Credit Valley Conservation

Terrestrial Monitoring Program Report

2005 - 2009

Monitoring Forest Integrity within the Credit River Watershed
Chapter 3: Forest Tree Health

CVC
CREDIT VALLEY CONSERVATION

Monitoring Forest Integrity within the Credit River Watershed

Chapter 3: Forest Tree Health 2005-2009

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ABSTRACT

Tree Health in the Credit River Watershed: Summary of Monitoring Results 2005-2009
Species Composition: Sugar Maple (*Acer saccharum ssp. saccharum*) is the dominant tree of forests in the Watershed, with White Ash, Paper Birch and American Beech as co-dominant species. Thirty-four tree species were detected in the canopy and sapling layers, two of which were non-native.
Temporal Trends: No significant temporal trends were detected for annual mortality in any canopy category or species group. Annual mortality of all tree and sapling parameters never exceeded the 5% threshold recommended by Sajan (2006a). Overall, crown health was improving in the Watershed. Proportions of trees or saplings with severely declining crowns never exceeded the 25% critical threshold. Proportions of Sugar Maple and White Oak trees showing declines over the monitoring period also decreased.
Spatial Trends: Generally, Dominant/Co-dominant trees were healthier, and more abundant in the upper two zones than the Lower Watershed. However, healthy Intermediate/Suppressed trees were more abundant in the Lower than the Middle and Upper regions. The upper zones also had higher proportions of dead trees than the Lower Physiographic Zone. Overall, sapling crowns were healthier in the Middle Watershed than the Lower and Upper Physiographic Zones. As expected, stem defects were proportionally more abundant in the Lower than the Upper and Middle Watersheds.
Recommendations: Although forest health appeared to be stable and even improving in some situations, the high proportion of monitored American Beech trees with Beech Bark Disease (78%) was alarming. Trends should therefore be watched closely to determine whether intervention will be needed to maintain stable tree health conditions in the Watershed over the long-term. Future analysis should make comparisons between the health of tree plots and surrounding landscape measures. An effort should also be made to integrate tree health results with other forest monitoring data. Due to the fact that sample sizes of most parameters were too low to detect critical thresholds in changing trends, consideration should be given to strategically increasing sample sizes in order to increase the likelihood of detecting trends over time.

Monitoring Forest Integrity within the Credit River Watershed.
Chapter 3: Forest Tree Health 2005-2009

Tree health monitoring was conducted as part of the terrestrial component of an Integrated Watershed Monitoring Program established at Credit Valley Conservation (CVC). Individual trees were surveyed at 25 forest sites throughout the Credit River Watershed from 2005 to 2009. Surveys were based on visual indicators and followed modified protocols of the Ecological Monitoring and Assessment Network (EMAN). Collected data were used to examine temporal and spatial trends in tree mortality, crown vigour, and stem defects. Thirty-four tree species were recorded in the monitoring plots, of which only two species, Common Apple (*Malus sylvestris*) and Common Buckthorn (*Rhamnus cathartica*) were non-native in origin. Sugar Maple (*Acer saccharum ssp. saccharum*) was the most commonly encountered species in the monitoring plots based on proportional and basal representation. White Ash (*Fraxinus americana*), Paper Birch (*Betula papyrifera*) and American Beech (*Fagus grandifolia*) were co-dominant species in Credit River Watershed forests.

Annual mortality rates were stable between 2005 and 2009 for all trees and saplings. Mortality rates never exceeded the 5% warning threshold established by Sajan (2006a). There were several significant temporal trends in crown vigour over the monitoring period, all of which suggest improving forest conditions. Overall, proportions of declining crowns decreased over the monitoring period, with healthy crowned trees increasing in abundance. Importantly, the annual proportion of trees and saplings experiencing severe dieback was well below the 25% warning threshold established by Sajan (2006a), never exceeding 7% for any individual species or groups of trees. Power analyses indicated that sample sizes were too low for most species and groups of trees to detect warning or critical thresholds for trends in mortality and proportional improvements or declines. However, sample sizes were sufficient enough to detect at least critical thresholds for trends in crown vigour change for most tree and sapling groupings.

The three Physiographic Zones of the Credit River Watershed did exhibit many significant differences in crown vigour, although none were detected for mortality rates of trees or saplings. Healthy Dominant/Co-dominant trees were more abundant in the Upper than Lower Zone, while moderately declining trees were more abundant in the Lower than the two upper Zones. Contrary to Dominant/Co-dominant trees, healthy Intermediate/Suppressed trees were more abundant in the Lower than the Middle and Upper regions. The upper zones also had higher proportions of dead trees than the Lower Physiographic Zone. Overall, sapling crowns were healthier in the Middle Watershed than the Lower and Upper Physiographic Zones.

When examining patterns of stem defect occurrences among the three Physiographic Zones, many differences were apparent. Overall, stem defects were more abundant in the Lower than the Middle and Upper Watersheds. Proportions of Dominant/Co-dominant trees with cankers were higher in the Lower than the Middle and Upper zones. Fungus/fruiting bodies were also more abundant in the Lower than the Middle Watershed. No significant spatial patterns were detected in the proportion of trees with open stem wounds. Of serious concern was that over three quarters of all monitored beech trees (full trees and saplings combined) had signs of Beech Bark Disease.

Overall, tree health in the watershed appeared to be stable and, in some cases, improving over the monitoring period.

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1.0 INTRODUCTION

1.1 BACKGROUND

Forests cover nearly one third of total land area in North America (UNFAO 2005) and, after Russia, Canada has the largest continuous forest area of any country in the world (Allen 2001). The country as a whole (and the province of Ontario in particular) has undergone dramatic change since the arrival of European settlers. A landscape that was historically dominated by upland forests and wooded wetlands has experienced rapid removal of habitat and the fragmentation of remaining natural areas by agriculture, urban development, and roads (Larson et al. 1999). Previous to settlement (ca. 1800), agricultural practices of aboriginal peoples were responsible for deforestation in southern Ontario. However, it is estimated that this led to a loss of only 5% of forested lands. In contrast, 90% of forests in southern Ontario were converted to non-forest land uses by 1920. The Carolinian zone, an ecological region encompassing the southern-most areas of the province, has seen a drop in proportional forest cover from a pre-settlement estimate of 80% to a mere 11% as of 1999 (Larson et al. 1999). However, changes in agricultural practices and reforestation efforts during the mid-90s did lead to a 5% increase in forested land cover south and east of the Canadian Shield. Despite this, the majority of re-naturalized wooded areas will never return to their original old-growth state. The average forest age in southern Ontario is between 47 and 53 years, lower than in any other Great Lakes or Boreal region of Ontario (Larson et al. 1999).

Removal of forests in Ontario has led to habitat loss and fragmentation. Fragmentation generally results in the reduction of total habitat available, the isolation of remaining patches, decreases in patch size and, often, an increase in total patch number (Noss and Cooperrider 1994; Fahrig 2003). Plant and wildlife species that are adapted to living in well-connected landscapes now face the challenge of acquiring all resources crucial to survival and reproduction from isolated habitat patches (Beier and Noss 1998). Isolation from neighboring patches can result in reduced ability to secure required resources, reduced gene flow and, ultimately, extirpation of a species (Fleury and Brown 1997). In addition, urbanization can lead to increases in non-native species (McKinney 2006). Urbanization also results in changes to the hydrological functioning of the forest, drastically altering hydrological patterns such as peak flow and runoff within a watershed (Duguay et al. 2007; Lull and Sopper 1969). The impact of these ecological and hydrological effects on forest health within the Watershed is still unknown. Through monitoring tree health as part of the Terrestrial Monitoring Program at Credit Valley Conservation (CVC), it is hoped that a deeper insight into these effects will be gained to guide future adaptive management and restoration efforts within the Credit River Watershed.

1.2 THE IMPORTANCE OF LONG-TERM MONITORING

There is an increasing demand from both resource managers and the public for better accounting of the condition and health of the environment in order to determine whether conditions are improving or deteriorating (Niemi and McDonald 2004).

Initially, the baseline classification of natural areas and populations is important for understanding spatial patterns of structure, composition, processes, and functions. However, the mapping and classification of populations usually produce only a "snapshot" of community status and do not capture the dynamics of the system (Gebhardt et al. 2005). A monitoring program must be implemented if one hopes to obtain an understanding of trends in dynamics and processes. Monitoring is the investigation of the status of something over time (Clarke et al. 2004) or, as defined by Stevens (2004), it involves "…tracking a particular environmental entity through time, observing its condition, and the change of its condition, in response to a well-defined stimulus". Monitoring is useful in providing managers with information on which long-term plans can be based, because temporal trends can be used to infer future conditions. A superior monitoring program should address both biotic and abiotic environmental components, as well as function across multiple scales. From an ecological perspective, a monitoring program can also provide insight into cause and effect relationships between environmental stressors and ecosystem responses (Reeves et al. 2004).

Within the Credit River Watershed several forest monitoring stations have been established in which soil, vegetation and wildlife parameters are measured to describe forest conditions in the Watershed and to monitor trends over a 25 year period (Fig. 1). Information gathered over time will enable the detection of changes in ecosystem structure and composition, and will be used to guide Watershed level management decisions in the future.

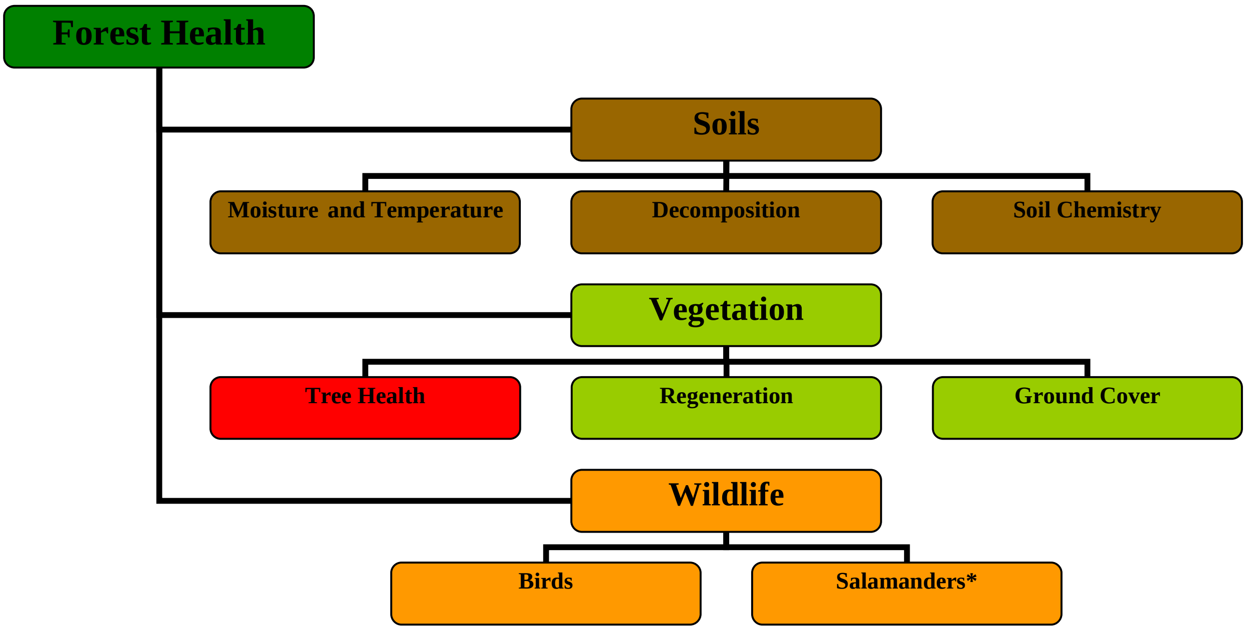


Figure 1. The relationship of the tree surveys to other indicators used to assess forest health in the Credit River Watershed.

1.3 WHY MONITOR TREE HEALTH?

Vegetation monitoring provides several useful indicators of ecosystem health, including estimates of species richness, species diversity, non-native species richness, community biomass, and community productivity (Geomatics International Inc. 1999). According to Ferretti (1997), forest health monitoring is of critical importance because above all, forests provide invaluable ecological, economic, and cultural resources. Forest management should be based on sound knowledge of their status and, hence, be able to recognize changes in their condition over time. Ferretti argues that long term monitoring is best suited to this task because causal experimental studies are difficult to perform on expansive, wide-ranging, and slowly changing systems such as forests. In addition, forests play an increasingly important indicator role in the study of global climate change due to their ability to reflect long-term regional transformations. Finally, forest monitoring is a way to provide accurate data for the construction and calibration of predictive models and the identification of critical system functions.

Mature temperate forests tend to have large trees, a diverse height structure, a broad size distribution of canopy gaps, and a significant component of shade tolerant species (Franklin et al. 1981; Peterken 1996). The long-term productivity of these forests is dependant on several factors, including sunlight, moisture, adequate growing temperatures, and suitable soil (Friedland et al. 2004). Trees themselves are key structural and biophysical components of the forests, and can justifiably be considered foundation species in these ecosystems. Foundation species usually occupy at lower trophic positions (as opposed to keystone predators) and are believed to control population and community dynamics, and to modulate ecosystem processes (Ellison et al. 2005). Trees accomplish this through the regulation of shade, atmospheric and soil moisture, nutrient inputs and extractions, and the physical provision of habitat for forest fauna and flora. For example, the species composition and relative health of understory vegetation is influenced in part by structural and compositional overstory characteristics and their associated modifications to the availability of key resources such as light, water, and nutrients (Barbier et al. 2008). Monitoring of tree health, in co-operation with the monitoring of other system components, can aid in an understanding of these types of ecological interactions.

Monitoring can also be useful in tracking the effects of stress on individuals and populations. This is particularly important when considering tree health because forests are generally sensitive to biotic and abiotic stress (Ferretti 1997). Perhaps the greatest perturbation to forest ecosystems in the last century has been in the form of introduced pests and pathogens (Vitousek et al. 1996). Similar to fire, disease remains an essential element in the ecological balance of natural forests in that it helps break down nutrients sequestered in trees and facilitates succession through tree mortality (Castello et al. 1995). However, the long-term effects of non-indigenous pathogens may involve a negative change in ecosystem state, such as shifting composition or the alteration of successional pathways, with consequent negative changes in ecosystem processes (Loo 2009). Pathogens exert their influence in forests primarily through tree mortality and, in mature and old growth forests, create a spatially heterogeneous matrix of susceptible and resistant species (Costello et al. 1995). A recent example of how a pathogen has significantly altered the state of North American forests can be seen in the plight of

American Chestnut (*Castanea dentata*). This tree was once a dominant component of deciduous forests but is now endangered throughout its natural range due to the introduction and proliferation of a fungal pathogen that causes chestnut blight (Tindall et al. 2004).

