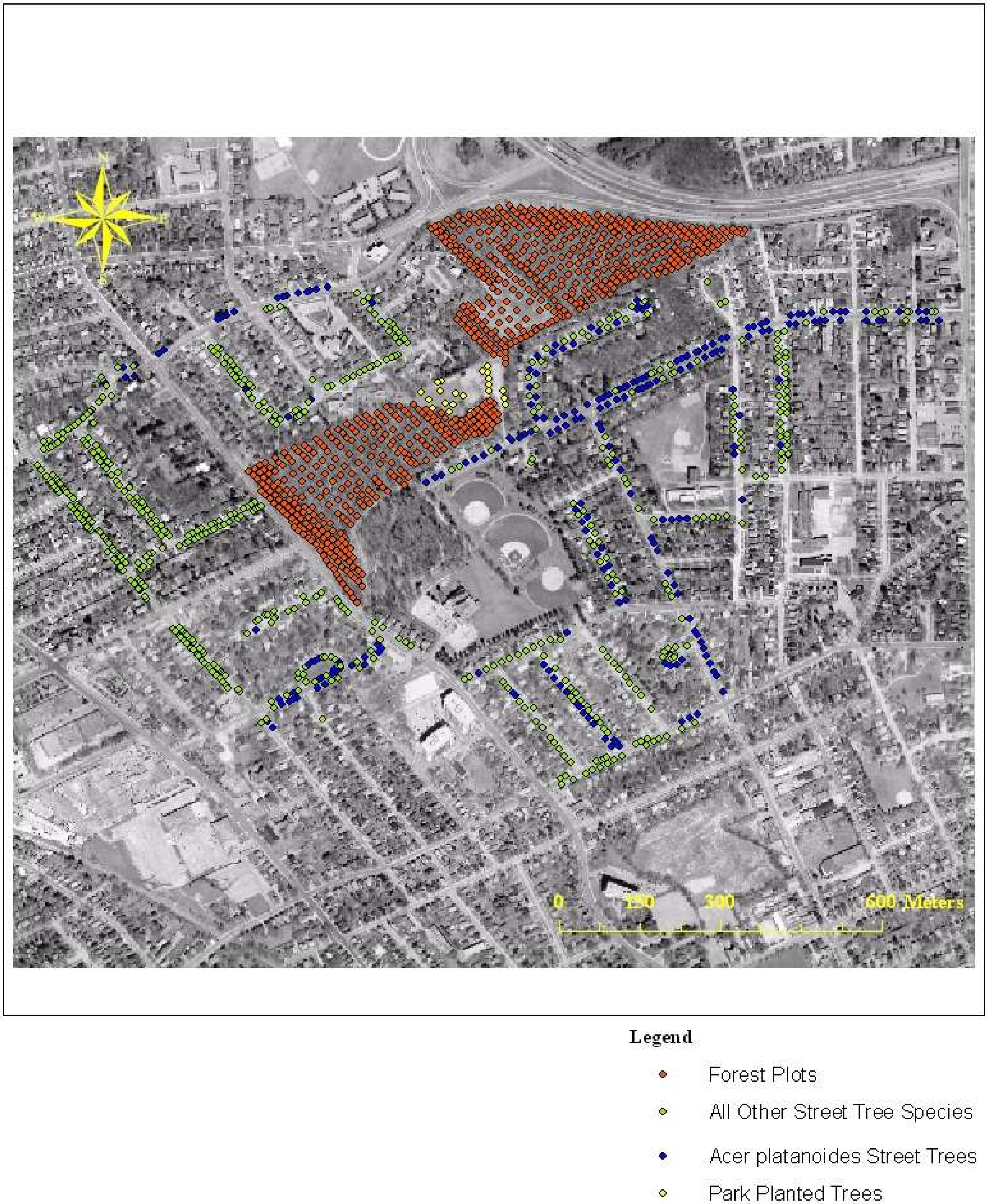
4.3. Statistical Analysis

The mean DBH, height and crown radius were determined for every species within both the street tree and forest populations. Mean tree condition and crown condition were also determined for every species of street tree, while mean overstory canopy percentage was determined for each species in the forest population. Using the data collected utilizing the line-plot sampling method, density of *Acer platanoides* trees and all species of trees were plotted against distance to the visual edge using bar plots. Further statistical analyses included both inter- and intra-species comparisons, calculating abundance of native and exotic species, and relative abundance of each species.

Chapter 5 - Results

5.1. Location of Urban Forest Plots and Street Trees

The two primary areas examined in this study were the forest tree population and the street tree population (Figure 5). Also measured were the 22 trees intentionally planted within the park, mainly around the parking lot and grassed children's park area.



Imagery From: City of Kitchener, 2003

Figure 5. Spatial Distribution of the Forest Plots and Street Trees in Breithaupt Park and the Surrounding Residential Area

5.2. Street Tree Composition and Characteristics

Overall, the street trees in the residential area surrounding Breithaupt Park were a varied population, representing 33+ different species of street trees. In total, 799 street trees were completely measured in this inventory. The following figure (Figure 6) illustrates the species of street trees, their absolute numbers counted and their percentage as a proportion of the street tree population. The species with the largest number of trees planted was *Acer platanoides* which composed 42% of the street tree population, followed by *Fraxinus americana* (10%), *Acer saccharum* (5%), *Staphylea trifolia (*5%) and *Juglans cinerea* (5%).

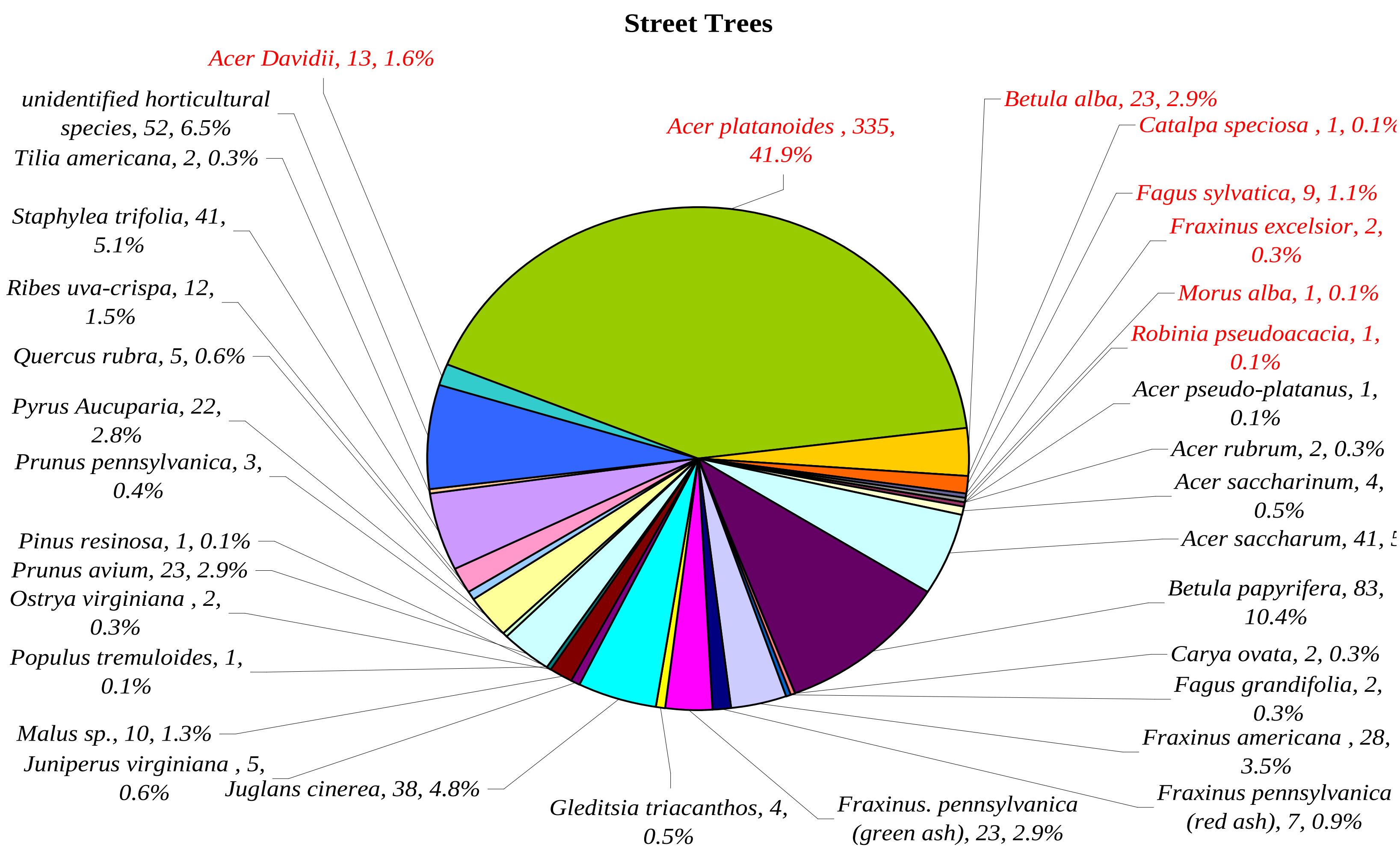


Figure 6. Composition of Street Tree Population (Species, Absolute Number of Trees, Species Percentage of the Population) with Red Labels Indicating Exotic Species

Within the street tree population, approximately 48%, or 362 trees, were native species and 52%, or 385 trees, were exotic species. The most abundant native species were: *Fraxinus americana* (83), *Acer saccharum* (41), *Staphylea trifolia* (41) and *Juglans cinerea* (38). The most abundant exotic species were: *Acer platanoides* (335) and *Betula alba* (23). Not including the unidentified horticultural trees, there were 8 species of exotic street trees and 25 species of native street trees. Overall, the mean DBH of all species was 21.5cm (+/-15.0cm), the mean height was 7.5m (+/-3.9m), the mean radius was 3.0m (+/-1.8m), the mean tree condition was 3.7 (+/-0.8) and the mean crown condition was 68.7% (+/-23.1%). The following table (Table 5) indicates the mean diameter at breast height, mean height, mean crown radius, mean tree condition, and mean crown condition of the street tree population.

Table 5. Descriptive Summary of the Characteristics of Street Tree Population

Species (with over 25 street trees)	Absolute Number of Trees	Mean DBH (cm) (+/-SD)	Mean Height (m) (+/-SD)	Mean Crown Radius (m) (+/-SD)	Mean Tree Condition (+/-SD)	Mean Crown Condition (%) (+/-SD)
Staphylea trifolia	41	9.2 (+/- 4.4)	4.3 (+/-1.3)	1.9 (+/-0.8)	3.6 (+/-0.6)	75.1 (+/-20.9)
Juglans cinerea	38	8.5 (+/-6.4)	4.4 (+/-2.1)	1.4 (+/-1.0)	4.0 (+/-0.5)	71.4 (+/-21.7)
Prunus avium	23	27.9 (+/-7.2)	6.4 (+/-1.2)	4.1 (+/-1.0)	3.2 (+/-0.7)	56.1 (+/-24.1)
Betula alba	23	7.2 (+/-7.5)	4.0 (+/-1.6)	1.3 (+/-0.7)	3.9 (+/-0.4)	51.3 (+/-24.9)
Fraxinus pennsylvanica (green ash)	23	18.8 (+/-6.2)	6.9 (+/-2.6)	3.0 (+/-1.5)	3.3 (+/-0.5)	71.3 (+/-13.8)
Pyrus aucuparia	22	15.0 (+/-5.7)	6.7 (+/-2.4)	2.3 (+/-0.9)	3.9 (+/-0.5)	74.8 (+/-14.8)
Acer platanoides	335	29.8 (+/-12.7)	9.0 (+/-2.4)	4.0 (+/-1.5)	3.5 (+/-0.8)	74.9 (+/-20.6)
Acer saccharum	41	30.4 (+/-18.4)	13.8 (+/-8.0)	3.7 (+/-2.4)	3.0 (+/-1.3)	52.4 (+/-29.1)
Fraxinus americana	28	18.8 (+/-15.4)	8.4 (+/-4.8)	2.6 (+/-1.9)	3.8 (+/-0.9)	67.1 (+/-28.7)
Betula papyrifera	83	6.1 (+/-6.3)	3.7 (+/-1.8)	1.3 (+/-0.8)	3.9 (+/-0.5)	50.4 (+/-20.3)

5.3. Forest Tree Composition and Characteristics

In contrast to the street tree population, the forest tree population was composed of 42% *Acer saccharum*, 19% *Fraxinus americana*, 11% *Ostrya virginiana,* 5% basswood and 4% *Fagus grandifolia*. In total, 1203 forest trees were completely measured in this inventory and 7900 trees and saplings were recorded. Using the line-plot method of sampling, it was determined that *Acer platanoides* composed 1.9% of all sampled trees in the forest, 3.2% of all sampled saplings and 2.7% of all sampled seedlings. Using the results from the point-quarter sampling method, the following figure (Figure 7) illustrates the species of forest trees, their absolute numbers measured and their percentage as a proportion of the measured forest tree population.