The influence of global climate change is also a long-term stressor and an emerging concern for forest managers and researchers. Climate change has the potential to seriously alter the structure and ecology of forests because changes in average seasonal temperatures and precipitation may impair the ability of the current suite of species found in temperate areas to exist in their present configurations and locations (Friedland et al. 2004). It is suggested that grasslands may replace the driest forests and drought intolerant species may regenerate poorly, leading to the invasion of drought tolerant species (Natural Resources Canada 2006). Forests, however, also possess the ability to counteract the process of global warming by helping to lower the amount of human-caused atmospheric CO_2 (Percy and Ferretti 2004). Such long-term changes can be preferentially detected and tracked through tree health monitoring because tree community health and species composition change more slowly and deliberately than do other indicators such as herbaceous ground vegetation.

Air pollution is another atmospheric abiotic factor considered to be an ongoing threat to forests (Skelly 1998). Pollutants such as nitrogen oxides, sulfur dioxide, and tropospheric ozone can have significant cumulative effects on natural areas (Percy and Ferretti 2004; Tkacz et al. 2008). Despite recent efforts to reduce or contain air pollution generated in highly industrialized areas, some toxic elements are still rising in concentrations. For instance, it is estimated that 49% of forests worldwide will become exposed to damaging concentrations of ozone by the year 2100 (Percy and Ferretti 2004). Airborne chemicals can affect trees by retarding growth, increasing water stress, and interrupting key biochemical cycles such as photosynthesis (McLaughlin and Percy 1999; Percy and Ferretti 2004). These physiological issues can be detected through such monitoring indicators as canopy vigour and tree mortality.

1.4 FORESTS IN A CHANGING WATERSHED

The Credit River Watershed encompasses approximately 950 square kilometres of land in southern Ontario, Canada (Credit Valley Conservation 2003). The River flows southeast for nearly 100 kilometres from its headwaters in Orangeville to its drainage point at Lake Ontario (Fig. 2). There are 21 sub-watersheds within the main Watershed boundaries, as well as zones which drain directly into Lake Ontario. These sub-watersheds contain almost 1500 kilometres of streams and creeks that empty into the Credit River (Credit Valley Conservation 2003). As of 2007, the Watershed was composed of 23% natural communities, 11% successional communities (*i.e.* cultural savannah, thicket and meadow), 37% agricultural land use, and 29% urban area (Credit Valley Conservation 2007a). Approximately 6% of the Watershed is classified as wetland, while upland forests make up 12% of the Credit River Watershed Landscape. Communities that are dominated by trees, but do not fall within the formal 'Ecological Land Classification' definition for forest, make up an additional 9% (4% treed swamps, 5% plantations and cultural woodlands; Lee et al. 1998, Credit Valley Conservation 2007a).

Though encompassing many unique landscape formations, the Watershed can be divided into three main Physiographic Zones based on topography, morphology, geologic origins, and the boundaries of the individual sub-watersheds (Credit Valley Conservation 2007b). The Lower Physiographic Zone is highly urbanized, containing over 85% of the Watershed population. The soils in the Lower Watershed are primarily clay, resulting in poor surface water infiltration (Credit Valley Conservation 2007b). The topography of this area is relatively flat and has, in places, been significantly altered by human development. The amount of both wetland and forest cover in the Lower Watershed has been classified as poor when applying proposed government guidelines (Environment Canada 2004). The Middle Zone contains the Niagara Escarpment, a region of steep slopes, rocky outcrops, and thin soil (Credit Valley Conservation 2005). Much of this zone is protected under the Greenbelt Plan (OMMAH 2005). Due to topographic factors, lower levels of urbanization, and protective legislation, the Middle Zone contains the greatest proportion of natural cover in the Watershed. The Upper Physiographic Zone lies above the escarpment and is characterized by hilly moraines, glacial spillways, and permeable loamy soils (Credit Valley Conservation 2005; Credit Valley Conservation 2007b). Agricultural land use dominates portions of the Upper Watershed, though it also contains several large wetland complexes and numerous headwater streams.

The majority of the Credit River Watershed is located in the Great Lakes – St. Lawrence Forest Region. The climax forest type for this area is dominated by Sugar Maple (*Acer saccharum ssp. saccharum*) and American Beech (*Fagus grandifolia*), in association with American Basswood (*Tilia americana*), White Elm (*Ulmus americana*), Yellow Birch (*Betula alleghaniensis*), White Ash (*Fraxinus americana*), Eastern Hemlock (*Tsuga canadensis*) and Eastern White Pine (*Pinus strobus*) (Credit Valley Conservation 1956; Fig. 3). The "Deciduous Forest" Region extends only a few kilometers into the Watershed from the mouth of the river. Characteristic associations in this region include Black and White Oak (*Quercus alba* and *Q. velutina* respectively), Sassafras (*Sassafras albidum*) and Shagbark Hickory (*Carya ovata*) (Credit Valley Conservation 1956). In 1851, it was estimated that forests covered approximately 67% of the Credit River Watershed (Fig. 4). However, in the following 50 years this number decreased substantially, to below 10%, as settlement increased (Credit Valley Conservation 1956). For the last 100 years, forest cover in the Credit River Watershed has lingered between 9% and 16%. When last reported in 2007, forests accounted for 12% of land use in the Watershed (Credit Valley Conservation 2007b). This is well below the 30% forest cover recommended by the Canadian Wildlife Service (Environment Canada 2004) for adequate wildlife habitat.

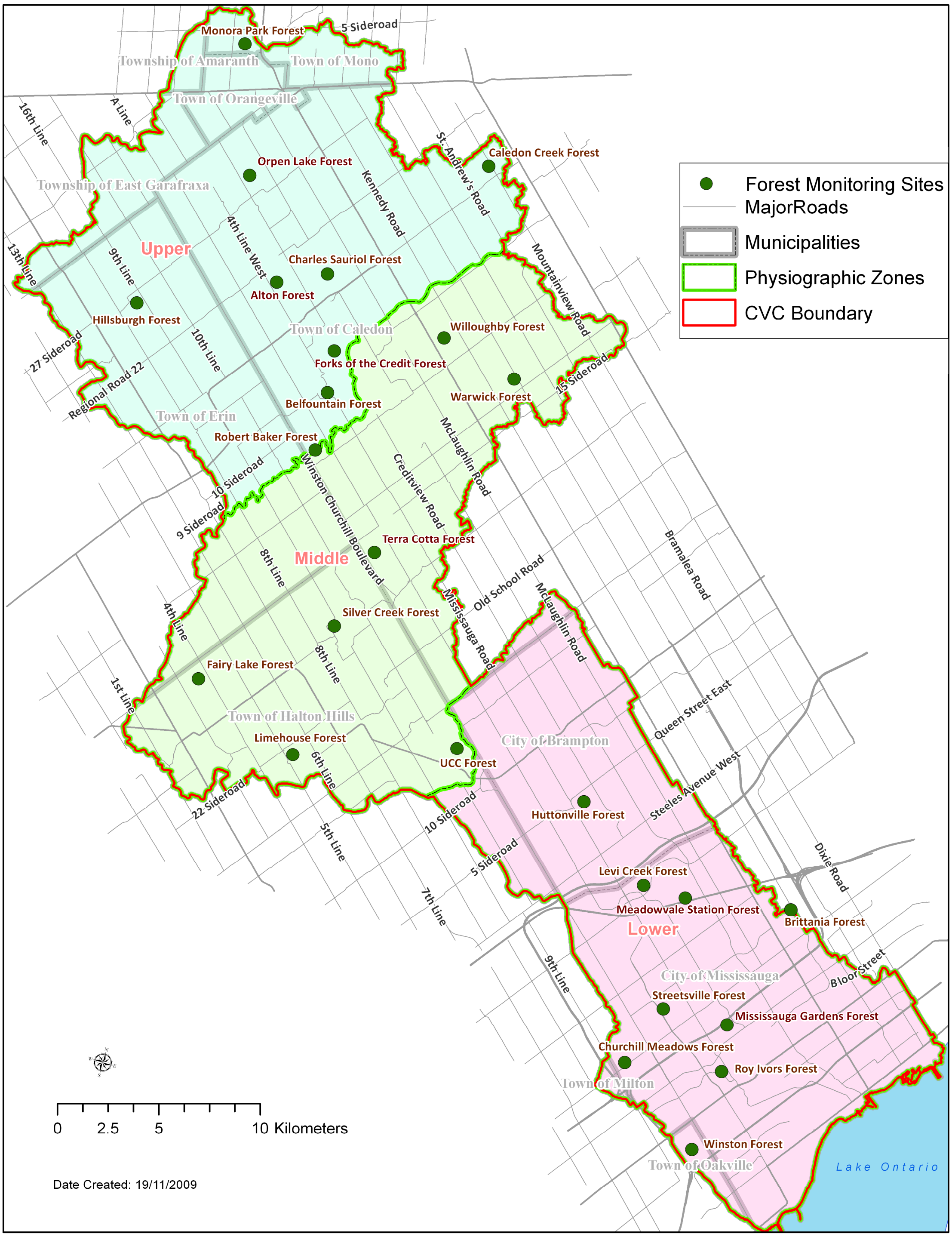


Figure 2. Forest monitoring sites in the Credit River Watershed.

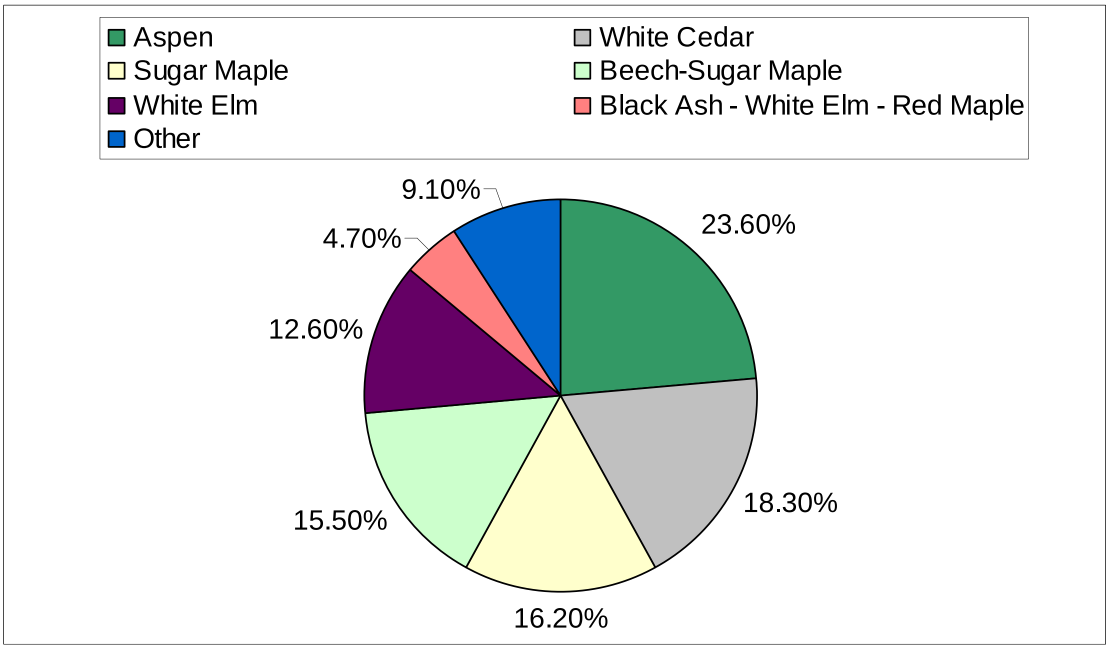


Figure 3. Forest cover types in the Credit River Watershed in 1954 (Credit Valley Conservation, 1956).

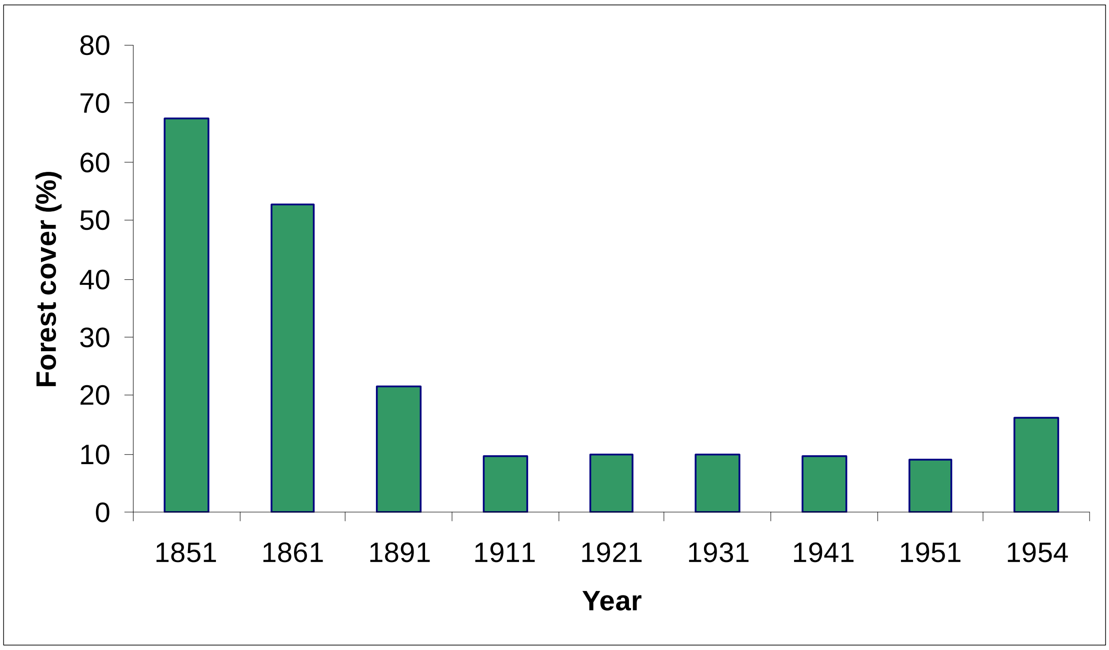


Figure 4. Estimated forest coverage in the Credit River Watershed from 1851-1954 (Credit Valley Conservation, 1956).

1.5 OBJECTIVE: MONITORING QUESTION

The purpose of the tree health component of the terrestrial monitoring program at Credit Valley Conservation is a) to detect long-term trends in a selected set of indicators in order to identify trends in tree health at the Watershed scale, b) to infer the impact of these trends on overall Watershed and forest health, and c) to provide meaningful data on which Watershed management decisions can be based. The central question being asked is a follows:

ARE INDICATORS OF TREE HEALTH IN FORESTS OF THE CREDIT RIVER WATERSHED STABLE?

More specifically, 1) has tree species composition in the Watershed changed over time or differed spatially?, 2) have tree mortality rates changed over time or differed spatially?, 3) has crown health changed over time or differed spatially?; and 4) has the occurrence of stem defects changed over time or differed spatially (Table 1)?

Trend analyses were used to examine parameters of interest for increasing or decreasing trends over time, and temporal analyses were used to examine whether or not differences occurred between years. Spatial analyses were used to examine whether there was a difference among the three Physiographic Zones in the Credit River Watershed. Tree groups examined included Dominant/Co-dominant trees, Intermediate/Suppressed trees and saplings due to their variable sensitivities to environmental stressors.

Table 1. Forest tree health monitoring framework for the Credit River Watershed.

Monitoring Question	Monitoring Variable	Unit of Measurement	Analysis Method
Trend Analyses			
Are tree and sapling mortality rates changing over time in the Credit River Watershed?	Proportion of trees that died from one year to the next	Percent (%)	Cochrane Armitage
Is the crown health of trees and saplings changing over time in the Credit River Watershed?	Proportion of trees in each crown vigour rating	Percent (%)	Cochrane Armitage
Spatial Analyses			
Did mortality rates differ among physiographic zones in the Credit River Watershed?	Proportion of trees that died from one year to the next	Percent (%)	Hierarchical Log-Linear
Did crown health differ among physiographic zones in the Credit River Watershed?	Proportion of trees in each crown vigour rating	Percent (%)	Hierarchical Log-Linear
Did stem defect occurrence differ among physiographic zones in the Credit River Watershed?	Proportion of trees with stem defects	Percent (%)	Kruskal-Wallis Test

2.0 METHODS

2.1 TREE AND SAPLING HEALTH SURVEYS

Tree health monitoring was conducted as part of the terrestrial component of an Integrated Watershed Monitoring Program established at Credit Valley Conservation. The tree surveys functioned as one of several biotic and abiotic indicators used to assess forests in the Watershed (Fig. 1). Tree and sapling health is a measure of dieback and mortality, which identifies potential species decline and overall forest health. Tree health data were collected for five years (2005-2009) at 25 forest monitoring plots distributed throughout the Credit River Watershed (Fig. 2; Appendix A). Nine of these sites were located in the Lower Physiographic Zone, eight were located in the Middle Physiographic Zone, and eight were located in the Upper Zone.

Tree selection and assessment followed community-based monitoring methods prescribed by the Ecological Monitoring and Assessment Network (Sajan 2000). The plots were generally orientated north-south (give-or-take a maximum of 15 degrees) with a minimum distance of 3 times the canopy height away from any edge (Fig. 5). Initial tree assessments included tagging, species identification, and observation of tree status. These tasks were completed prior to 2005 during the original forest plot set-up in 2002. Although the ideal plot selection strategy would have been to select sites randomly throughout the Watershed, for logistical and practical purposes, forest plots were selected based on availability of suitable habitat and potential for long-term access. An additional objective was to have at least one plot within each of the Credit River's sub-Watersheds.

During the five survey years, all trees within a 20x20m plot, with a diameter at breast height (1.3m above ground; DBH) of 4 cm or greater were assessed annually. Saplings were defined as all stems from 4.0-9.9cm in diameter. Trees were defined as all stems with a DBH greater than or equal to10cm. Trees were assessed for crown class, overall tree status, crown vigour, the presence of stem defects, and overall tree health during each visit. Assessments were conducted between July and September, annually.

Assessed trees were divided into five categories based on crown class. Dominant trees were those whose crown extended well above the general canopy, receiving full sun on top of the crown and partial sun on the sides. Co-dominant trees formed the general canopy, receiving full sun on top but minimal at the sides of the crown. Intermediate trees extended into the base of the general canopy. They received little sun at the top of the crown and no sun on the sides. Suppressed trees were positioned well below the general canopy, receiving no direct sunlight on either the tops or sides of the crown. The fifth category, open grown, consisted of trees characteristic of old fields or urban streets in that they received full sunlight at both the top and the sides of the crown. Open grown trees were not present in any of our monitoring plots.

Trees were further evaluated for overall tree status. Trees were divided into four categories: living (green foliage attached), recently dead (no green foliage, fine branches and bark still attached), old dead (no green foliage, no fine branches, bark falling off), and cut down (cut down/girdled, human caused).

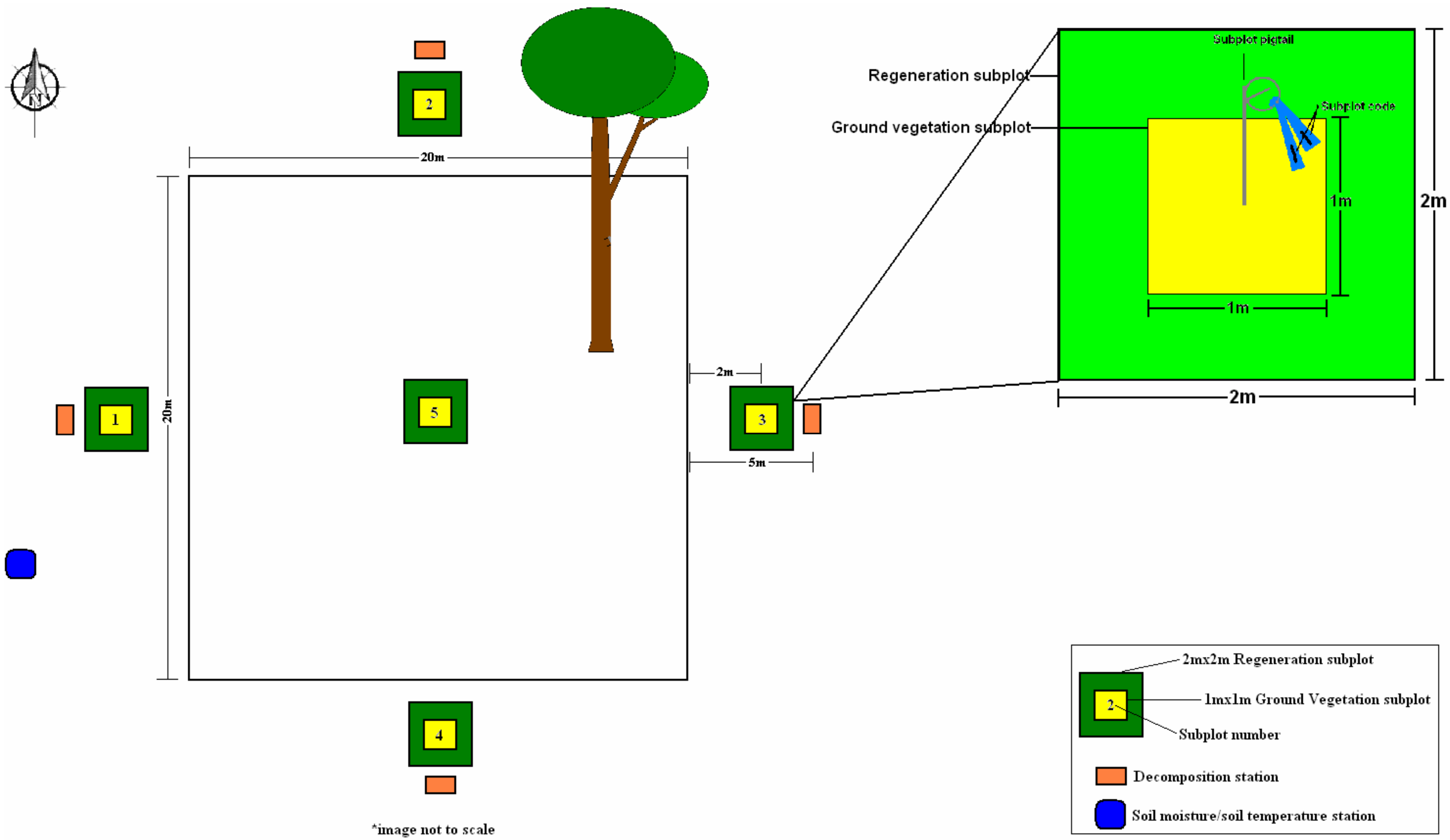


Figure 5. Forest monitoring site layout.

Crown vigour, representing the amount of dieback observed in the crown, was separated into five categories: healthy (less than 10% dieback), light to moderate decline (between 10% and 50% dieback), severe decline (greater than 50% dieback), natural dead, and human caused death.

Following standardized EMAN protocols (EMAN 2004), tree health evaluations included the identification of major stem defects of all trees and stems within one 20x20m quadrat (Table 2). The presence of both naturally occurring and introduced pests and diseases were recorded as potential causes of forest decline. The presence of stem defects were noted on each tree according to their location on the stem (lower, upper, entire, or root collar) and in some cases, their severity was recorded. In 2006, a top-ten list of "Forest Pests and Diseases of Concern" was created by CVC to track the foremost risk-factors of forest decline in the Credit River Watershed. The list includes the following:

- Beech Bark Disease
- Butternut Canker
- Target Canker (*Nectria*)
- Cobra Canker (*Eutypella*)
- Black Bark
- Shoe-string Root Rot
- Dutch Elm Disease
- White Pine Blister Rust
- Gypsy Moth
- Two-lined Chestnut Borer

Table 2. Stem defect categories observed during tree health surveys.

Defect Categories	
1. Decay Fungus, Fruiting Body	6. Canker
2. Seam, Frost Crack (Dry)	7. Insect Damage
3. Seam, Frost Crack (Bleeding/Wet)	8. Pruned
4. Open Wound	9. Animal Damage
5. Closed Wound or Scar	10. No Damage

An increased frequency of any pests or diseases as well as the introduction of new threats such as the Emerald Ash Borer (*Agrilus planipennis Fairmaire*) provides information on forest health over the long-term.

In 2009, following tree health observations, all live trees were placed into one of two health categories based on crown and stem condition, following guidelines outlined in the Ontario Ministry of Natural resources tree marking guidelines (OMNR 2004):

- Healthy: Tree/sapling has a full crown. Good structure, primarily from a single main leader. No sign of decay, insect attack, large wounds, tissue necrosis, dieback or chlorotic foliage. Tree is not leaning. Epicormic branching is absent or minimal.

- Declining: Tree/sapling is declining in health and will likely die within 10-20 years. Tree has crowns in moderate to severe decline. Evidence of disease, tissue necrosis, large stem scars, insect infestation and decay. Presence of dead and broken branches, decay/rot in the root collar, cavities (natural or created by woodpeckers). Tree/sapling may have poor structure and discoloured foliage. All trees/saplings with major defects as outlined by OMNR are considered declining, moderate defects may also designate a tree/sapling declining if associated rot is extensive (i.e. Mossy Top Fungus). Trees are likely to have >50% crown dieback.

2.2 DATA PREPARATION

Tree counts were converted to proportions for all analyses in order to account for changes in total monitored trees over the analysis period. The total number of surveyed trees changed between years due to the addition or removal of monitoring plots, or in circumstances where individual trees changed canopy classes. Based on EMAN recommendations, the five crown class categories were compressed into only two for the purposes of analysis. The first category, representing the main forest canopy, included Dominant and Co-dominant trees. The second category represented the understory and was composed of trees classified as Intermediate or Suppressed. Open grown trees were not identified in our plots during tree health surveys. Unless otherwise stated, analyses were conducted on deciduous trees only, as coniferous trees were not abundant enough to get a true representation of Watershed-wide trends.

Where possible, the crown vigour and tree status of each individual tree was compared between sequential years from 2005 and 2009. Analyses were conducted on observed change in crown vigour or tree status for each two-year temporal comparison. Trees that showed an improvement in vigour (*e.*g. moving from moderate decline one year to healthy the next) were classified as “improving”. Trees that showed a decline in vigour (*e.g.* moving from moderate decline one year to severe decline the next) were classified as “declining”. Trees that did not show a change in crown vigour between years were classified as “stable”. This data was used to calculate the proportion of trees in both the Dominant/Co-dominant and Intermediate/Suppressed categories that had declining or improving crown health over the study period. Trees that were living one year and dead the next contributed to the percent mortality rate calculated for each two year period, both Watershed-wide and for each of the three Physiographic Zones.

Trends in crown vigour for saplings were compared for 2005 to 2008 only. Changes in protocol in 2009 for saplings made it difficult to compare data collected after 2008.

Analyses of individual species were only conducted for trees measuring greater than or equal to 10cm in diameter. For trends in the mortality and crown vigour of individual tree species, Oak species were clumped into two groups. The Red Oak group included Northern Red Oak (*Quercus rubra*), Black Oak (*Quarecus velutina*) and Pin Oak (*Quercus palustris*). The White Oak group was composed of White Oak (*Quercus alba*), Bur Oak (*Quercus macrocarpa*) and Swamp White Oak (*Quercus bicolor*). Due to difficulties distinguishing between Red and Green Ash (*Fraxinus pensylvanica)*, and their similar ecological niches, these two species were also grouped together. White Ash however was analyzed separately due to their unique habitat requirements compared to the other ash species. The two birch species, Paper Birch (*Betula papyrifera*) and Yellow Birch (*Betula alleghaniensis*), were also grouped into one category. The remaining species were all analysed independently.

Patterns in stem defects were only analysed for 2009 because data collected in previous years were deemed inaccurate and unreliable. As a result, no temporal trend analysis could be performed on the stem defect data. Spatial differences in defect frequency were analyzed for only three of the stem defects, Decay Fungus/Fruiting Bodies, Open Wounds and Cankers, due to reliability of data and their relevance to discussions about forest health.

2.3 STATISTICAL ANALYSIS

2.3.1 Trend Analyses

Tree and sapling health trends between 2005 and 2009 were analyzed using Cochrane-Armitage test (Agresti 2002) in XLStat (Addinsoft), with results considered significant when $p<0.05$. Trend analysis was performed in order to examine possible sequential patterns in mortality and crown vigour data across the five monitoring years. This test is often used to examine linear trends in binomial proportions of response across increasing levels of dosage in medical studies.Cochrane-Armitage trend analysis was employed for these tests because the tree health count data had been converted to yearly proportions. Cochrane-Armitage, though chiefly applied as a chi-square-like test for independence using ordered categorical data (Agresti 2002), can also be employed as a non-parametric analysis of trend to examine proportion instead of count data, as it is considered the closest proportion-based equivalent of parametric linear regression.