Forest Trees in Breithaupt Park (DBH >5cm)

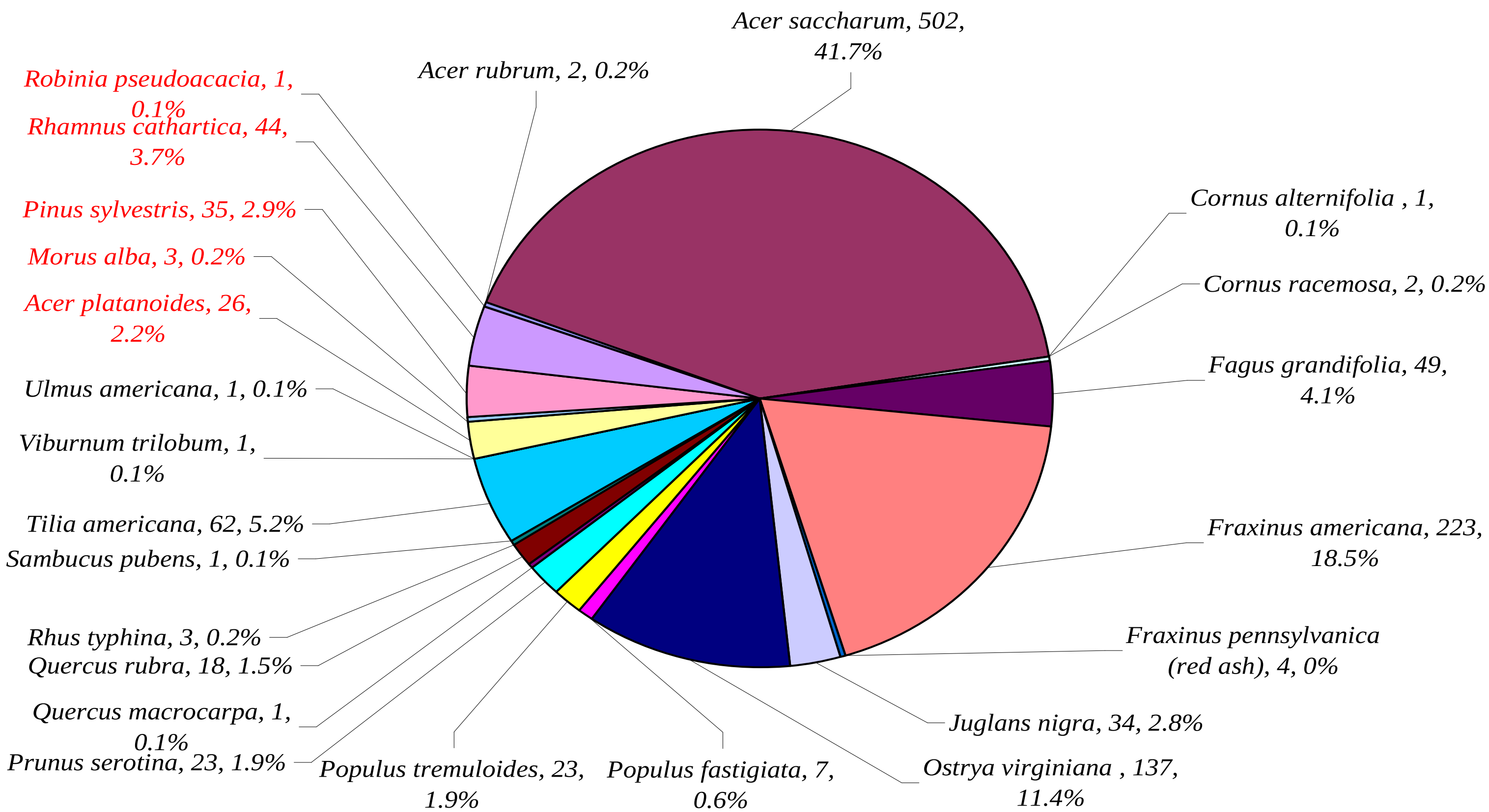


Figure 7. Composition of Forest Tree Population (Species, Absolute Number of Trees, Species Percentage of the Population) with Red Labels Indicating Exotic Species

Within the sampled forest tree population, approximately 91%, or 1094 trees, were native species and 9%, or 109 trees, were exotic species. The most abundant native species included: *Acer saccharum* (501), *Fraxinus americana* (223), *Ostrya virginiana* (137), *Tilia americana* (61) and *Fagus grandifolia* (49). The most abundant exotic species included: *Rhamnus cathartica* (44), *Pinus sylvestris* (35) and *Acer platanoides* (26). Overall, there were 5 different species of exotic forest trees and 19 different species of native forest trees.

Upon examination of the two primary sections of the forest (the southwest section and the northeast section) separately, a slight difference in the species composition existed. Using the point-quarter sampling method, it was determined that in the southwest section of the forest, approximately 89%, or 505 trees, were native, while 11%, or 64 trees, were exotic. In the northeast section of the forest, approximately 93%, or 577 trees, were native, while 7%, or 45 trees, were exotic. Overall, the mean DBH of all forest species was 19.4cm (+/-15.4cm), the mean height was 14.3m (+/-7.0m), the mean crown diameter was 5.5m (+/-3.1m), and the mean overstory canopy was 74.6% (+/-22.9%). Using the results from the point-quarter sampling method, the following table (Table 6) illustrates the mean diameter at breast height, mean height, mean crown diameter and mean overstory canopy of the forest trees.

Table 6. Descriptive Summary of the Characteristics of Forest Tree Population

Species (with over 25 forest trees)	**Total**	**Mean DBH (cm) (+/-SD)**	**Mean Height (m) (+/-SD)**	**Mean Crown Diameter (m) (+/-SD)**	**Mean Overstory Canopy (%) (+/-SD)**
Fagus grandifolia	49	19.3 (+/-16.3)	13.6 (+/-7.4)	6.1 (+/-3.7)	82.9 (+/-17.2)
Tilia americana	62	16.6 (+/-13.6)	10.6 (+/-6.9)	5.0 (+/-3.2)	72.4 (+/-25.8)
Prunus serotina	23	20.3 (+/-16.6)	13.4 (+/-7.3)	5.8 (+/-3.4)	76.9 (+/-24.4)
Juglans nigra	34	27.4 (+/-14.0)	16.0 (+/-5.8)	6.6 (+/-3.0)	66.5 (+/-20.0)
Rhamnus cathartica	44	6.6 (+/-2.1)	5.6 (+/-1.8)	3.0 (+/-1.2)	81.5 (+/-20.2)
Ostrya virginiana	137	13.2 (+/-11.6)	12.5 (+/-5.7)	4.8 (+/-2.4)	77.9 (+/-19.9)
Acer platanoides	26	12.9 (+/-11.3)	10.3 (+/-6.4)	4.4 (+/-1.9)	76.6 (+/-23.2)
Pinus sylvestris	35	29.5 (+/-11.1)	19.6 (+/-6.8)	5.0 (+/-1.9)	70.0 (+/-28.3)
Acer saccharum	502	24.7 (+/-16.5)	17.1 (+/-6.6)	6.5 (+/-3.4)	76.2 (+/-21.6)
Populus tremuloides	23	11.2 (+/-3.8)	11.7 (+/-5.5)	4.1 (+/-1.4)	78.0 (+/-21.2)
Fraxinus americana	223	13.0 (+/-10.7)	11.9 (+/-5.9)	4.1 (+/-2.3)	68.2 (+/-24.9)

5.4. Age of Street Trees and Forest Trees

The following table (Table 7) illustrates the approximate mean age of tree species measured as determined using the age multiplication factor as determined by the International Society of Arboriculture (1988). For example, age of *Acer platanoides* was estimated by multiplying its DBH in inches by 3.5 or, equivalently, its DBH in cm by 1.38. The range in age of *Acer platanoides* forest trees spanned from 6.9 years (for the smallest tree with a DBH of 5cm) to 66.7 years (for the largest tree with a DBH of 46.2cm). The species included in the table are those for which the age multiplication factor was available and of which there were more than 10 individual trees measured in this study.

Table 7. Approximate Age of Forest Trees and Street Trees

Street Trees

	Absolute Number of Trees	**Mean DBH (cm)**	**Mean DBH (inches)**	**Factor**	**Approximate Age**
Fagus grandifolia	2	34.8	13.7	6	82.1
Betula alba	23	7.2	2.8	4	11.4
Fraxinus pennsylvanica (green ash)	23	18.8	7.4	3.5	26.0
Acer platanoides	335	29.8	11.7	3.5	41.1
Acer saccharum	41	30.4	12.0	4	47.9
Fraxinus americana	28	18.8	7.4	4	29.7
Betula papyrifera	83	6.1	2.4	4	9.6

Forest Trees

Species	**Absolute Number of Trees**	**Mean DBH (cm)**	**Mean DBH (inches)**	**Factor**	**Approximate Age**
Fagus grandifolia	49	19.3	7.6	6	45.5
Prunus serotina	23	20.3	8.0	4	32.0
Juglans nigra	34	27.4	10.8	3.5	37.7
Acer platanoides	26	12.9	5.1	3.5	17.8
Pinus sylvestris	35	29.5	11.6	3.5	40.7
Acer saccharum	502	24.7	9.7	4	38.8
Fraxinus americana	223	13.0	5.1	4	20.5