2.3.2 Spatial and Temporal Analysis

To examine spatial patterns of forest vegetation parameters in the Credit River Watershed, monitoring sites were grouped into Lower, Middle and Upper zones, with nine, eight and eight sites established in each zone, respectively (Fig. 2). It is hypothesized that differences in physiography, land cover and landscape configuration among the three zones are likely to influence forest health parameters, including species richness, diversity and floristic quality.

Spatial analyses of tree health data using Hierarchical Log-Linear analysis, were conducted in STATISTICA 7.0 (Statsoft Inc.). Results were considered significant when $p<0.05$ (Zar 1999). Hierarchical Log-Linear analysis is designed to examine associations in frequency data between two or more categorical variables that have two or more levels each. This analysis was used to examine differences in mortality, crown vigour and stem defect data. The increased levels of interaction incorporated into this analysis allowed both spatial (between zones) and temporal (between individual monitoring years) differences to be detected. In lieu of post-hoc analysis, which is not available for the Hierarchical Log-Linear test, differences between groups were inferred through visual examination of the data.

2.3.3 Statistical Process Control

Statistical Process Control (SPC) is an application which uses time series data to develop thresholds (Maurer et al. 1999). Though similar to regression, SPC is not based on hypothesis testing. Instead, this application seeks to identify instances when a time series exhibits non-random behaviour. A series demonstrating this non-random behaviour is considered “out of control” and, as such, unsuitable for developing a monitoring baseline. If the time series exhibits natural random variability around a reference point (usually the mean), the series is considered “in control”. Data that are in control can be treated as a baseline from which monitoring thresholds can be generated. A recommended minimum of five years of “in control” data have been used to set monitoring thresholds (Paul Zorn pers. comm.).

Statistical Process Control charts are divided into six zones based on the mean value of a time series and its standard deviation adjusted to sample size (example in Fig. 6) (Maurer et al. 1999). The upper and lower critical limits, defined as +/- 3 standard deviations (SD) from the mean, encompass the “in control” range of the time series. Control charts for stable systems will not contain any points outside the +/- 3 SD “in control” range. In such a case, the series represents appropriate reference conditions from which the +/- 3 SD critical limit thresholds can be adopted. Series with points outside the “in control” range may represent an ecosystem under stress or moving slowly toward some alternate state. A data set in this type of flux would not provide appropriate reference conditions on which thresholds could be based.

For this study Individual Moving Average and Moving Range Charts were examined to determine if each tree health parameter was in control (Paul Zorn pers. comm.). Values that exceed the critical limits and are associated with significant increasing or decreasing trends should always be investigated thoroughly. Often in monitoring, early detection of changing trends or significant decline in parameters is desired in order to recognize problems before the effects become irreversible. To address these early detection concerns, the upper and lower warning limits on control charts are represented by +/- 2 SD from the mean. Trends of series that exceed the warning limits but not the critical limits should be tracked closely for further changes. A time series with values falling within the warning limits is exhibiting natural variability and is considered to be stable and not of concern based on SPC alone. All statistical control charts for vegetation data were generated using SPC XL (SigmaZone), a third-party add-on application to Microsoft Excel.

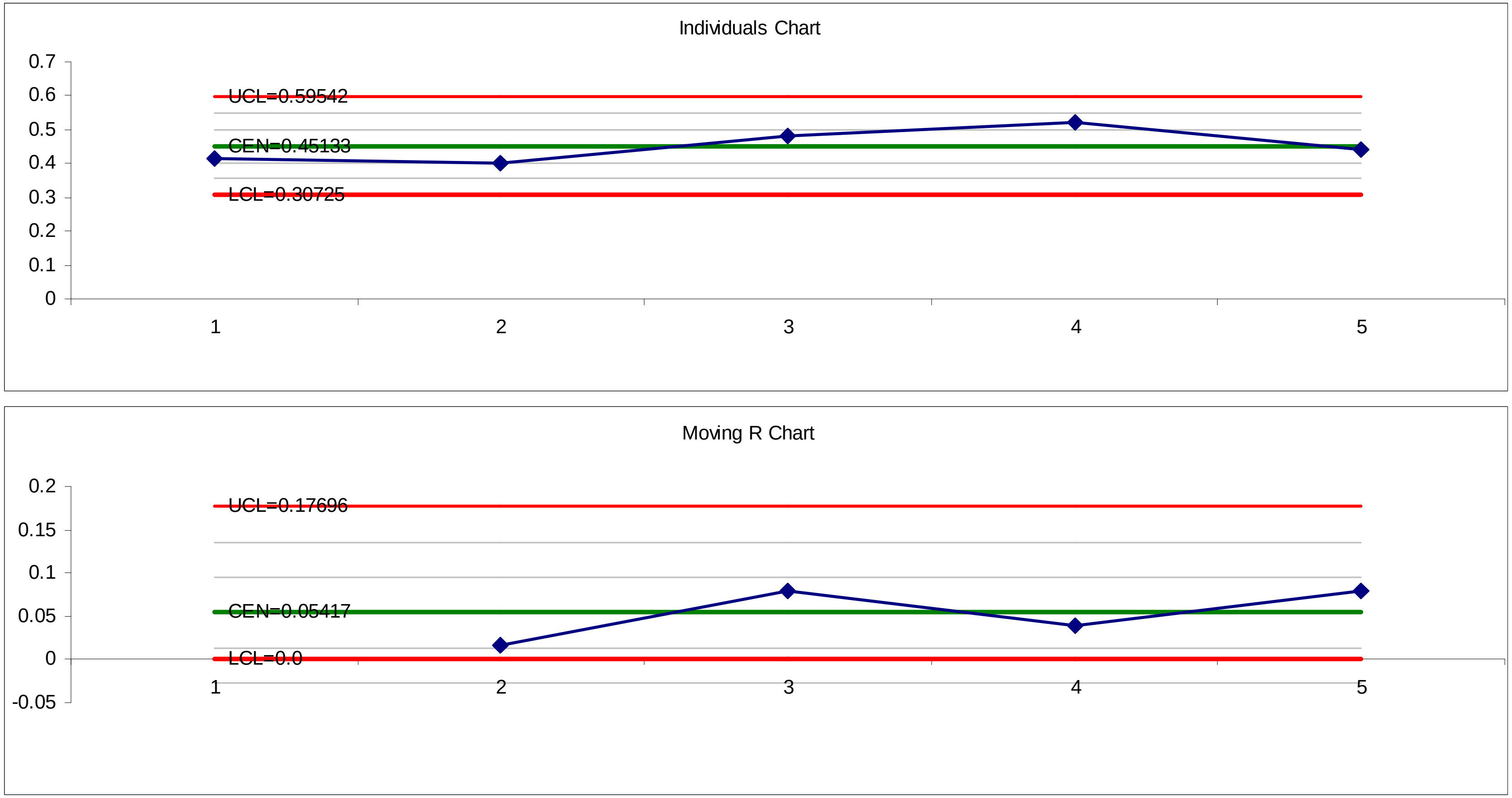


Figure 6. Example of Statistical Process Control charts used to establish thresholds. Both the individual moving average chart (showing the parameter values for each year) and the Moving Range chart (showing the amount of change in the parameter between years) are "in control" from 2005 to 2009. The green line indicates the time series mean and the red lines show the upper and lower critical limits (+/- 3 SD). Given that the data set is in control, the mean from 2005-2009 can be used as a baseline for future monitoring.

2.3.4 Power Analysis

Power analyses were conducted in PASS (NCSS Inc.) to determine the number of monitoring sites required in order to detect significant levels of change in various tree and sapling health parameters. Tests were run using a set power level (1-β) of 90% and a significance level (α) of twenty percent. Power analysis uses baseline monitoring data to determine if additional monitoring sites are required to detect significant trends. Effect size refers to the detectable change in the time series over a given interval, and is often related to a specific monitoring threshold. Power analysis is most frequently used to calculate the sample size required to detect a significant change, or to calculate a specific effect size given the variance of the time series being considered. It can also be used to determine the minimum effect size detectable in a time series given the scope of sampling. Currently, five years of in control data are being used to determine the five year effect size.

The monitoring baseline with which power analysis is performed is usually based on at least five consecutive years of "in control" data as determined by Statistical Process Control (SPC). However, reliable tree health data for mortality and crown health are available for only four (mortality, the improvement or decline of crown vigour) or five years (crown vigour categories). For sapling health data, only three (mortality) or four years (crown vigour categories) of reliable data are available. Therefore, the power analysis presented in this report should be considered a preliminary examination only. Results may change as data collection continues and "in control" baselines become established. Power analysis presented here will be based on variance observed over the three to five study years, and all calculations will be run under the assumption that the effect sizes are to be detected over a five year monitoring period. In addition to the calculation of required *n*, the minimum effect size that can currently be measured under the monitoring program was determined for each trend analysis. These results were used to determine the quality of current monitoring data.

In the absence of specific monitoring thresholds for tree health, thresholds for this program were based on the standard deviation of the collected data. Based on statistical process control, which also uses baseline monitoring data to generate monitoring thresholds, changes in a parameter of ± 1 SD represent natural variability in stable systems and are not considered to be of concern. Changes in a parameter of ± 2 SD are considered outside of normal variability expected in stable communities and represent early warning signs. To address these early detection concerns, the upper and lower warning thresholds are represented by +/- 2 standard deviations from the baseline mean. Trends of series that exceed the warning limits but not the critical limits should be tracked closely for further changes. The upper and lower limits, defined as +/- 3 standard deviations from the baseline mean, are considered the critical monitoring thresholds. Changes in a parameter of ± 3 SD represent instability and situations in which causal factors must be investigated. Values that exceed the critical limits are associated with significant increasing or decreasing trends and should always be investigated thoroughly. The effect sizes considered in the power analyses have therefore been set at 1, 2 and 3 SD to represent ecologically relevant statistical differences in forest vegetation communities. Often in monitoring early detection of changing trends or significant declines in parameters is desired in order to recognise problems before the effects become irreversible. The sample size required to detect 1, 2, and 3 standard deviations of change per year were calculated for each trend parameter. In addition, the minimum detectable effect size (expressed in standard deviations) were calculated for each parameter.

2.3.5 Data Quality

The term "Data Quality" will be defined here as the statistical robustness of a data set given the current variance and sample size. The quality of the underlying tree health data will be categorized using power analysis results. Data for which both warning threshold and the critical threshold changes can be detected over a five year monitoring period will be classified as "good quality", or "Green". Data for which only a critical threshold change can be detected will be classified as "medium quality", or "Yellow". Finally, data for which neither warning threshold nor critical threshold changes can be detected will be classified as "poor quality", or "Red". These three colour-thresholds are based loosely on those developed by Dobbie et al. (2006) for use in cases where no established a priori thresholds have been agreed upon. It should be noted that data quality will naturally be better for measures that display more variance over the study period. This is because the critical and warning thresholds are themselves based on the standard deviation of baseline data. For example, it is easier (requires a smaller sample size) to detect a two standard deviation change in mortality when the underlying variability of the mortality data is high. If variability were low, two standard deviations would represent a very small change in proportion. These smaller changes would be more difficult to detect than larger changes over the same time period.

3.0 RESULTS AND DISCUSSION

3.1 DESCRIPTIVE RESULTS

3.1.1 Tree Species Composition

Monitoring Question: What are the most common tree species in forests of the Credit River Watershed?

- Sugar Maple (*Acer saccharum ssp. saccharum*) is the dominant tree species of forests in the Credit River watershed.
- Only one non-native tree species, Common Apple (*Malus sylvestris*), was detected in the study plots.

Thirty-one tree species with a diameter at breast height (1.3m above ground; DBH) of 10 cm or greater were recorded in forest plots throughout the Watershed from 2005 to 2009 (Appendix B). Twenty-six of these species were deciduous and the remaining five were conifers. The dominance of deciduous tree species is consistent with forest plot classifications. As of 2009, 21 of the 25 monitoring plots were categorized according to Ecological Land Classification (ELC; Lee et al. 1998). Nineteen of the 21 plots are classified as deciduous forests, with at least 75% of the canopy layer composed of deciduous tree species. The remaining two plots are considered to be mixed deciduous forests, where conifer tree species and deciduous tree species each make up at least 25% of the canopy layer (Appendix A).

One species ranked as federally and provincially endangered (Ministry of Natural Resources 2010), the Butternut (*Juglans cinerea*), was detected in only one of the forest tree plots. Butternut trees are susceptible to a fatal canker-causing disease known as *Sirococcus clavignenti-juglandacearum*, which has lead to the decline of the species province-wide. Common Apple (*Malus sylvestris*), a naturalized agricultural escapee, was the only recorded non-native species.

In 2004 Credit Valley Conservation Authority ranked species in the Watershed according to their sensitivity to environmental change and disturbance. According to a draft version of the ranking, a total of 205 species in the Credit River Watershed have been designated as Tier 1: Species of Conservation Concern (SoCC). These species are designated at risk either federally and/or provincially, or are provincially rare according to OMNR's Natural Heritage Information Centre. Tier 2: Species of Interest (SoI), are either uncommon in the watershed and/or have exhibited a significant population decline in the past 25 years. Tier 3: Species of Urban Interest (SoUI), show signs of decline in urban areas but are thought to be relatively secure in more natural environments. Based on the draft version of the list (Credit Valley Conservation 2009), nine of the thirty-one species were ranked as regionally uncommon or unsecure (SoCC, SoI and SoUI; Table 3). The remaining species were considered to be stable.

Table 3. The surveyed tree species assigned a SCC Tier ranking of three or less. These species are considered to be regionally uncommon or unsecure.

Common Name	Latin Name	SCC Tier Ranking (Regional)
American Beech	*Fagus grandifolia*	3
Balsam Fir	*Abies balsamea*	3
Black Ash	*Fraxinus nigra*	3
Blue Beech	*Carpinus caroliniana*	3
Butternut	*Juglans cinerea*	1
Swamp White Oak	*Quercus bicolour*	2
White Spruce	*Picea glauca*	2
White Oak	*Quercus alba*	3
Yellow Birch	*Betula alleghaniensis*	3

Of the detected species, Sugar Maple (*Acer saccharum ssp. saccharum*) was the most dominant species in terms of basal area and proportional representation of stems, accounting for approximately 46% of all monitored trees (Fig. 7). This is expected, as Sugar Maple has increased in dominance in northern temperate forests since pre-settlement times (Wang et al. 2009) and has long been considered a characteristic tree of broadleaf forests in southern Ontario (Farrar 1995; Tominaga et al. 2008). Co-dominant species included White Ash, Paper Birch and American Beech, at approximately 8%, 7.5% and 6.5% composition, respectively. This tree species assemblage is consistent with characterization of climax forests in Southern Ontario. Eastern White Cedar (*Thuja occidentalis*), which is generally more prevalent in the upper half of the Watershed, was the most common conifer species recorded.

The complete dominance of Sugar Maple, though somewhat expected, raises concerns about both current and future forest biodiversity in the watershed. Although Friedland et al. (2004) found that tree species diversity in northern U.S. forests (contiguous with those in southern Ontario) was generally stable in recent decades, any further decreases in other forest tree species could potentially put additional pressure on Sugar Maple to provide additional and in some cases a large majority of ecosystem services. This is of great concern as the two Co-dominant tree species, American Beech and White Ash are currently threatened by Beech Bark Disease and the imminent arrival of the Emerald Ash Borer to the Credit River Watershed. This could have devastating effects on forest and ecosystem health if a fatal pest or disease were to suddenly target Sugar Maple populations. Though it is not currently threatened, Sugar Maple has nonetheless shown decline throughout its range over the past 50 years (Payette et al. 1996; Horsley et al. 2008).

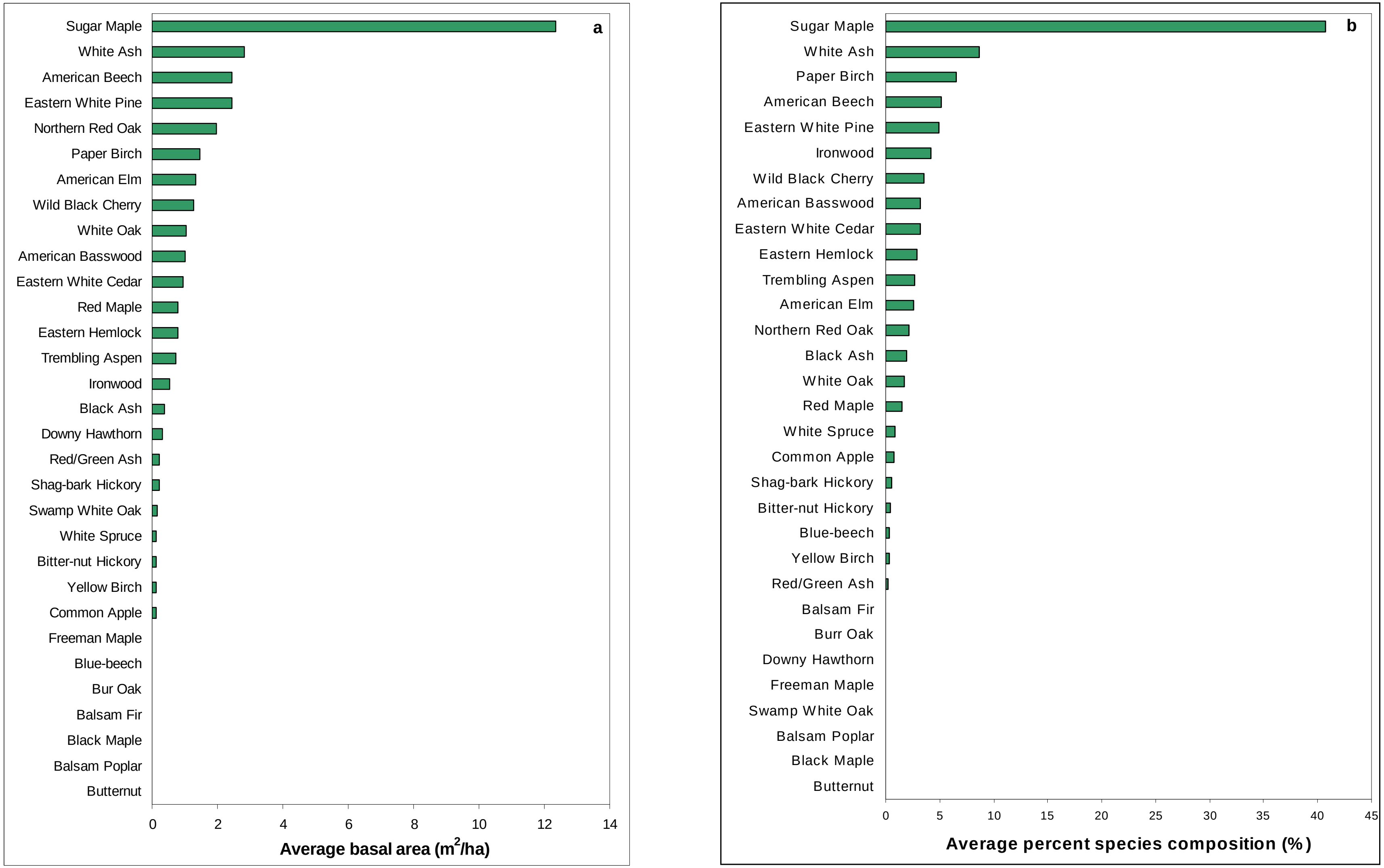


Figure 7. Proportional species composition by basal area (a) and stem count (b) of 31 tree species in tree health plots across the Credit River watershed, by year.

3.1.2 Sapling Species Composition

Monitoring Question: What are the most common sapling species in forests of the Credit River Watershed?

- Sugar Maple is the dominant sapling species in forests of the Credit River Watershed.
- Two non-native tree species, Common Apple and Common Buckthorn (*Rhamnus cathartica*), were detected in the study plots.

Twenty-six sapling species with a DBH of 9.9cm or less were recorded in forest plots throughout the Watershed from 2005 to 2009 (Appendix B). Twenty-one of these species were deciduous and the remaining five were conifers. In addition to Common Apple, Common Buckthorn (*Rhamnus cathartica*) was another non-native species detected in the sapling layer. Similar to tree species composition, Sugar Maple was the dominant species, followed by White Ash and American Beech as co-dominants (Fig. 8).

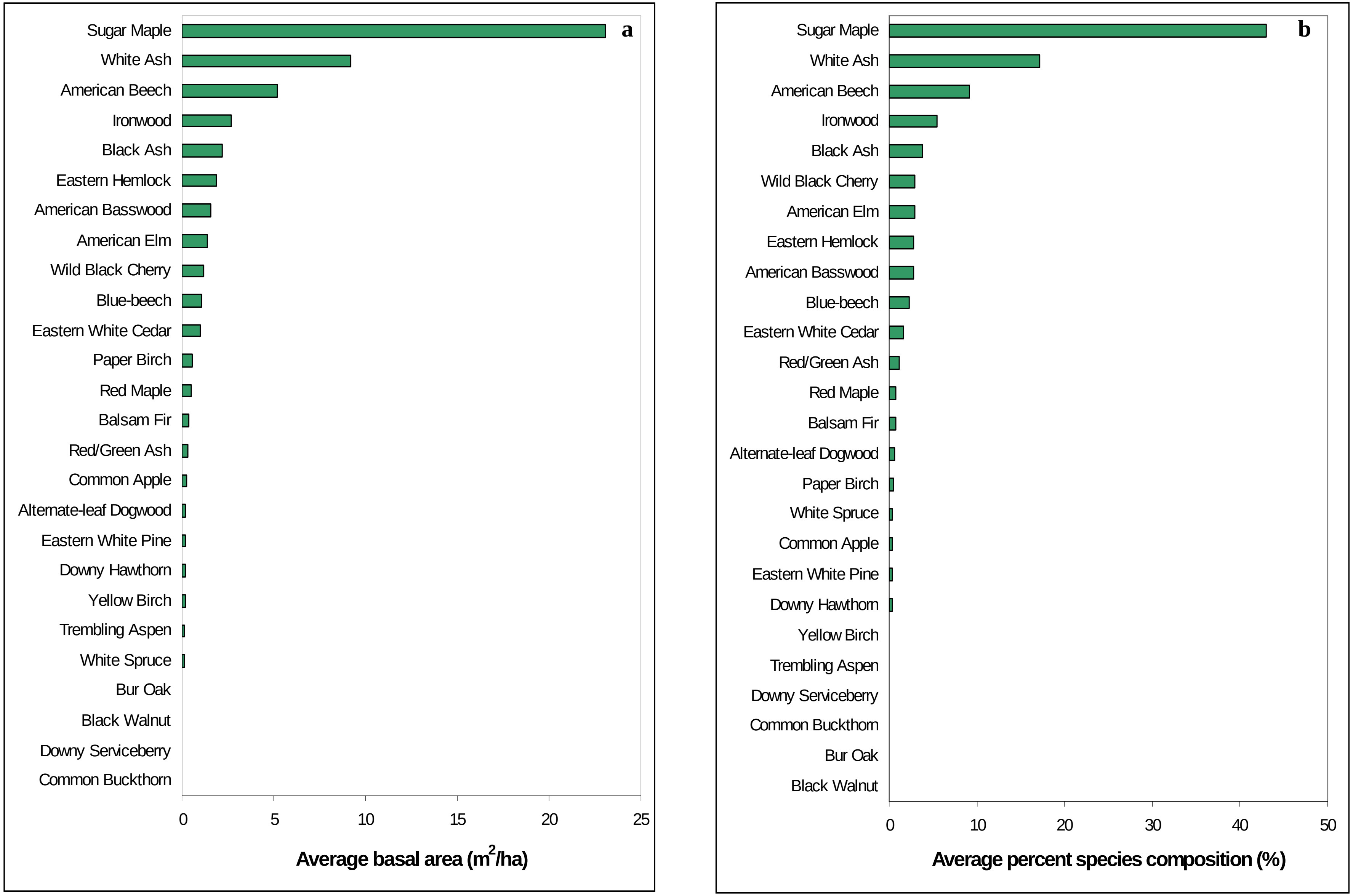


Figure 8. Proportional species composition by basal area (a) and stem count (b) of 26 sapling species in tree health plots across the Credit River watershed, by year.

3.2 TEMPORAL ANALYSES OF TREE INDICATORS

3.2.1 Mortality

Monitoring Question: Are annual mortality rates of trees and saplings in forests of the Credit River Watershed changing over time?

- Annual mortality rates were stable in both the Dominant/Co-dominant and Intermediate/Suppressed categories.
- Annual mortality rates did not change for individual species.
- Annual mortality rates were stable for saplings in the Watershed.

3.2.1.1 Tree Mortality: Trends in tree mortality are of critical concern to managers because they can lead to significant and irreversible impacts on overall forest health. Several tree mortality models suggest that physiological systems within a tree function in an integrated fashion when in the absence of significant biotic or abiotic stressors (Guneralp and Gertner 2007). It is only when the tree is seriously affected by stress and this co-ordinated structure is lost that mortality becomes an immediate possibility. Changes in tree mortality rates can alter forest structure, composition, and ecosystem services through both species change and changes in gap dynamics (Mantgem et al. 2009). Increases in mortality can also have an effect on the amount and type of detritus being deposited on the forest floor (Busing 2005). Sajan (2006a) proposes that a forest stand should be considered healthy if the annual mortality rate is found to be less than 5% in Dominant/Co-dominant trees. Based on this threshold alone, forests in the Credit River Watershed can be considered healthy. This is because the highest mortality determined during the monitoring period between any two consecutive survey years was 2.9% (for Intermediate/Suppressed trees between 2005 and 2006). The lowest detected mortality rate (0.3%) occurred in Dominant/Co-dominant trees between years 2006 and 2007 as well as 2008 and 2009.

This study found that annual tree mortality rates were stable in the Watershed for all trees (z = 0.474, p = 0.636; Table 4), those in the Dominant/Co-dominant category (z = 0.105, p = 0.916, n=3 to 5, Table 4), and the Intermediate/Suppressed category (z = 0.709, p = 0.478, n=3 to 4) based on the change in rates over four consecutive-year pairings (2005 and 2006, 2006 and 2007, 2007 and 2008, 2008 and 2009; Table 4, Fig. 9). This is consistent with other studies in temperate northern forests (Sajan 2006a), but contradictory to several studies in the western United States that have found mortality rates increasing significantly over the past few decades (Mantgem and Stephenson 2007; Mantgem et al. 2009). This western trend is likely influenced by regional warming and consequent water deficits (Mantgem et al. 2009). No significant trends were detected when examining mortality trends of individual species or groups.

Table 4. Population Trends and Statistical Process Control Results for Tree and Sapling health metrics monitored between 2005 and 2008/9 in the Credit River Watershed.