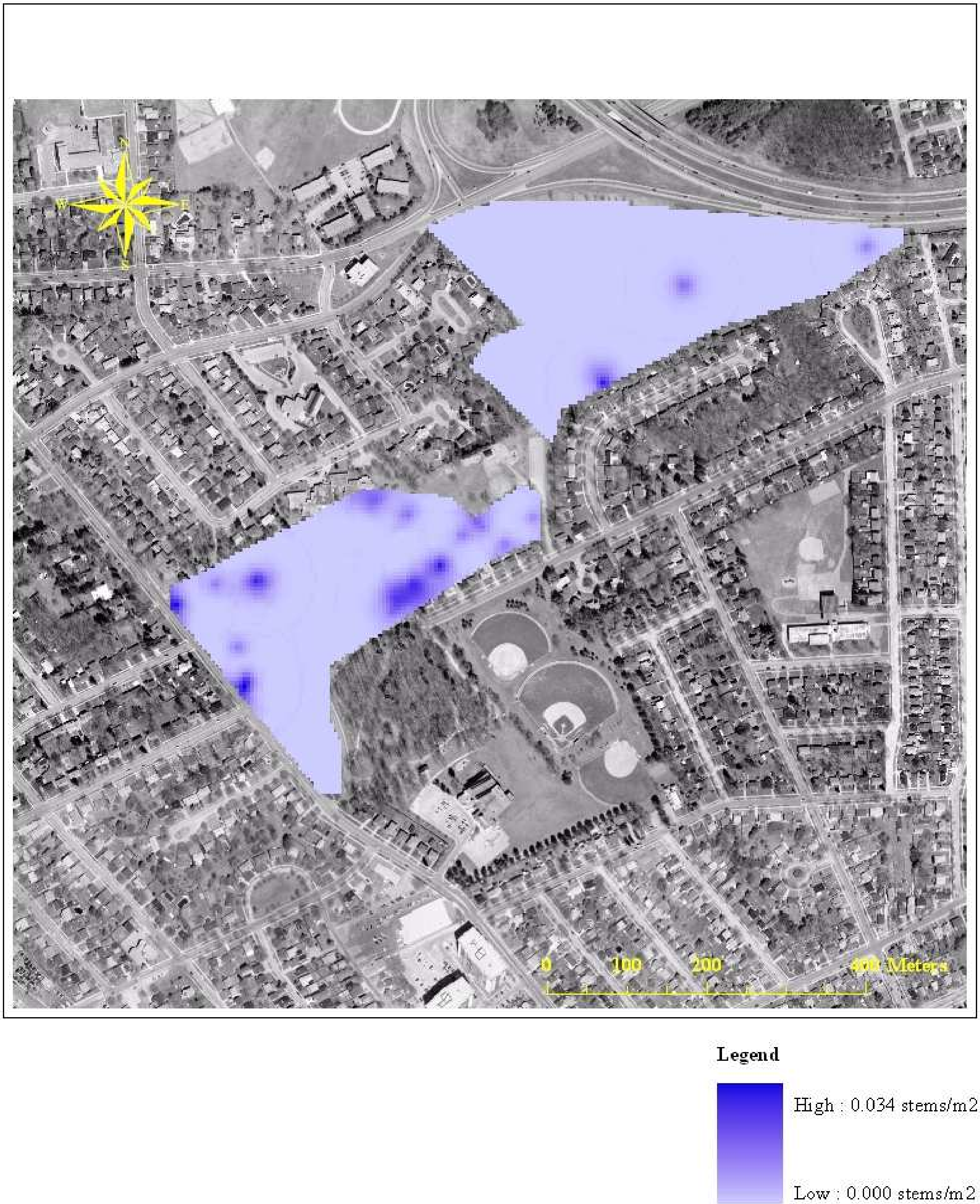
(International Society of Arboriculture, 1988)

5.5. Spatial Distribution

Spatial analysis of the field site involved mapping the density of all species, *Acer platanoides* and *Rhamnus cathartica* throughout Breithaupt Park. Results from the line-plot sampling method were used for the following figures (Figures 8 to 13). Note that the magnitude of tree density differs between the maps, resulting in different color scales. For example, the color scales on the density map of all species of trees and the density map of *Acer platanoides* trees are dramatically different.

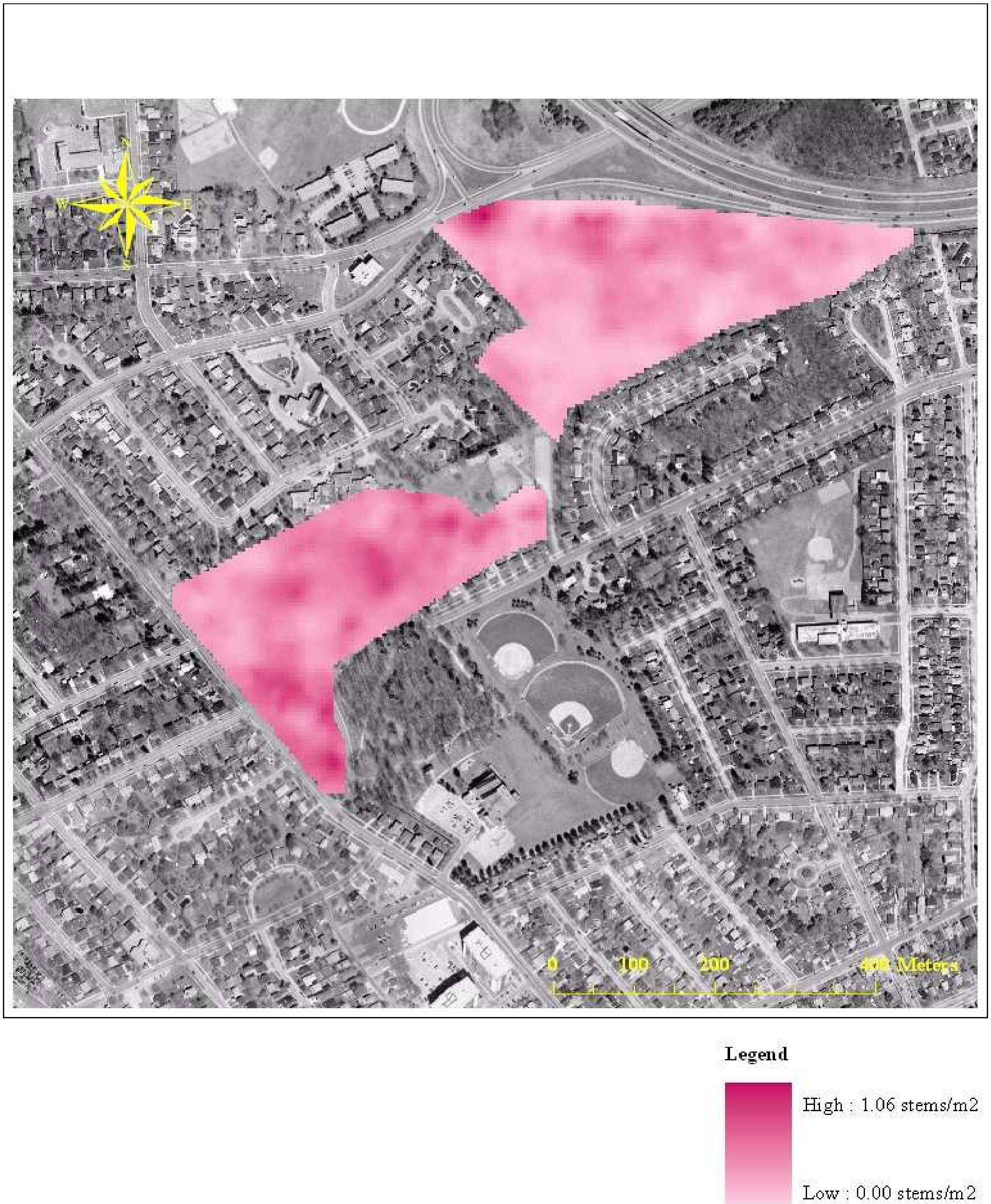
Imagery From: City of Kitchener, 2003

Figure 8. Density of Trees of All Species in Breithaupt Park



Imagery From: City of Kitchener, 2003

Figure 9. Density of *Acer platanoides* Trees in Breithaupt Park



Imagery From: City of Kitchener, 2003

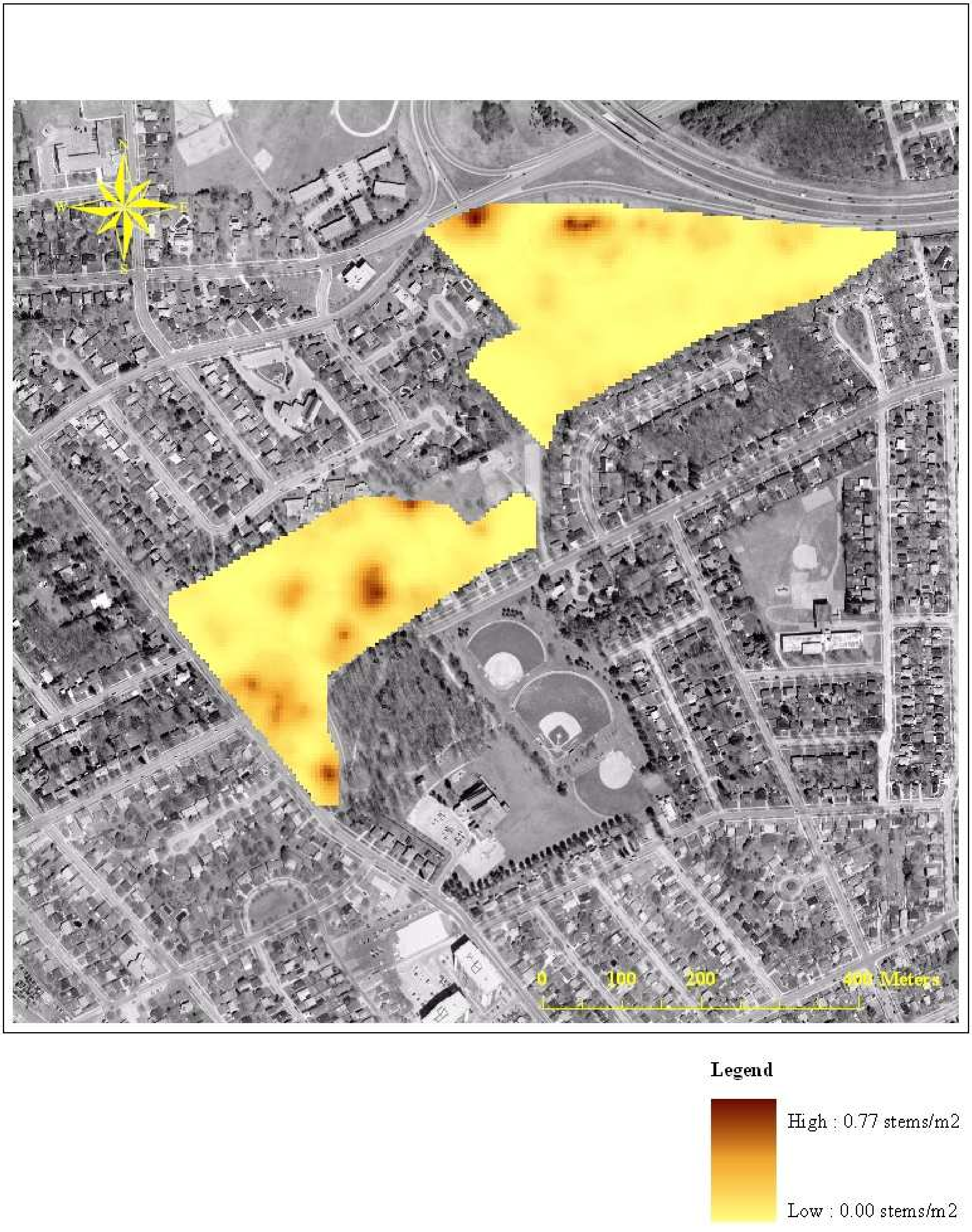
Figure 10. Density of Saplings of All Species in Breithaupt Park

Imagery From: City of Kitchener, 2003

Figure 11. Density of *Acer platanoides* Saplings in Breithaupt Park

Imagery From: City of Kitchener, 2003

Figure 12. Density of *Rhamnus cathartica* Trees in Breithaupt Park



Imagery From: City of Kitchener, 2003

Figure 13. Density of *Rhamnus cathartica* Saplings in Breithaupt Park

The following figures (Figures 14 and 15) are bar plots illustrating the density of all species of forest trees versus distance to visual edge, and the density of *Acer platanoides* trees versus distance to visual edge respectively.