Group		Observed z	p-Value [a]	Observed Trend	Statistical Process Control
Mortality					
All Trees		0.474	0.636	stable	in control
Dominant/Co-dominant trees		0.105	0.916	stable	in control
Intermediate/Suppressed trees		0.709	0.478	stable	in control
Saplings		0.133	0.894	stable	in control
Crown Vigour					
Dominant / Co-dominant trees	Healthy	8.373	<0.001	**increasing**	in control
	Moderate Decline	7.793	<0.001	**decreasing**	in control
	Severe Decline	1.846	0.065	decreasing trend	in control
	Dead	2.259	0.024	**decreasing**	in control
Intermediate / Suppressed trees	Healthy	0.931	0.352	stable	in control
	Moderate Decline	4.266	<0.0001	**decreasing**	in control
	Severe Decline	4.266	<0.0001	**decreasing**	in control
	Dead	1.578	0.114	stable	in control
Saplings	Healthy	3.065	0.002	**increasing**	in control
	Moderate Decline	4.409	<0.001	**decreasing**	in control
	Severe Decline	1.770	0.077	decreasing trend	in control
	Dead	0.869	0.385	stable	in control
Crown Improvements and Declines					
Dominant / Co-dominant trees	Stable	1.662	0.122	stable	in control
	Improved	0.962	0.301	stable	in control
	Declined	4.149	<0.0001	**decreasing**	in control
Intermediate / Suppressed trees	Stable	1.998	0.050	increasing trend	in control
	Improved	1.104	0.270	stable	in control
	Declined	1.541	0.123	stable	in control

[a] p significant at <0.05

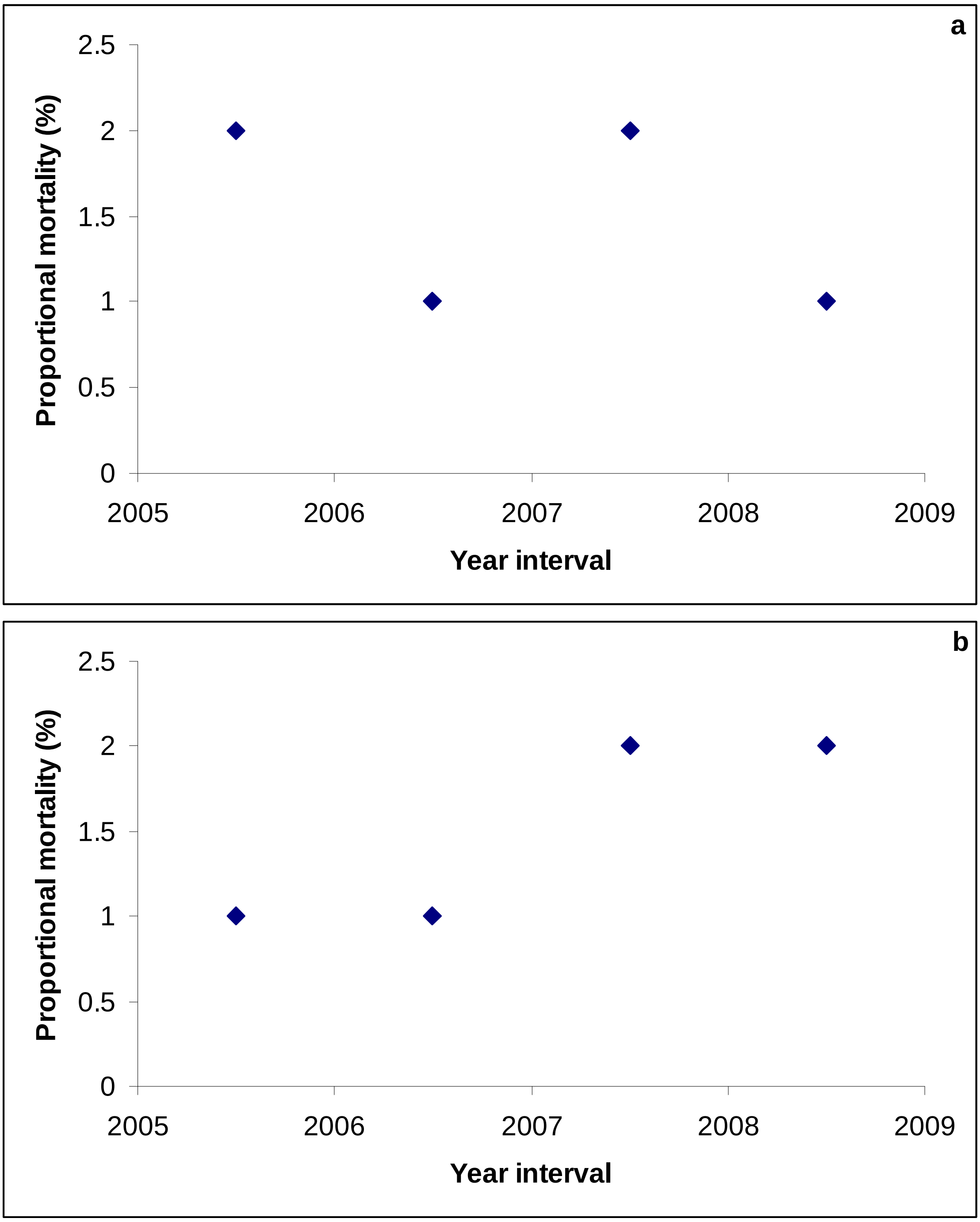


Figure 9. Between-year mortality rates for all trees (a), Dominant/Co-dominant trees (b), and Intermediate/Suppressed trees over the 5-year monitoring period.

3.2.1.2 Sapling Mortality: Annual mortality rates of saplings in Credit River Watershed forest plots remained stable over the monitoring period (z = 0.133, p = 0.894, n=4 to 7). Mortality rates were at their lowest between 2008 and 2009 at 0.7%, and highest between 2007 and 2008 at just over one percent (Table 4, Fig. 10).

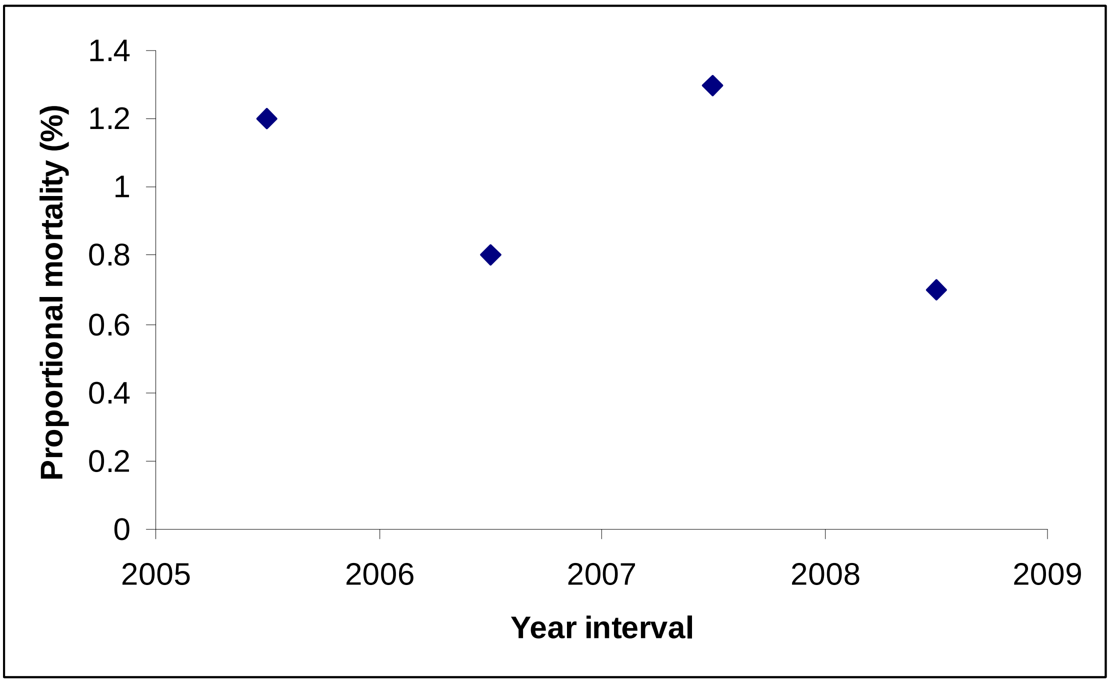


Figure 10. Between-year mortality rates of saplings over the 5-year monitoring period.

3.2.2 Crown Vigour

Monitoring Question: Is the crown vigour of trees and saplings in forests of the Credit River Watershed changing over time?

- Credit River Watershed forests had very low proportions of trees with crowns exhibiting severe decline.
-The proportion of Dominant/Co-dominant trees with healthy crowns increased, and proportions with moderate decline and dead crowns decreased.
- The proportion of Intermediate/Suppressed trees exhibiting moderate and severe crown decline decreased over the monitoring period.
-Proportions of saplings with healthy crowns increased, and moderately declining crowns decreased between 2005 and 2008.
-Overall, crown vigour trends suggest improving forest conditions.

3.2.2.1 Tree Crown Vigour: Crown vigour evaluations have been applied more widely in forest monitoring than any other visual indicator (Alexander and Palmer 1999). This is due both to the conspicuous nature of canopy foliage and the fact that the crown of a tree plays an important role in regulation of solar energy, nutrient cycling, and moisture retention (Zarnoch et al. 2004). Factors such as insect pests, pathogens, air pollution, and drought can influence the distribution, amount, and condition of foliage in crowns (Tkacz et al. 2008). Since the foliar canopy is the most transient and fragile component of the living tree, the first signs of stress on a forest are often seen in tree crowns in the form of foliage loss and dieback (Duchesne et al. 2003; Zarnoch et al. 2004; Tkacz et al. 2008). This dieback can in turn be an early warning of serious decline, as there is evidence that linear increases in defoliation can be associated with an exponential increase in tree mortality (Dobbertin and Brang 2001).

Sajan (2006a) proposes that a forest stand should be considered healthy if the proportion of trees with severe crown decline is less than 25%. Based on such a threshold alone, forests in the Credit River Watershed are healthy. Dominant/Co-dominant and Suppressed/Intermediate trees with severe decline did not exceed 2.7% and 2.8%, respectively, which are well below the established 25% threshold. The majority of Dominant/Co-dominant trees were assessed as healthy (less than 10% dieback) during each survey year, ranging from 74% in 2006 to 95% in 2009 (Table 4, Fig. 11a-d).

According to the Cochrane-Armitage trend analyses, the proportion of Dominant/Co-dominant trees with a healthy crown increased ($z = 8.373$, $p < 0.001$; Fig. 11a), while proportions with moderate decline ($z = 7.793$, $p < 0.001$; Fig. 11b) and dead crowns ($z = 2.259$, $p = 0.024$; Fig 11d) significantly decreased over the monitoring period. Although not significant, there was a trend towards a decrease in the proportion of trees with severe decline over the same period ($z = 1.846$, $p = 0.065$; Fig. 11c). Although the proportions of Intermediate/Suppressed trees assessed as healthy during each survey year were noticeably lower than Dominant/Co-dominant trees, there were no significant changing trends for this crown vigor class ($z = 0.931$, $p = 0.352$; Fig. 12a). Similar to Dominant-Co-dominant trees, Intermediate/Suppressed trees exhibited improving tree health as the proportion of trees with moderate ($z = 4.266$, $p < 0.0001$; Fig. 12b) and severe decline ($z = 4.266$, $p < 0.0001$; Fig. 12c) decreased over the monitoring period. The proportion of trees with dead crowns remained stable over the monitoring period ($z = 1.578$, $p = 0.114$; Fig. 12d). Trend analyses of crown vigor therefore suggest that tree health is improving in Credit River Watershed forests.

Analyses of the proportions of trees showing improvement or declines in crown vigour between consecutive survey years further suggest improving forest conditions in the Credit River Watershed. Dominant/Co-dominant trees showed a decrease in proportion of trees declining between two consecutive years ($z = 4.149$, $p < 0.0001$; Fig. 13). The greatest change towards improved crown health occurred between 2006 and 2007 (16.0%), whereas the greatest change towards decline occurred between 2005 and 2006 (11.0%). Although Intermediate/Suppressed trees did not exhibit any significant proportional improvements or declines over the monitoring period, the greatest change towards improvement occurred between 2006 and 2007 (9.5%) and the greatest change towards decline occurred between 2005 and 2006 (7.0%; Fig. 14). It is important to note however, that additional years of data may be required to make any conclusions concerning trends in proportional improvement or decline because current analysis was conducted using only four year-to-year pairings.

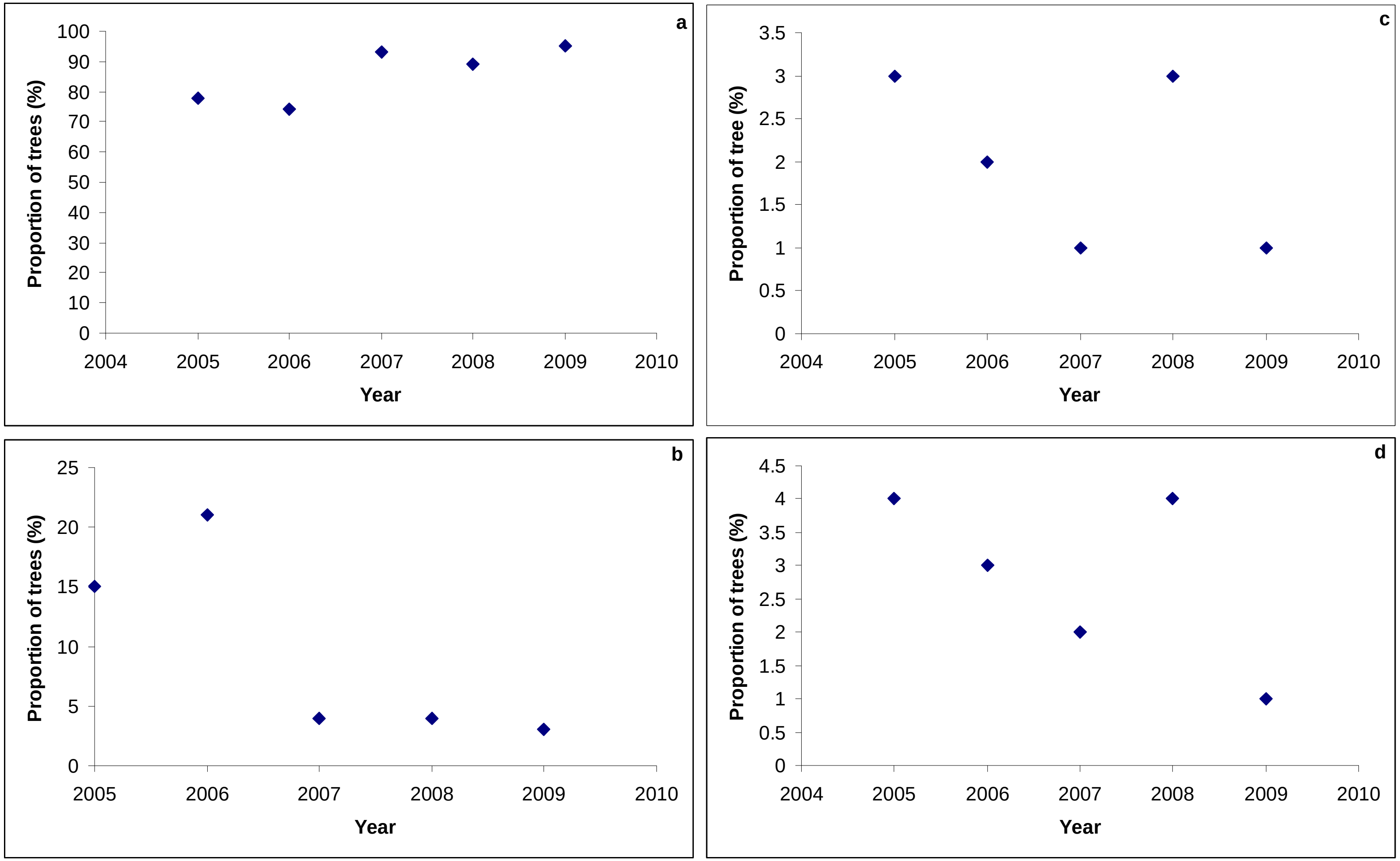


Figure 11. Proportion of Dominant/Co-dominant trees belonging to the four crown vigour rating categories of healthy (a; less than 10% dieback), moderate decline (b;between 10% and 50% dieback), severe decline (c; greater than 50% dieback), and dead (d) between 2005 and 2009 in the Credit River Watershed.