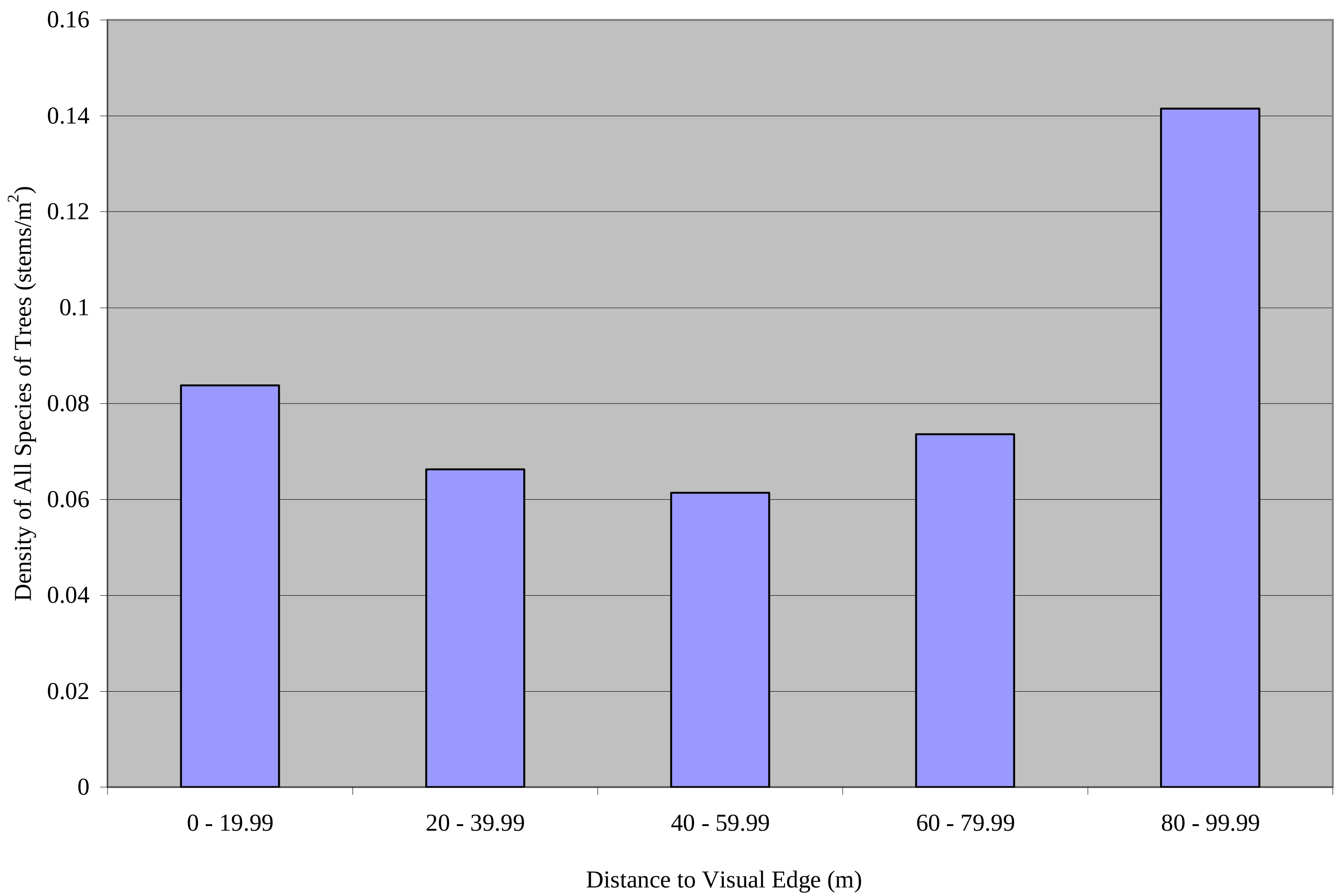


Figure 14. Density of All Measured Forest Trees vs. Distance to Visual Forest Edge

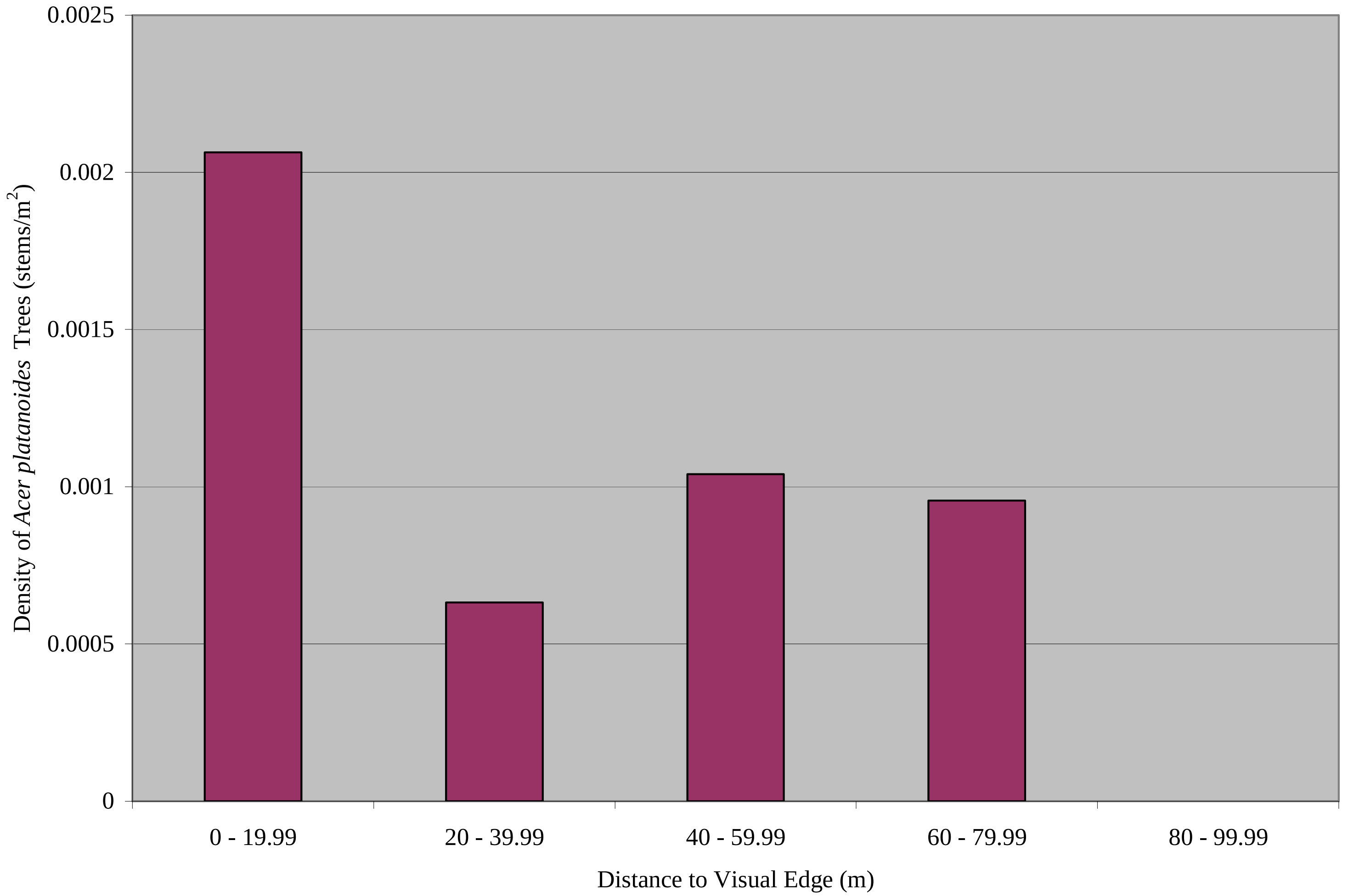


Figure 15. Density of All Measured *Acer platanoides* Forest Trees vs. Distance to Visual Forest Edge

5.6. Comparison of 1990 and 2006 Studies

In 1990, a study of Breithaupt Park was performed by David Schmitt, who is currently the Environmental & Urban Forest Project Manager for the City of Kitchener (Schmitt, 1990). Although the sampling methods differed in Schmitt's (1990) study in comparison to those used in this study, it is still valuable to examine both change in species composition and characteristics over the last 15+ years. The following table (Table 8) illustrates a comparison of these results.

Table 8. Comparison of Inventory Results from 2006 and 1990.

Inventory 2006

	DBH 5-24 cm	**DBH 25-40 cm**	**DBH 41+ cm**	**Total**	**Percent**
Acer saccharum	259	157	86	502	41.7
Fraxinus americana	204	10	9	223	18.5
Ostrya virginiana	121	8	8	137	11.4
Tilia americana	49	6	7	62	5.2
Fagus grandifolia	32	10	7	49	4.1
Rhamnus cathartica	44	0	0	44	3.7
Pinus sylvestris	10	19	6	35	2.9
Juglans nigra	12	18	4	34	2.8
Acer platanoides	23	1	2	26	2.2
Prunus serotina	16	5	2	23	1.9
Populus tremuloides	23	0	0	23	1.9

Inventory 1990

	DBH 5-24 cm	**DBH 25-40 cm**	**DBH 41+ cm**	**Total**	**Percent**
Acer saccharum	112	113	22	247	42
Fraxinus americana	126	6	3	135	23
Ostrya virginiana	36	0	0	36	6
Fagus grandifolia	11	3	10	24	4
Prunus serotina	18	4	2	24	4
Pinus sylvestris	10	14	0	24	4
Tilia Americana	8	11	1	20	3
Rhamnus cathartica	17	0	0	17	3
Ulmus Americana	17	0	0	17	3
Pinus strobes	2	5	8	15	3
Quercus rubra	0	2	9	11	2

	DBH 5-24 cm	DBH 25-40 cm	DBH 41+ cm	Total	Percent
Populus fastigiata	7	0	0	7	0.6
Fraxinus pennsylvanica (red ash)	4	0	0	4	0.3
Cornus racemosa	2	0	0	2	0.2
Acer rubrum	1	0	1	2	0.2
Rhus typhina	3	0	0	3	0.2
Morus alba	3	0	0	3	0.2
Cornus alternifolia	1	0	0	1	0.1
Robinia pseudoacacia	1	0	0	1	0.1
Quercus macrocarpa	1	0	0	1	0.1
Viburnum trilobum	1	0	0	1	0.1
Sambucus pubens	0	1	0	1	0.1
Ulmus americana	1	0	0	1	0.1
Total	**824**	**242**	**137**	**1203**	**100**
Percent	**68.5**	**20.1**	**11.4**	**100**	

	DBH 5-24 cm	DBH 25-40 cm	DBH 41+ cm	Total	Percent
Juglans cinerea	1	2	0	3	1
Acer rubrum	3	0	0	3	1
Quercus macrocarpa	2	1	0	3	1
Celtis occidentalis	2	0	0	2	0
Carya ovata	1	0	1	2	0
Pinus resinosa	0	1	0	1	0
Total	**376**	**163**	**56**	**595**	**100**
Percent	**63.2**	**27.4**	**9.4**	**100**	

(Schmitt, 1990)

Chapter 6 - Discussion

6.1. Interpretation of Results

6.1.1. Condition of the Urban Forest

Condition of the Street Trees

The overall condition of the street tree population was fair to good (mean tree condition = 3.66), indicating that most street trees exhibited only minor problems or no apparent problems (Kenney and Puric-Mladenovic, 2002). Criteria for assessing the overall condition of the street tree population included assessing individual tree condition, measuring the population's biodiversity, and examining the abundance and proportion of native and exotic species. The most common street tree, *Acer platanoides*, was found to be in fair to good condition (mean condition of 3.53), just slightly lower than the mean for all species of street trees; while its congener, native *Acer saccharum*, was found to be in fair condition (mean condition of 3.02), slightly lower than *Acer platanoides* and the average street tree. The mean condition of this urban street tree population was slightly lower than that found in Chicago and the City of Kitchener, both of which reported approximately 2/3 of their species to be in good to excellent condition (McPherson et al., 1994; City of Kitchener, 1998). Though not recorded quantitatively, many of the trees on the street exhibited signs of the fungus, *Anthracnose*, while many of the forest trees exhibited both *Anthracnose* and the fungus *Rhytisma (*tar spot). Tar spot was found only on the leaves of *Acer platanoides* forest trees, while *Anthracnose* was found mainly on the *Acer saccharum* trees within the forest, and on various street trees. Neither of these fungi result in tree death; however, they can cause extensive defoliation and weakened trees respectively (Celetti, 2003; Hudler et al., 1987; Natural Resources Canada, 2003).

To be able to overcome adversity such as disease, disturbance and other urban stressors, a street tree population must have trees of varying ages in good condition and exhibit biodiversity (Welch, 1994). The biodiversity of the street tree population in this study was relatively low with only 33 species recorded. In comparison, McPherson and Rowntree's (1989) inventory of 22 urban street tree populations in the United States yielded that the mean number of species per street tree population was 53 (McPherson et al., 1999). Thus, the 22 cities' street tree populations measured in the United States had a higher biodiversity than that found in the surrounding residential area of Breithaupt Park. While Moll and Ebenreck (1989) suggest that an urban forest should be composed of a maximum of 5% of any specific species, the current study illustrated that 42% of the street tree population was *Acer platanoides,* while 10% was *Betula papyrifera*. All other species each accounted for less than 5% of the street tree population. The current study also exhibited a high percentage of exotic species with 52% of the trees in the street tree population being exotic. In comparison, other cities such as Oakland have exhibited exotic species abundances as high as 69% (Nowak, 1994). McKinney (2002) also noted that the percentage of exotic species tends to increase along the gradient from rural to urban areas. He noted that rural areas can ideally have less than a few percent exotic species while the heart of urban areas can have over half of their urban forest as exotic species. This is due to higher disturbance in urban areas and higher populations of humans near the urban core who tend to plant a higher percentage of cultivars (McKinney, 2002). A high number of cultivars and exotic species was also the trend found within the street tree population in the current study (52% exotic species), while the proportion of exotic species found in the forested park (9% exotic species) was actually more comparable to that of rural areas in McKinney's (2002) study. From the above results, it can be concluded that the study site exhibited a low level of biodiversity and that the condition of the street tree population needs to be improved. This can be accomplished by better care of current street trees and recently planted saplings, planting more suitable and hardy urban species and planting a diversity of street trees as the aging *Acer platanoides* street tree population dies.

Condition of the Forested Park

Overall, the forested park within Breithaupt Park was in good condition, with only 9% exotic species, and a biodiversity of 24 counted tree species. Previous inventories of Breithaupt Park have estimated a total of 130 floral species, including trees, shrubs, flowers and groundcover (Schmitt, personal communication, July 2007). The most abundant species found in Breithaupt Park was *Acer saccharum* (41.7%). This was unsurprising considering the park, located in the Great Lakes – St. Lawrence region, is a climax *Acer saccharum-Fagus grandifolia* forest. However, there was a surprisingly low relative abundance of *Fagus grandifolia* in the park (4.1%), though this has not notably changed since 1990. This is likely due to the general devastation of *Fagus grandifolia* in Southern Ontario attributed to *Cryptococcus fagisuga*, Beech Bark Disease and other diseases and infestations (Waldron, 2003). Overall, the interpolated density maps of all species of trees illustrated a heterogeneous forest where density of trees was variable throughout. The lowest density of all species of trees was unsurprisingly in the naturalization area, which had consisted mainly of grass and a few saplings until Earth Day, 2007, when many *Pinus strobus* seedlings were planted. The most notable difference between the 1990 and 2006 studies of *Acer platanoides* was that there was no evidence of *Acer platanoides* in Schmitt's (1990) inventory, nor, in fact, was there any mention of the presence of *Acer platanoides* in an inventory performed by student Kevin Schmidt in 1981 (Schmitt, 1990; Schmidt, 1981). While a few *Acer platanoides* were measured in the park during the current study whose DBH (converted to age) suggested that they would have been present in Breithaupt Park in 1990, it is possible that these trees were either accidentally misidentified in the current study, or were present in 1990, but at such low levels that they were not detected using Schmitt's (1990) sampling technique. The three species with the highest relative abundance within the forest population remained the same from 1990 to 2006; these were *Acer saccharum*, *Fraxinus americana* and *Ostrya virginiana*. The ten species with the highest relative abundance also remained relatively consistent over that same time period. This suggests that those species with the highest relative abundances continued to successfully produce seeds and thus have continued their establishment in the forest. Between 1990 and 2006, the age structure of the forest changed, forming a younger tree population as the percentage of trees with a DBH of 5-24cm increased by 5.3%. This overall younger population perhaps can be attributed to the death of older *Acer saccharum* and *Fagus grandifolia* trees due to disease or old age. In addition to evaluating the change in forest composition since 1990, the condition of the forested park was also evaluated by its biodiversity in combination with the presence of invasive or exotic species. As mentioned previously, 9% of the trees within Breithaupt Park were exotic; however, some of these, such as *Pinus sylvestris*, were actually planted and did not invade the park through natural processes. Thus the percentage of species that have actually invaded the park naturally is lower than 9%. This number of exotic trees, both as an absolute value and as a percentage of the total number of trees within the park, was surprisingly low in comparison to other studies by Martin and Marks (2006), Webb and Kaunzinger (1993) and Bertin et al. (2005). These studies found *Acer platanoides* abundances varying from 11 to 18%, with the percentage of total exotic species likely being higher within these sites.

6.1.2. Distribution and Dispersal of Exotic Species in Breithaupt Park

Threat from Street Tree Population

Despite the unsurprisingly high abundance of exotic trees on the street, there were few exotic species in Breithaupt Park that could be traced in origin to the street tree population. Of the three exotic species found both on the street and in the forested park, *Morus alba* and *Robinia pseudoacacia* were sporadic (n_{street} = 1 and n_{park} = 3 for *Morus alba;* n_{street} = 1 and n_{park} = 1 for *Robinia pseudoacacia*). The third species, *Acer platanoides*, (n_{street} = 335 and n_{park} = 26) accounted for 42% of the measured street trees. This predominant species of the street tree population was therefore the main ecological threat to the forest. While many studies have examined invasion of rural intact or old-growth forests, few have studied the direct invasion of an urban forested park by species planted as part of the street tree population. In their study of the control of *Ailanthus altissima* (tree of heaven), Meloche and Murphy (2006) hypothesized that the source of *Ailanthus altissima* which invaded Rondeau Provincial Park were garden ornamental *Ailanthus altissima* planted in a nearby community. To the contrary, Bertin et al. (2005) noted that there was little evidence that *Ailanthus altissima* had, or could, invade intact urban forests due to their shade intolerance. Vincent (2005) also documented the invasion of disturbed urban woodlots by *Pyrus calleryana* (pear tree) and concluded that *Pyrus calleryana* was rapidly becoming invasive to disturbed sites, though may not be invasive to natural sites. Therefore, it is possible that other street tree species in other populations are a threat to their local urban forests; however, in the current study, the local street tree population of *Acer platanoides* was shown to be the only local major threat and possible source of invasion of exotic species in the forested park.

Acer platanoides Distribution

Acer platanoides were mainly planted to the south and east of Breithaupt Park. The exception to this were the 19 *Acer platanoides* planted along Erb Street East, which is to the north of the park (though further than the 50m threshold) and the 40 *Acer platanoides* trees planted on Hartwood Avenue East and Hartwood Place, which are to the west of the park. To a certain extent, the ages and species of the street trees could be correlated with the age and location of the housing developments in the residential area surrounding Breithaupt Park. The older trees and the majority of *Acer platanoides* were found in the residential areas south and east of Breithaupt Park. These areas were built in approximately 1952, and as such, were built in the height of the era when planting *Acer platanoides* was popular (Schmitt, personal communication, July 2007). Some of these streets were essentially monocultures of *Acer platanoides*. To the west of Breithaupt Park were newer housing developments where the trees ranged from 5 to 25 years old. These developments demonstrated a greater biodiversity, including species such as *Juglans cinerea* and *Staphylea trifolia*, and had virtually no *Acer platanoides*.

The *Acer platanoides* population within the forested park was a young population of trees, mainly concentrated in the more disturbed southwest section of Breithaupt Park. The 26 measured trees had a mean DBH of 12.9cm which can be converted to a mean of approximately 18 years old, while the 190 recorded saplings were a maximum of 7 years old. Within Breithaupt Park, *Acer platanoides* trees were distributed mainly near the edge of the forested park and graphical analysis revealed that *Acer platanoides* trees had a much higher density at a distance of up to 20m from the visual edge of the forest than any other interior location (Figures 9 and 15). This can be compared to the density of all species, which appeared to remain relatively constant as distance from the visual edge increased (with the exception of the outlier bar at 80-100m from the visual edge). Thus, it can be concluded that primary establishment of *Acer platanoides* was along the edge of the forest; a pattern not reflected by other species within Breithaupt Park (Figure 14).

The most noticeable clusters of *Acer platanoides* were primarily concentrated in the southwest section of the park. The clusters with the highest density of *Acer platanoides* trees were located just northwest of the houses on Union Street and in the northwest corner of the southwest section, along Margaret Avenue. As the houses along Union Street had a number of *Acer platanoides* planted as street trees and in their backyards, it is likely, based on proximity, that they were the parent trees of the aforementioned forest cluster. The clusters along Margaret Avenue were at the forest edge where it met the road. Roads such as Margaret Avenue abutting the park could have facilitated *Acer platanoides* seed dispersal. This is because they provide a flat surface over which seeds could have been blown or fallen onto passing cars travelling along the road. From there, they could have been transported along this corridor, closer to the forest than their natural dispersal distance would usually allow (Davies and Sheley, 2007; Wangen and Webster, 2006). *Acer platanoides* saplings followed a similar distribution pattern to that of the *Acer platanoides* trees. The density and number of *Acer platanoides* saplings was also highest in the southwest section of Breithaupt Park. Here, there were two main clusters which spanned the length of the park diagonally from northwest to southeast. The cluster further to the east was in close proximity to the main cluster of *Acer platanoides* trees in this section. Due to this close proximity, it can be hypothesized that this particular cluster of trees was likely acting as parent seed sources of the *Acer platanoides* saplings. It is likely that here, a parent tree was either planted in the backyard of one of the houses, or directly in the forest, and then continued to produce seeds which dropped nearby, established and then grew into saplings and eventually trees.

Acer platanoides were largely absent from the naturalization area northeast of the parking lot within Breithaupt Park. As urban foresters from the City of Kitchener have assured that there has not been active removal of *Acer platanoides* within Breithaupt Park, the question remains as to why this species had not established itself in this area of the park that was presumably vulnerable to invasion. *Acer platanoides* was also not found in any of the grassed areas. As these areas are routinely mowed, any seedlings that could establish themselves would have been killed. In the naturalization areas, however, mowing did not occur and therefore *Acer platanoides* would have had an opportunity to establish itself. There were some *Acer platanoides* (likely planted) that were located abutting both the naturalization areas and the backyards which could have functioned as parent trees. As the ecology of *Acer platanoides* suggests that it is capable of establishing itself in these naturalization areas, it is likely that there had been some human interference preventing *Acer platanoides* establishment (Raloff, 2003; Munger, 2003; Meiners, 2005; Wangen and Webster, 2006).