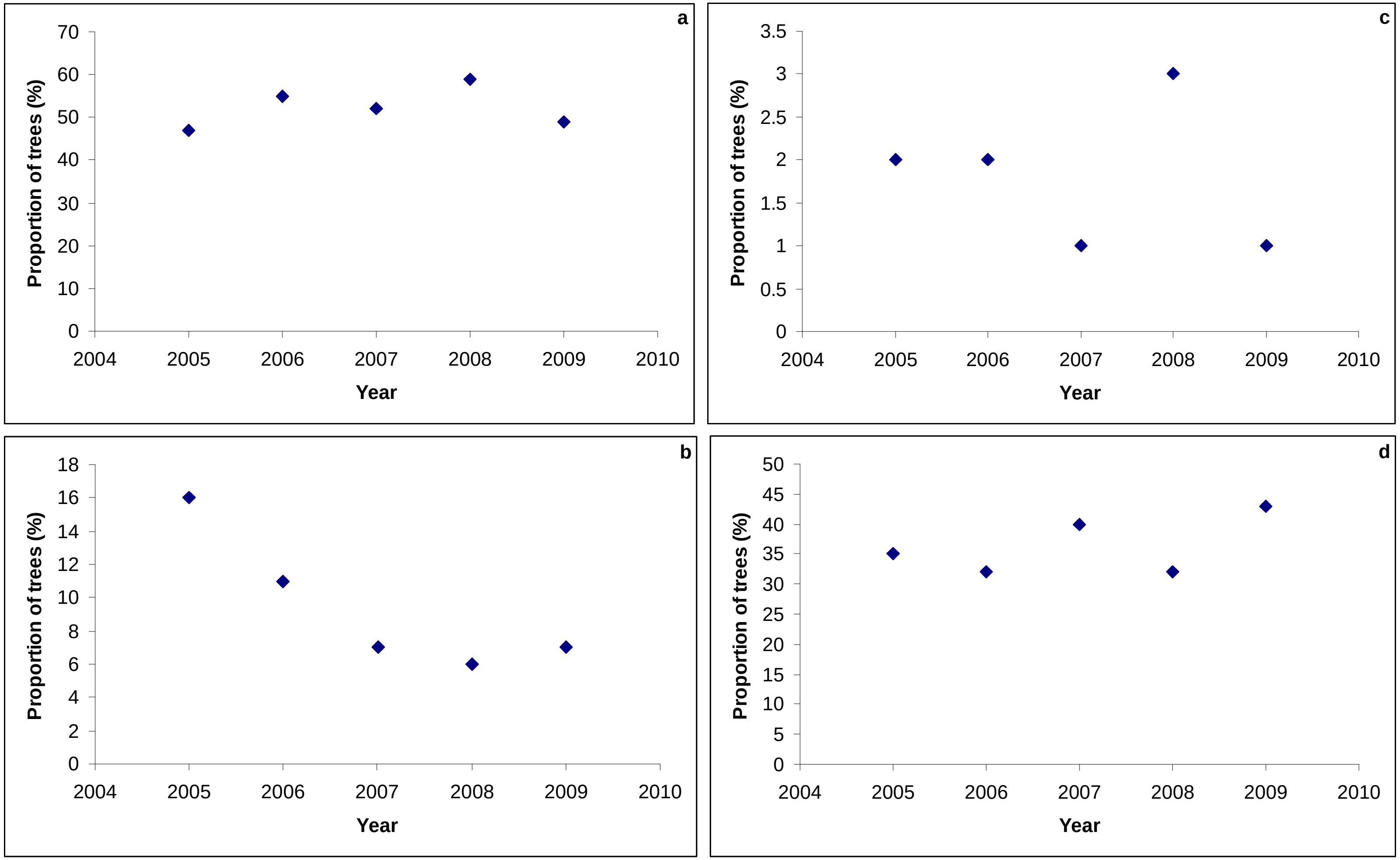


Figure 12. Proportion of Intermediate/Suppressed trees belonging to the four crown vigour rating categories of healthy (a; less than 10% dieback), moderate decline (b;between 10% and 50% dieback), severe decline (c; greater than 50% dieback), and dead (d) between 2005 and 2009 in the Credit River Watershed.

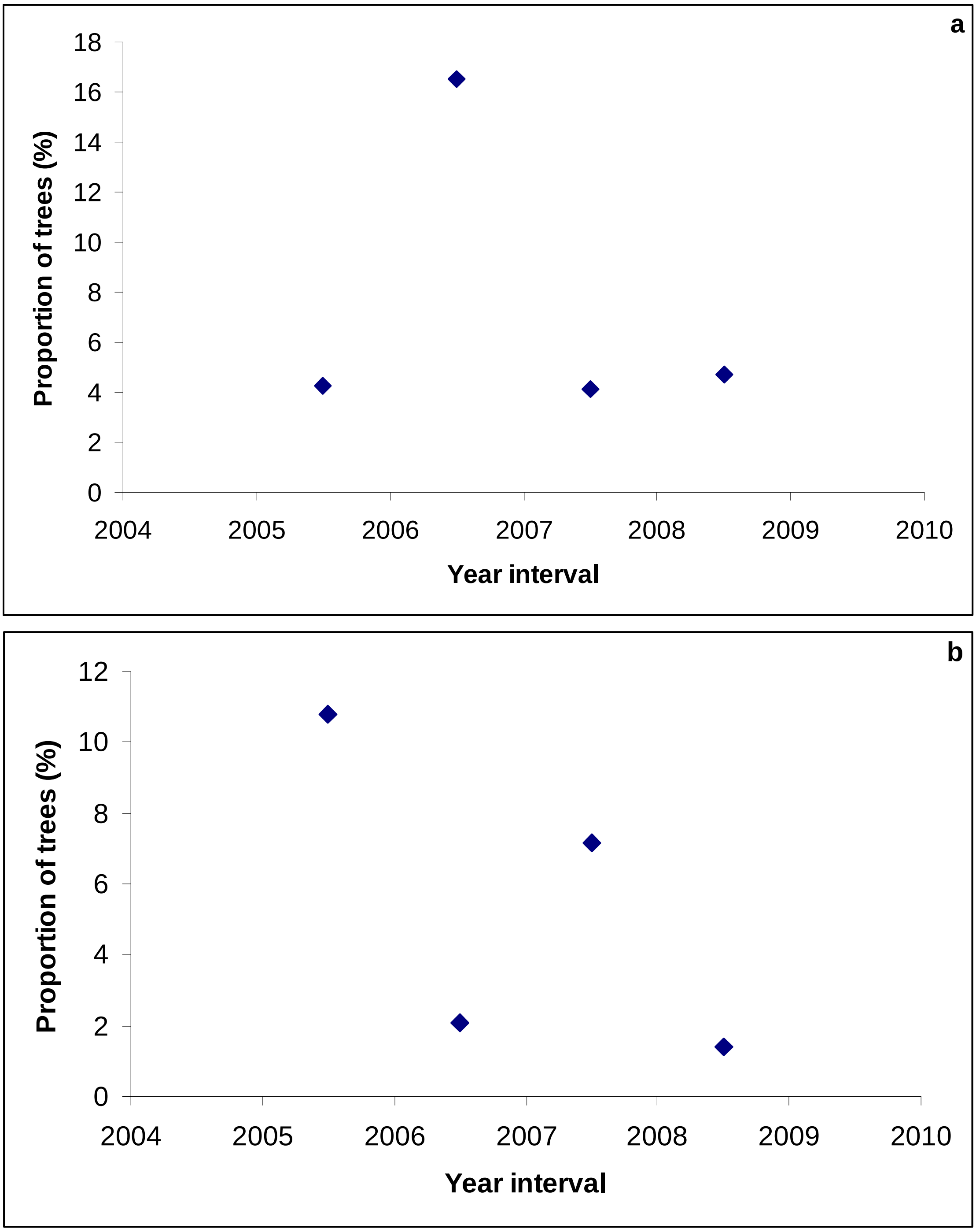


Figure 13. Proportion of Dominant/Co-dominant trees with a) improving and b) declining crown vigour ratings between two successive years in the Credit River Watershed.

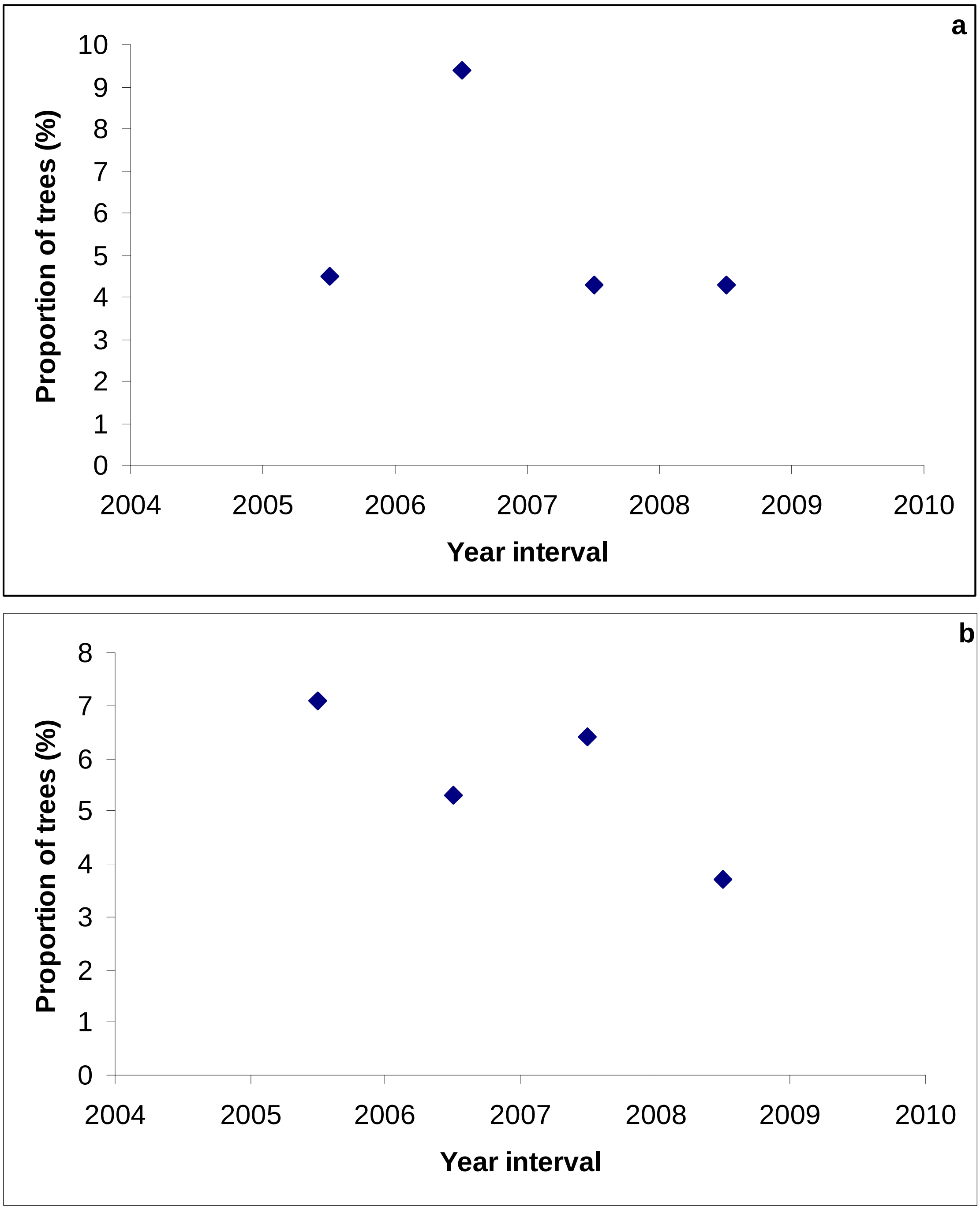


Figure 14. Proportion of Suppressed/Intermediate trees with a) improving and b) declining crown vigour ratings between two successive years in the Credit River Watershed.

3.2.2.2 Individual Tree Species Crown Vigour: When crown classes were combined, the majority of species or species groupings (*e.g*. White Oak group, Red/Green Ash) had stable levels of improvement and declines between years. However, the proportion of Sugar Maple (z = 3.833, p <0.0001; Fig. 15) and White Oak trees (z = 1.960, p =0.018; Fig. 16) showing declines in crown vigor ratings between years decreased over the monitoring period. The significant slowing of decline of Sugar Maple is particularly encouraging because this species constitutes such a significant proportion of trees in forests of the Watershed.

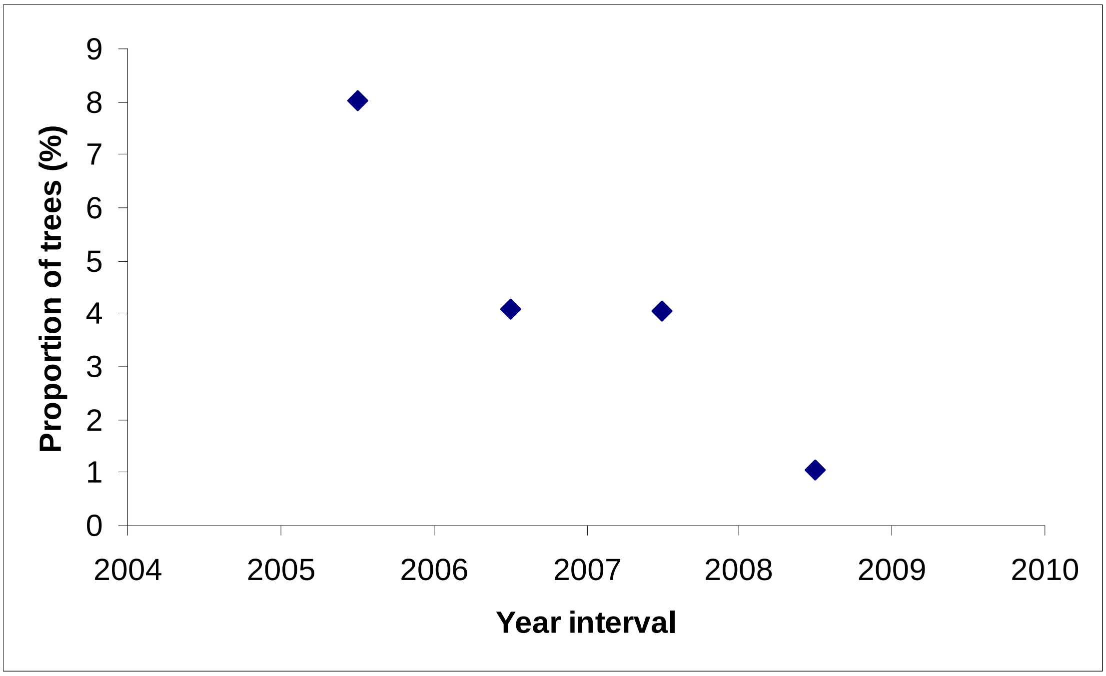


Figure 15. Proportion of Sugar Maple trees declining crown vigour ratings between two successive years in the Credit River Watershed.