Quantifying an Acer platanoides Invasion

The extent of an invasion of a forest by an invasive species can be determined by a count of the absolute number of invasive species in the forest or by an examination of whether native forest species are being displaced by the particular incoming species (Luken, 2004). A certain amount of natural colonization by the processes of seed dispersal, establishment and growth would be expected within a forested park that directly interfaces with residential streets (Millard, 2000). However, when these new species begin to displace the native species, especially to a point where their relative abundance exceeds that of the natural native species, the possibility of an 'invasion' must be examined. There are three stages to invasion: introduction of a new species, establishment of this species, and finally expansion of the species' range (Andow et al., 1990). If *Acer platanoides* have indeed successfully invaded and established in Breithaupt Park, this would demonstrate that there are negative ecological effects in having *Acer platanoides* as the most predominantly planted street tree in Kitchener.

As there is no threshold defining at what point a forest has been invaded, it is necessary to compare the current study to other studies in which *Acer platanoides* has been definitively characterized as having invaded a forest. The following studies of *Acer platanoides* invasion exhibit relative abundances of *Acer platanoides* that are much higher than that of the current study. A study by Webb and Kaunzinger (1993), in which the invasion of *Acer platanoides* into a *Fagus grandifolia-Acer saccharum* forest was measured, determined that the relative abundance of *Acer platanoides* was 17.2% and was second in presence in the forest only to *Fagus grandifolia*. They also determined that *Acer platanoides* had begun to establish in the forest by 1915, at least 75 years before their study took place. Based on its prevalence and ecological impact on the forest, they decisively categorized the forest as having been invaded by *Acer platanoides* (Webb and Kaunzinger, 1993). In contrast to the current study, however, *Acer platanoides* in Webb and Kaunzinger's (1993) study site had a much longer history and passing of time since it invaded and established itself in their study site. Likewise, Bertin et al. (2005), in their examination of 32 woodlands in a city in Massachusetts, determined that in their urban forest, 11% of all measured trees and 23% of all measured seedlings and saplings were *Acer platanoides*. Another study of *Acer platanoides* invasion examined Mont Royal in Montreal (CBC News Online, 2006). Brisson and Midy determined that of trees aged 10 years and older, the forest had 1200 *Acer platanoides* trees and 4200 *Acer saccharum* trees (CBC News Online, 2006). They also determined that the *Acer platanoides* sapling abundance within the forest was three times that of the native *Acer saccharum* sapling population, indicating that a much higher composition of *Acer platanoides* trees would possibly occur in the future, with dire ecological consequences (CBC News Online, 2006). Unfortunately, the population count of other species was not made available and thus, actual percentage composition could not be compared; however, it is noteworthy to mention that, using the point-quarter sampling method in the current study, there was 502 *Acer saccharum* trees measured in comparison to only 26 *Acer platanoides* tree; a much lower ratio than that found by Brisson and Midy. Finally, in their study, Martin and Marks (2006) added *Acer platanoides* seeds to a forest over the period of three years to experimentally determine whether they could survive under differing canopy conditions. Their results demonstrated that "intact forests only weakly resisted *A. platanoides* colonization, but strongly suppressed its rate of invasion" (Martin and Marks, 2006, p. 1070). This could be one possible explanation for why *Acer platanoides* have actually been found in the current study's forested park, but why this number was fairly low.

As illustrated in recent studies by Martin and Marks (2006), Webb and Kaunzinger (1993), and Bertin et al. (2005), there is no question as to whether *Acer platanoides* can be an invasive species, as it has effectively demonstrated this ability at other study sites and physiologically has the necessary characteristics for a potentially invasive species. Using the plot sampling method in this study, it was determined that *Acer platanoides* constituted 1.9% of all trees, 3.2% of all saplings and 2.7% of all seedlings in the forest sample. Comparison of these percentages from the current study with the above studies illustrates that *Acer platanoides* presently has not invaded or established itself in Breithaupt Park to an extent comparable to that of the aforementioned studies.

Dispersal of Acer platanoides

In this particular study, it was concluded that there were four possible sources of *Acer platanoides* seeds that could potentially establish in the forest. These were: street trees, trees planted in front yards and backyards (excluding street trees), the parking lot in Breithaupt Park (only in the fall) and the possibility that *Acer platanoides* were planted directly in the forest (in addition to the 6 that were planted in the grassy area around the parking lot). The parking lot was located between the two largest sections of forest, and is where street tree samaras and leaves, such as those of *Acer platanoides*, were deposited in the fall. This was the City of Kitchener's local leaf drop-off site. While there was porous fencing on three sides of the leaf drop-off site, it was open to the south and was not covered on the top at all. Leaves and other detritus were dumped loosely into these designated areas. Within 50-100m of the visual edge of some of the forested park, there were also possible parent *Acer platanoides* trees planted in the front and back yards of the surrounding residential houses, and as street trees. As the samaras of *Acer platanoides* have an average dispersal distance of 50m from the parent tree, which could increase in high winds, it is likely that these locations could serve as a source of *Acer platanoides* seeds (Matlack, 1987). Bertin et al. (2005) determined that the seeds could possibly be dispersed, though only occasionally; up to hundreds of meters from their source, thus increasing the possible number of parent *Acer platanoides* trees within the vicinity of the forested park. In addition, it is also possible, though unlikely, that one or two parent *Acer platanoides* may have been planted by unknowing local citizens in the forest itself. Without genetic testing however, it is impossible to definitively ascertain the source of the *Acer platanoides* trees growing within Breithaupt Park.

Why haven't Acer platanoides invaded Breithaupt Park?

Unlike many studies on this species (Martin and Marks, 2006; Webb and Kaunzinger, 1993; Bertin et al., 2005), *Acer platanoides* has not invaded Breithaupt Park despite a 50 year history of being planted on the streets. Possible explanations as to why *Acer platanoides* did not appear to have successfully invaded this forested park or why this particular invasive species could possibly be just beginning to establish itself in Breithaupt Park, include: 1) houses located between *Acer platanoides* street trees and Breithaupt Park functioning as a barrier to seed dispersal; 2) the highway traversing the northeast corner of the park; 3) the short length of time since *Acer platanoides* street trees reached their age of maturity to produce enough viable seeds to invade the forest and the lag time in the establishment phase; 4) unique park characteristics; and 5) opposing predominant wind directions.

An important spatial separation exists between the forested park and the street trees, mainly due to the houses forming a barrier between the two. The houses located between streetscape *Acer platanoides* and Breithaupt Park may have formed a major barrier to seed dispersal. The houses are located on the two longest sides of the park and, while only 1-2 storeys, the footprint was approximately 8m high and 50m deep, meaning that they created both a vertical and horizontal barrier. This needs to be tested and modelled more carefully; however, it was noted that *Acer platanoides* trees were usually 2-3m in front of the houses and typically 5-10m tall. Property rights prevented detailed inventories of trees in the backyards that abut the park but visual surveys from the street determined that only 42 *Acer platanoides* trees were planted in some backyards within the delineated boundary surrounding Breithaupt Park – much fewer than those actually planted as street trees within the delineated boundary.

This spatial separation between the street tree population and the forested park was also due to the highway, Conestoga Parkway, which was constructed in 1969 and effectively bisected the park into two parts. This section of the parkway is four lanes plus one on-ramp in either direction. The 45 to 60m wide parkway likely functioned as a barrier to seed dispersal. Since the seed dispersal distance of *Acer platanoides* samaras is normally 50m, it is unlikely that many seeds could successfully traverse the distance, especially with the added factor of interference by cars and trucks (Matlack, 1987). In addition, *Rhamnus cathartica* generated a high density barrier along the edge of Breithaupt Park where it faces the highway. This may have created an additional physical barrier to the wind dispersal of seeds from possible *Acer platanoides* sources on the other side of the parkway into Breithaupt Park.

Evaluating the ecological integrity of an ecosystem involves comparing its historic reference state and its current state, examining the species composition of the forest and the health of the trees within the forest, seeking evidence of structural complexity and evaluating the impact of invasive species on this forest (Christensen et al., 1996; Dale and Beyeler, 2001; Parks Canada, 2007). The historic reference state of this park was a climax *Acer saccharum-Fagus grandifolia* forest; however, without a quantitative description of the other species, this is a vague state to compare the current state of the forest to. Though it is not possible to determine the degree of ecological integrity that this park has, it can be concluded that the park is exhibiting a certain degree of ecological integrity as the park is definitely demonstrating a resistance to *Acer platanoides* invasion. This is likely due to its biodiversity, the structure of the forest, the additional factors of structural barriers to seeds of invasive species and its varying age distribution as well as species distribution.

Examination of the interpolated density maps revealed that the southwest section (where more recent disturbances occurred) was characterized by a dense understory - reflected in both the high density of all species of saplings and its abundant groundcover. This is where the densities and relative abundances of both *Acer platanoides* saplings and trees were higher. The northwest section, with its longer history of passive management, was an interior forest, with a less dense understory, reflected by less groundcover and fewer saplings. Fewer *Acer platanoides* were found here, which can be attributed to the barriers formed by the highway, the houses with few *Acer platanoides* in their backyards and the 'wall' of *Rhamnus cathartica* along the highway. Differences in microclimate conditions such as soil and topography could have also influenced the growth of trees and understory in the northeast and southwest sections of the park. The topography of the two sections of the park differed considerably. The northeast section has a steep hill that runs diagonally through the northeast section, while the southwest section has a variable topography, but with no distinguishing prominent features. The steep hill in the northeast section likely affects microclimate conditions such as shade, light and wind exposure. Previous studies of Breithaupt Park also illustrated that the soils remarkably differed between the two sections, with a more gravelly soil found in the northeast section and a more sandy soil in the southwest section (Schmidt, 1981). Both topography and soil are factors that influence the microclimate conditions of the forest, with different combinations making some areas more conducive to the growth of some species of trees over others. For example, *Acer platanoides* prefers mesic, deep and fertile and slightly alkaline soils over those that are acidic, too wet or too dry (Bertin et al., 2005; Nowak and Rowntree, 1990). *Acer platanoides* also grows in a range of soil conditions from sands to moderately compacted clays; however, it may not exhibit optimal growth in the slightly gravelly soils of the northeast section of Breithaupt Park (Modry et al., 2004). Also, while *Acer platanoides* is shade tolerant as a seedling and sapling, as it gets older, its shade tolerance is reduced; therefore differences in sun exposure and canopy gaps between the two sections may also affect establishment and growth (Nowak and Rowntree, 1990).

Spatial analyses of the street tree population of *Acer platanoides* revealed that the majority of *Acer platanoides* street trees were planted to the south of the park. As the predominant winds in Kitchener-Waterloo are northerly or westerly winds, and as *Acer platanoides* seeds are wind dispersed, it is possible that the prevailing winds would have influenced the direction of seed drop, and this would have been, for the most part, facilitating the dispersal of seeds in the opposite direction of the forested park (The Weather Network, 2007).

The Forest Edge

Considerable research has focused on boundary and edge determination, illustrating the difficulty and complexity of defining this portion of a fragmented forest (Fagan et al., 2003). The edge of the forest is a transitional zone, exhibiting characteristics of both the exterior and interior of the forest (Bott et al., 2003). The edge can be determined by analyzing the gradient in microclimate conditions between the exterior and interior of the forest and by changes in species composition, which can drastically change from the edge to the interior (Forman and Godron, 1986). As *Acer platanoides* is not necessarily an edge species and can often establish in the interior of forests where there are gaps or where there has been disturbance, the exact width of the edge could not be determined based solely on the distribution of *Acer platanoides* or other exotic species such as *Rhamnus cathartica* (Munger, 2003). Therefore, in this specific case study of Breithaupt Park, it would be presumptuous to assign a value to an edge width without further measurements and examination of the forest, since this forest: a) is located in an urban area; b) has been bisected by a highway; c) has been bisected by a residential road; d) has been cut into by one dead-end road and one crescent to form residential streets; and e) has numerous trails totalling 7.6 km transversing it (Schmitt, 1990). Future research involving extensive meteorological and ecological sampling of the soil, and measurement of air temperature, wind speeds, amount of light and other edge indicators, combined with an inventory of the forest population, could decisively determine the extent of the edge habitat, though those measurements were beyond the scope of the current study.

Possibility of Future Invasion by Acer platanoides

While the number of both *Acer platanoides* trees and saplings are low in comparison to the number of both *Acer saccharum* trees and saplings and to the number of all species of trees and saplings, these results could demonstrate the initial stages of an invasion of the forest. Given that *Acer platanoides* reach their age of maturity at 25-30 years old and that they were planted a maximum of 55 years ago, it is likely that they only begun to produce viable samaras 25-30 years ago (Wangen and Webster, 2006). Thus, while they have a 50 year history as a street tree, they were only viable seed producers for a maximum of 30 of those years. Therefore, it is possible that not enough time has passed since their planting on the street as a source of seeds to allow for a full-fledged invasion of the nearby forested parks, indicated by a current lack of establishment by *Acer platanoides* trees and saplings. As the forested park did have a primarily native tree canopy, presence of exotic tree seedlings or saplings would indicate possible movement of residential tree species into the forested park areas. *Acer platanoides* could also have been demonstrating a potential lag time in their establishment before a full-fledged invasion (Wangen and Webster, 2006). In their analysis of the timeline of an invasion by *Acer platanoides* in a natural forest, Wangen and Webster (2006) demonstrated that *Acer platanoides* has the ability to build up a large seed bank in the soil before they actually establish themselves as a population. In their study, *Acer platanoides* trees exhibited a 34 year establishment phase in which clusters of *Acer platanoides* were found and the majority of saplings were non-reproductive (Wangen and Webster, 2006).

Rhamnus cathartica

The other major exotic and invasive species with a number of trees and saplings found growing within Breithaupt Park was *Rhamnus cathartica. Rhamnus cathartica* is a historically invasive species which has not been planted as street trees or landscape cultivars within the residential area surrounding Breithaupt Park. This is mainly because it is known to be highly invasive and generally is not a viable street tree (Zipperer, 2002; Archibold et al., 1997; Moffatt and McLachlan, 2004). In addition, as *Rhamnus cathartica* is not wind-distributed, its seed source was likely outside the study area (Duncan, 2005). Presently, *Rhamnus cathartica* has established itself in Breithaupt Park at a low relative abundance, which has not appreciably changed since 1990 (Schmitt, 1990). As to the origins of Rhamnus, there was no distinguishable pattern concerning the *Rhamnus cathartica* trees as its density was quite low, and only one notable cluster was observed in the southwest section, just north of Union Street. The most notable cluster of *Rhamnus cathartica* saplings is in the northeast section was along the edge of the forest facing the expressway (the Conestoga Parkway). Anecdotally, there was a narrow "wall" of *Rhamnus cathartica* here – perhaps likely to resist colonization by other exotic species and native species alike. Because *Rhamnus cathartica* is dispersed primarily by birds and it is shade tolerant, its seeds could have been easily be dispersed to any location within the forest, including both the interior and the edge (Duncan, 2005; Raloff, 2003). This explains the patchy and discontinuous pattern in Breithaupt Park. While removal of this species is ideal, removal of *Rhamnus cathartica* would also result in removal of the barrier along the highway, which is possibly preventing *Acer platanoides* dispersal, and would create gaps in which *Acer platanoides* would likely establish. While *Rhamnus cathartica* is a concern in Breithaupt Park, its relative abundance, and lack of increase in numbers since 1990 means that it is less of a concern than *Acer platanoides*. As such, it is recommended that management of the urban forest begins primarily with removal of *Acer platanoides* in the forested park, and then control and possible removal of *Rhamnus cathartica*.

6.2. Application of Research Findings

The issue of invasive and exotic species in urban forested parks and residential neighbourhoods, and specifically the issue of invasive species and their potential threat to urban forested parks, is a current concern for municipalities who want to effectively manage these ecosystems. While municipalities have acknowledged and embraced the social, economic and ecological benefits of trees, they have just recently begun to seriously consider and understand the ecological impacts of their planting decisions (Miller, 2005). This study exhibits external validity in that the results, the methodology and the recommendations can be generalized beyond the specific parameters of this study and the study site to other municipalities in North America, and perhaps further abroad. One caveat of these results which may affect their generalizability to other municipalities is the specific circumstances of Breithaupt Park and its surrounding residential area. These include: the park itself is surrounded by houses which could act as a seed and wind barrier, most *Acer platanoides* street trees have been planted to the south of the park while there is a north-westerly wind (potentially affecting seed dispersal), and that the street trees were planted approximately 40 to 50 years ago and therefore have likely only been producing viable seeds for the past 20 to 30 years. However, if indeed *Acer platanoides* does invade Breithaupt Park in the future, this study provides the baseline data to which future inventories of the composition of the forest can be compared. This will enable academic researchers and urban foresters in the City of Kitchener to study this invasion and allow them rare insight into the lifetime and pattern of an invasion.

The methods used in this study to complete the street tree inventory, measure species spatial distribution and characteristics within an urban forest, and both spatially and statistically analyze the dispersal of street trees into the nearby urban forested park can all be easily applied in other municipalities. These methods can be simply modified to be utilized in areas with fragmented forests of any shape and size, as long as they interface directly with a residential area of planted street trees. Likewise, the recommendations from this study can be modified and taken into account for urban forest management plans throughout North America. Many of the recommendations are not necessarily site specific or species specific but address the broader issues of managing urban forests with both residential and forested area components. Many of these recommendations also address the issue of *Acer platanoides* street trees, which is a current concern for many municipalities in North America.

The results of this research and the resultant suggestions for management and planning practices will be significant for local urban foresters. Urban foresters in the City of Kitchener will utilize this research to inform their proposed ten-year management plan for their urban forest, including both residential trees and forested parks. They will have a ten-year commitment of capital and operating funding that will allow for $200,000 per year in capital investment for protected (natural) areas by 2015 (Murphy, personal communication, July 2007). This is remarkable considering that the current and historical capital budget has been non-existent. The baseline of data created during the proposed tree inventory and the resulting recommendations stemming from this study will be used by these foresters to inform their revisions of their current urban forest management practices and policies. These recommendations can also be utilized by local policy makers in deciding what species of trees are allowed to be, or mandated to be, planted in Kitchener's residential areas.

6.3. Conclusions

Breithaupt Park, located on the border of the cities of Waterloo and Kitchener, is an urban forested park, vulnerable to invasion by exotic street tree species due to its fragmented composition, its long length of edge habitat, and the fact that it is continuously subjected to the unique stressors of urban areas. To study the potential invasion of the forested park, it was first necessary to examine the distribution of the likely source of this invasion, the street tree population of the surrounding residential neighbourhood. The spatial distribution of the street tree population was reflective of the housing developments and their age. Older housing developments built in the 1950's, such as those to the south of Breithaupt Park, tended to have exotic *Acer platanoides* planted as their street trees, while newer housing developments tended to have a wide variety of species planted. Within the forested park, *Acer saccharum* was the most abundant forest species. The highest density of all species of trees was in the more disturbed, southwest section of the park, and *Acer platanoides* was most abundant in this section as well. The other major exotic species in the forest, *Rhamnus cathartica* was found primarily along the edge of the forested park facing Conestoga Parkway, and in various clusters throughout the rest of the forested park. The only exotic tree species which had more than a few individuals in either the forested park or the street tree population was *Acer platanoides*. Hence, this study focused primarily on the dispersal and spatial distribution patterns of *Acer platanoides* throughout the study site.

As many of the street tree species in Kitchener that are dying are the exotic *Acer platanoides*, the question was thus raised as to whether exotic or native species should be planted to replace dead trees (GRCA, 2004a). This is both a function of the general ideology that native trees are preferable from a natural heritage perspective, while the fact remains that exotic trees tend to be more adaptable to climate change and more resilient to the stresses of urban areas (Meffe and Carroll, 1997). Analysis of the condition of both the street tree population and forest tree population were necessary to answer this question. The street tree population in the residential areas surrounding Breithaupt Park proved to be in good condition. Species exhibiting excellent condition included *Juglans cinerea*, *Fraxinus americana* and *Betula papyrifera*. These trees obviously can overcome the urban stressors of the Kitchener area to survive and perhaps even thrive in urban ecosystems. While individual trees were, on average, in good condition, it would be ideal if the native biodiversity of the forest was higher. As mentioned previously, this would increase the forested park's resistance to disturbance, disease and insect infestations (Kenney and Rusak, 2005; SER, 2004). It would also be ideal if the high relative abundance of *Acer platanoides* was decreased and that the suggestion made by Moll and Ebenreck (1989), that no species have a relative abundance higher than 5%, be implemented. The forested park was also in relatively good condition, as it demonstrated a high biodiversity and a relatively low percentage of exotic species.

One of the primary reasons that *Acer platanoides* was the most predominant street tree planted in the twentieth century was that it was resilient to urban stresses. In comparison to *Acer saccharum* and other native, traditional street trees, *Acer platanoides* tend to have stronger branches, grow faster and be less negatively affected by salt, mechanical stresses and urban heat island effect (Lanken, 1992; Munger, 2003; Metsger, 2000; Meiners, 2005). However, *Acer platanoides'* resistance to urban stresses, the fact that it can establish in forest gaps and edges, rapid growth of seedlings, shade tolerance at early ages and its ability to grow in a variety of microclimate conditions all give it the capability to establish, survive, and effectively 'invade' urban forested parks, as illustrated in studies by Nowak and Rowntree (1990), Munger (2003) and Wangen and Webster (2006). These studies have conclusively demonstrated that *Acer platanoides* had successfully invaded the urban forested park from the street tree population.

Since the last forest evaluation in 1990, the relative abundances of each species of tree in Breithaupt Park had not notably changed, and the three species of trees with the highest relative abundances in the 1990 study (*Acer saccharum*, *Fraxinus americana* and *Ostrya virginiana*) remained so. The exception to this was the presence of *Acer platanoides* in the park, which was not detected (though likely present in low numbers) in the 1990 study. However, at present, *Acer platanoides* is not demonstrating a major presence in the forested areas of Breithaupt Park. *Acer platanoides* constituted 1.9% of all trees, 3.2% of all saplings and 2.7% of all seedlings in the forest sample. Especially in the current study, the method of dispersal of *Acer platanoides* seeds must also be considered. As they are wind-dispersed, this would suggest that the temporal distribution of establishment would likely be from the perimeter of the forest to the interior as was seen in this study. Examination of the interpolated density maps revealed that there were few *Acer platanoides* trees growing within the park and that they were concentrated mainly in the southwest section and were located primarily within the first 20m of the forested park from the visual edge. Though *Acer platanoides'* relative abundance has increased since 1990, the conclusion of this study is that *Acer platanoides* are currently not showing a substantial presence in the park, and their relative abundance is much lower than that found in the aforementioned studies. Reasons for this lack of invasion include: the surrounding houses and highway functioning as a seed barrier, the predominant winds blowing seeds in the opposite direction of the park and resistance of the park to invasion due to its ecological integrity, structure, composition and microclimate conditions.

As *Acer platanoides* were planted on the surrounding residential streets 40 to 50 years ago and reach the age of maturity at 25 to 30 years, they have only had a maximum of 25 years of viable time to produce seeds that could infiltrate the forest edge (Wangen and Webster, 2006). Thus, there is a possibility that *Acer platanoides* is still yet to 'invade' the forested park in this study, and establish itself at levels which will be detrimental to the native trees such as *Acer saccharum*. As of 1990, there were no (or very few) *Acer platanoides* trees, saplings or seedlings established in the park at that time (Schmitt, 1990). In addition, studies have shown that *Acer platanoides* is capable of having a 35 year establishment phase before successful invasion occurs (Nowak and Rowntree, 1990; Wangen and Webster, 2006). These facts, when evaluated together, suggest that any currently found *Acer platanoides* are indicative of a recent dispersal or invasion (though this would be in its infancy), or that the park has shown resiliency and resistance to invasion by *Acer platanoides* and that the influx of *Acer platanoides* is only indicative of a natural movement of seeds of any species planted close to a natural forest into that forest to some degree. As there have been notably few *Acer platanoides* trees found in the park, this study can be deemed as an early assessment of the potential for invasion of *Acer platanoides*. Overall, however, it can be concluded that *Acer platanoides* is a relatively new presence in Breithaupt Park, though it has been planted on the surrounding streets for at least 40-50 years and that *Acer platanoides* is not currently invading the park but it may be tending towards a future invasion.

While each species of tree has a set of attributes that makes it more desirable for being planted in urban areas, there are benefits and costs of each. The cost of the *Acer platanoides* is that, once established in a forested park, it has been shown to have negative ecological effects by considerably impeding the growth of native species (Munger, 2003; GRCA, 2004a; Wangen and Webster, 2006). Based on other studies of *Acer platanoides*, and taking into account the fact that *Acer platanoides* has likely only had 25 years of viable production in the residential area surrounding Breithaupt Park, and may be exhibiting an undetectable lag phase, it is necessary to invoke the precautionary principle and suggest that management plans be made so that the chances of *Acer platanoides* successfully invading and establishing within Breithaupt Park are minimized. Good urban forest ecology, management and planning practices within the City of Kitchener may be able to mitigate the threat of *Acer platanoides* that other municipalities have been negatively affected by.

6.4. Recommendations

The following recommendations are based on the results of the research, and influenced by the current ecological literature concerning urban forests, and specifically street trees and invasive species:

1) It is recommended that *Acer platanoides* currently planted on the street continue to be managed under the same management plan as other street trees. It is recommended that these trees not be cut down or removed (except in the case of tree decline, death or being generally hazardous) from the street. This is ecologically justified by the previous discussion on the lack of invasion of local forested parks at this site by *Acer platanoides* street trees.

2) It is recommended that other exotic street trees, including *Morus alba* and *Robinia pseudoacacia*, also not be removed from the street, but also be managed under the same management plan as the other street trees.

3) It is recommended that *Acer platanoides* not be planted in the future to replace those street trees which have died. This is for the reason that as the cohort of planted *Acer platanoides* are reaching maturity, the source of seeds is growing and less future plantings of this species will minimize the risk of future invasion. This is based on the ecological literature which shows this potential for invasion, and the fact that *Acer platanoides* seedlings, saplings and trees are still found in the forest, likely emanating originally from street tree plantings (Wangen and Webster, 2006). Note however, that because the other exotic street trees found on the street were not also found in the forest, this study can not make any conclusions about the ecological impact of those species of trees specifically on nearby forested areas. Though these trees were not found in the forest, indicating that they are not invading, they were also planted on the street in much smaller numbers, which means they may have not been able to produce the seed drop necessary for establishment in the nearby forest. However, this study is in no way condoning the planting of any exotic species on the street, as they have the potential to be ecologically damaging and are not as preferred since they have a higher potential to be invasive than do native species (Duncan, 2005).

4) It is recommended that hardy native trees be planted as a replacement for dead exotic street trees. This could include native species such as *Amelanchier canadensis* (serviceberry), *Acer rubrum*, *Acer saccharum*, *Celtis occidentalis* (common hackberry), *Gleditisia triacanthos* (honeylocust), *Quercus alba* (white oak), *Sorbus americana* and *Tilia americana* (City of Waterloo, 2004). These species are recommended as street trees by the City of Waterloo (2004). Choice of these species is also justified by the current population of *Amelanchier canadensis, Sorbus americana*, *Fraxinus americana* and *Tilia americana* that are thriving and exhibiting good to excellent conditions on the residential streets surrounding Breithaupt Park.

5) It is recommended that a diversity of trees be planted on the streets. Though not necessarily directly supported by the results of this study, a diversity of species will protect against disease and insects that tend to be species-specific. An urban forest exhibiting biodiversity is therefore necessary for a continuing healthy population and survival (Kenney and Rusak, 2005; SER, 2004).

6) It is recommended that native trees (specifically non-*Acer platanoides*) be planted on streets where there are currently no street trees. For this specific research area, this would include planting of trees on Arlene Place, Margaret Avenue, Bluevale Avenue and other crescents which do not have trees planted in the grassy centres of the crescent.

7) It is recommended that monitoring of all street trees, and especially young saplings recently planted as street trees, take place over the next few decades. Long-term monitoring of recently planted trees will provide data on the health and condition of these trees over their lifetime, and their ability to survive in urban areas. While these young trees were shown to be in good to excellent condition in this study, knowledge of their long-term survival and condition will be useful in determining future street trees to be planted.

8) It is recommended that further education of homeowners, especially those whose houses back onto natural grassed and forested areas, occur. Suggestions for homeowners to protect forested areas in their residential neighbourhoods include:

a) sweeping up fallen *Acer platanoides* samaras from their driveways and lawns and bagging them

b) refraining from dumping any sort of vegetation refuse (dead or alive) in the forest

c) refraining from planting invasive species (either groundcover or shrubs or trees) in their front yards or backyards

d) removing invasive species currently growing on their property

e) ensuring that groundcover such as *Vinca minor* and *Hedera helix* do not continue to grow beyond their property lines onto natural areas, and ideally remove them

9) During the course of this study, it was noted that the City of Kitchener has a leaf dump site in the fall in the parking lot of the park. Though no specific study was undertaken specifically to examine the relationship between the dumpsite and the growth of invasive trees, it is possible that samaras and seeds could be blown from the parking lot into the forest. It is thus recommended that the effect of the leaf dump site, if any, be examined, and that in the meantime, the leaf dump site be moved to somewhere less likely to influence naturally forested areas such as the nearby, but slightly removed, Breithaupt Community Centre.

10) It is recommended that all *Acer platanoides* in the forest, including seedlings, saplings and trees be removed. This will prevent current *Acer platanoides* seed sources from propagating further within the forest. This comes with the caveat that the forest must be monitored carefully after *Acer platanoides* removal to ensure that this does not encourage or allow subsequent invasion by other species, capitalizing on the newly created gaps. Thus, it is further suggested that this recommendation be executed in conjunction with the implementation of Recommendation #12.

11) It is recommended that expansion of other invasive species' ranges be monitored within the park. Ideally, it is recommended there should be removal of these other invasive species in the forest, including *Rhamnus cathartica*, smaller species such as

Elaeagnus angustifolia, and groundcover such as *Hedera helix*, *Vinca minor* and *Alliaria petiolata.* Though not quantitatively measured within the current study (with the exception of *Rhamnus cathartica*), visual inspection revealed that these species are notably expanding their ranges within the forest. These species have also been found to be highly invasive in other forested parks in Southern Ontario (GRCA, 2004a; Waldron, 2003). However, this is a recommendation that must also be executed in conjunction with the implementation of Recommendation #12.

12) It is recommended that ecological restoration of this site occur. This could entail removal of all invasive species, planting of native species, and management of the current naturalization areas. One excellent suggestion for restoration by Jacques Brisson (CBC News Online, 2006) was to plant young seedlings and saplings, such as *Acer saccharum* and *Fagus grandifolia*, in the forest. This will ensure that these species remain an important part of the urban forest in the future. However, restoration efforts must consider the ultimate goals of the restoration project (to restore structural features or processes), the physical size of the project, the potential impacts of the project and how the objectives or the outcomes of the project will be maintained over the long-term (George and Zack, 2001; Hobbs and Harris, 2001; Kuluuvainen et al., 2002).

6.5. Suggestions for Future Research

There is a great deal of future research to be conducted concerning urban forest ecology and especially the ecology of the invasive *Acer platanoides*. A major area of research which has thus far been only modestly studied concerns the interaction between the exotic species *Acer platanoides* and *Rhamnus cathartica*. Ideally, it would be recommended to remove all invasive exotic species such as *Rhamnus cathartica* and *Acer platanoides* from this field site. However, the ecological interactions between *Acer platanoides* and *Rhamnus cathartica* are unknown. Thus, *Rhamnus cathartica* could potentially be currently acting as a barrier to wind dispersal of *Acer platanoides* samaras into the forest, decreasing the ability of *Acer platanoides* to infiltrate the forest edge. *Rhamnus cathartica* also uses aggressive methods such as chemical inhibition of growth and dense shading, both of which inhibit growth or prevent establishment of *Acer platanoides* seedlings or saplings nearby (Martin, 1999; Munger, 2003; Sanford et al., 2003). Further research should be conducted to fully understand the interactions of these species, as

Rhamnus cathartica seeds or seedlings may be currently outcompeting *Acer platanoides* seeds or seedlings that have managed to establish themselves in Breithaupt Park and/or preventing initial establishment of *Rhamnus cathartica*.

It is also suggested that manipulative experiments be performed at either this field site or others to determine the effect of removing all invasive species without restoration work. Removal of invasive species with no further work done to protect the forest could potentially expose the site to invasive species or could renew the integral ecological integrity of the park. It would also be an interesting experiment to remove all of the invasive exotic species, especially *Rhamnus cathartica,* along the edges and plant a native species in its place to act as a wind dispersal barrier around the park. This would likely be more effective in protecting the park from wind-dispersed species such as *Acer platanoides* and less effective with bird-dispersed species such as *Rhamnus cathartica*.

Another suggestion for further research is to examine the interaction between invasive groundcover or tree species and the trails throughout the park. These trails could potentially act as a conduit for invasive groundcover or tree species movement (Wangen and Webster, 2006). Breithaupt Park currently has an extensive trail system with a length of almost 7.6km transversing the forest. In the current study, data has been collected on the groundcover composition of each plot and the density of *Acer platanoides* and the distance between the plot and the closest trail. This data could be further analyzed to determine if a relationship between invasive groundcover such as *Alliaria petiolata* or *Acer platanoides* and trails does indeed exist.

While in the current study it has been concluded that *Acer platanoides* should no longer be planted in urban areas as street trees, and definitely not be planted directly in urban forested parks, the implications of climate change must be considered in future urban forest management plans. The climate in the Region of Waterloo is predicted to become warmer, drier and stormier which will affect whether trees currently in their optimal conditions for growth will continue to remain so in the future (Barrow and Lee, 2000). For example, a study performed by Environment Canada’s Adaptation and Impacts Research Division in Toronto concluded that by 2100 “the range for *Acer saccharum* trees will shift northward by up to two degrees latitude” and that eventually *Acer saccharum* "will mostly be extirpated from (almost all of) the United States, although, they will likely remain in the Great Lakes region" (Smith, 2006, p. F4). Though this may seem ominous, the range of the *Acer saccharum* will still cover that of Southern Ontario over the next 100 years. This means that those street trees planted now will still be within their healthy spatial range by the time they reach maturity and likely still will be in their optimal range by the time they die. However, the effects of climate change, both short term and long term are unknown for many other species. A suggestion for further research would be to model the effects of climate change specifically in the Waterloo Region on the optimal range of many of the city of Kitchener's street trees and determine their future conditions and chances of survival.

Two final suggestions for future research would be to replicate this field work at other urban forests within the Kitchener-Waterloo area and to utilize the current and future collected data in models. Using the same methodology to conduct an inventory of a forest at other study sites would be advantageous. This could establish whether the results of the current study are unique to this particular site, or confirm that this is indeed a pattern that can be applied to other urban forests within the same ecozone. Current and future data can also be utilized in computer models such as *CityGreen*. The purpose of programs such as *CityGreen* is to determine urban ecosystem values, using GIS programs such as *ArcView* and *ArcInfo* to analyze the data. The benefit of this program is that it can calculate the monetary value of a given urban forest canopy, which is a much more practical and tangible way for policymakers in local governments to view their local urban forests (Moll, 1995).

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