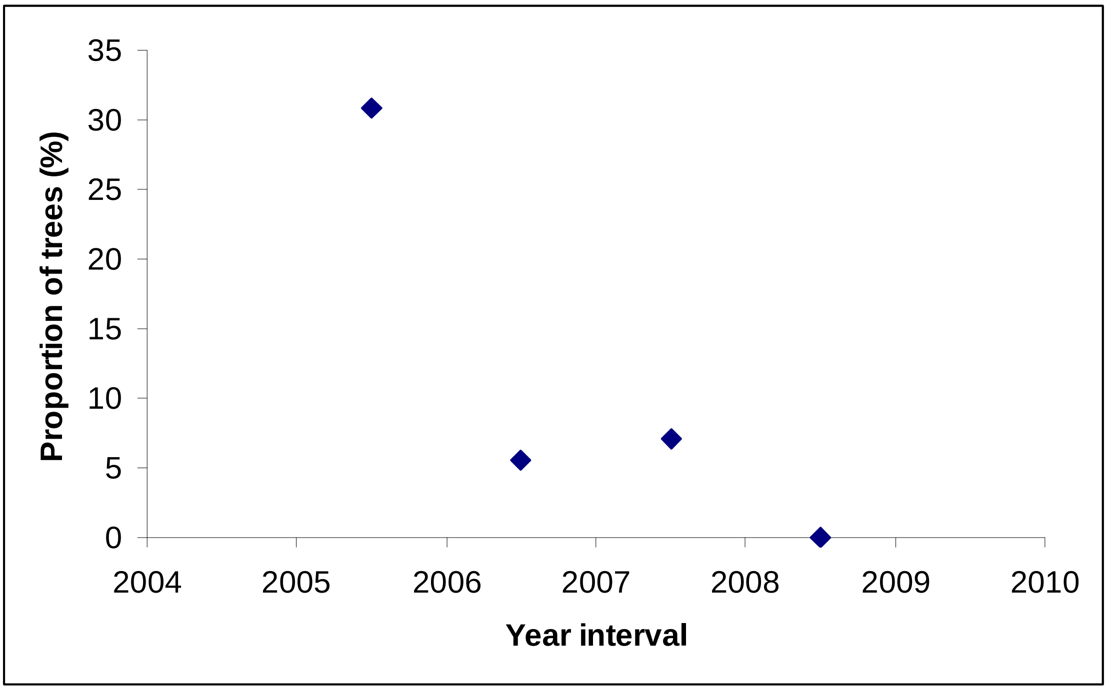


Figure 16. Proportion of White Oak group with declining crown vigour ratings between two successive years in the Credit River Watershed.

3.2.2.3 Sapling Crown Vigour: Although crown vigour ratings were not collected in 2009 for saplings in the forest monitoring plots, data from 2005 to 2008 were analyzed in order to compare with general trends observed for tree crown vigour. Trends in sapling health can potentially provide insight into the condition of forests in the future, as these trees will make up the forest canopy once they reach a diameter of 10cm at breast height.

Similar to tree health, trends of sapling crown vigor ratings suggest improving forest conditions over the monitoring period. According to the Cochrane-Armitage trend analyses, the proportion of saplings with healthy crowns increased (z = 3.065, p =0.002; Table 4, Fig. 17a), while proportions with moderate decline decreased (z = 4.409, $p <$ 0.001; Table 4, Fig. 17b). The proportions of saplings with severely declining and dead crowns remained stable between 2005 and 2008 (Fig. 17c & 17d).

Based on sapling crown vigour and species composition trends observed over the monitoring period, forests of the Credit River Watershed are expected to remain stable or improve under current conditions. However, it is difficult to predict how the introduction of the Emerald Ash Borer or spread of American Beech Bark Disease will influence forest conditions over the long-term.

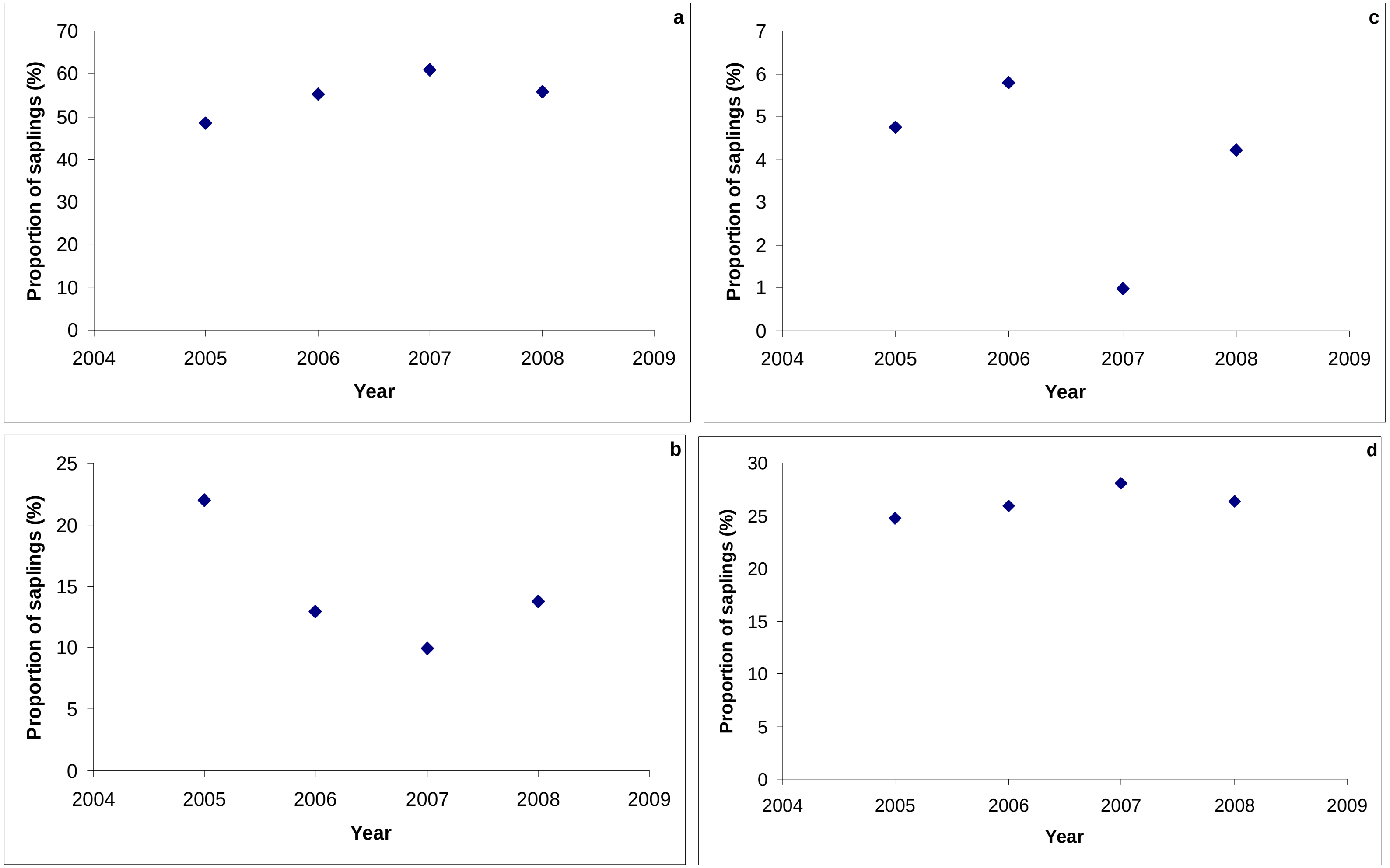


Figure 17. Proportion saplings belonging to the four crown vigour rating categories of healthy (a; less than 10% dieback), moderate decline (b;between 10% and 50% dieback), severe decline (c; greater than 50% dieback), and dead (d) between 2005 and 2009 in the Credit River Watershed.

3.2.3 Power Analysis

Power analysis was completed for all proportional tree health parameters (Tables 5-6). According to the power analyses, changing trends in proportional mortality could only be detected at the critical and warning threshold levels (three standard deviations and two standard deviations, respectively) for trees of all species and crown classes combined. Data quality was categorized as “Red”, or poor, for the remaining parameters as sample sizes were too low to detect even 3 standard deviations of change in mortality rates. This is because mortality numbers were very low (less than 5%) and because the sample sizes of several tree species were low as well. For instance, an eight standard deviation change in proportional mortality of even a co-dominant species such as American Beech, may only represent one or two more deaths per year above the established baseline. Based on this power analysis, the theoretical changes to sample size listed in Appendix D would improve proportional mortality data quality.

Power analysis results for trends in categorical crown vigour yielded more favourable results with respects to the program’s capability of detecting tree health changes in the Credit River Watershed. Critical and warning threshold changes could be detected for healthy and moderately declining crowns of trees and saplings and dead Intermediate/Suppressed trees. However, only critical threshold changes could be detected for dead Dominant/Co-dominant trees, and dead and severely declining saplings. Sample sizes of severely declining trees in both crown class groups were too low to detect any of the warning thresholds. Critical threshold and warning threshold changes could be detected for stable and improving Dominant/Co-dominant trees. Only critical thresholds could be detected for declining Dominant/Co-Dominant trees based on sample sizes. However, none of the warning thresholds could be detected for crown improvements and declines of Intermediate/Suppressed trees. Based on these results, the theoretical changes to sample size listed in Appendix D would improve crown vigour data quality.

Power analysis results for trends in proportional crown improvement and decline indicated that sample sizes for most species were too low to detect tree health changes. Critical and warning thresholds could be detected for stable Sugar Maple trees. Critical thresholds could be detected for improving and declining Sugar Maple, and stable and improving White Oak trees. For all other species or species groups, sample sizes were too low to detect any of the warning thresholds. Based on these power analysis results, the theoretical changes to sample size listed in Appendix D would bolster crown vigour improvement and decline data quality.

Table 5. Power analysis results for proportional mortality, crown vigour and crown improvements and declines for tree and sapling groups across the entire Watershed, based on Cochrane-Armitage trend analysis for proportions.

Group		Average Sample Size	Sample size required to detect thresholds			Minimum detectable effect size [a]	Data Quality
			1 SD	2 SD	3 SD		
Mortality							
All Trees		576.5	1135	511	338	1.86 SD	Medium
Dominant/Co-dominant trees		315.0	2312	1151	765	5.21 SD	Poor
Intermediate/Suppressed trees		261.5	4304	1234	820	6.71 SD	Poor
Sugar Maple		266.8	1980	986	654	5.25 SD	Poor
White Ash		47.8	426	209	136	6.14 SD	Poor
Paper/Yellow Birch		40.0	624	307	202	10.63 SD	Poor
American Beech		29.8	527	259	169	11.97 SD	Poor
White Pine		21.0	307	149	96	9.95 SD	Poor
Eastern White Cedar		17.5	244	118	75	18.04 SD	Poor
Eastern Hemlock		20.0	471	231	151	15.83 SD	Poor
Trembling Aspen		13.5	193	92	58	9.77 SD	Poor
American Elm		12.5	393	118	75	13.21 SD	Poor
Red/Green Ash		12.5	269	114	84	14.53 SD	Poor
White Oak group		15.3	348	169	110	15.29 SD	Poor
Red Oak group		14.3	331	161	104	15.54 SD	Poor
Saplings		610.5	4732	2359	1493	5.58 SD	Poor
Crown Vigour							
Dominant / Co-dominant trees	Healthy	358	104	48	30	0.29 SD	Good
	Moderate Decline		124	59	37	0.35 SD	Good
	Severe Decline		934	464	307	2.51 SD	Poor
	Dead		640	317	209	1.72 SD	Medium
Intermediate / Suppressed trees	Healthy	322	214	104	67	0.65 SD	Good
	Moderate Decline		240	117	76	0.73 SD	Good
	Severe Decline		1493	743	493	4.43 SD	Poor
	Dead		218	106	68	0.67 SD	Good
Saplings	Healthy	613	263	128	82	0.32 SD	Good
	Moderate Decline		261	128	78	0.32 SD	Good
	Severe Decline		782	327	215	0.77 SD	Medium
	Dead		1744	487	322	1.16 SD	Medium
Crown Improvements and Declines							
Dominant / Co-dominant trees	Stable	295	254	122	79	0.63 SD	Good
	Improved		219	105	67	0.55 SD	Good
	Declined		300	146	94	0.74 SD	Medium
Intermediate / Suppressed trees	Stable	257	415	355	232	1.16 SD	Poor
	Improved		548	269	177	1.52 SD	Poor
	Declined		919	455	300	2.54 SD	Poor

[a] The minimum detectable effect size is based on the current sample size (number of trees) associated with each test.

Table 6. Power analysis results for proportional improvement and decline across the entire Watershed, based on Cochrane-Armitage trend analysis for proportions.

Tree Species	Health Category	Average Sample Size	Sample size required to detect thresholds			Minimum detectable effect size [a]	Data Quality
			1 SD	2 SD	3 SD		
Sugar Maple	Stable	276.5	235	113	72	0.62 SD	Good
	Improved		294	142	92	0.77 SD	Medium
	Declined		471	231	151	1.22 SD	Medium
White Ash	Stable	46.5	153	72	45	2.35 SD	Poor
	Improved		413	202	132	6.11 SD	Poor
	Declined		126	59	36	1.96 SD	Poor
Paper and Yellow Birch	Stable	48.5	231	111	71	3.34 SD	Poor
	Improved		413	202	132	5.86 SD	Poor
	Declined		455	195	146	6.46 SD	Poor
American Beech	Stable	34.5	127	59	36	2.65 SD	Poor
	Improved		101	46	28	2.14 SD	Poor
	Declined		348	169	110	6.92 SD	Poor
White Pine	Stable	31.3	240	115	74	5.30 SD	Poor
	Improved		179	85	54	4.01 SD	Poor
	Declined		100	45	27	2.32 SD	Poor
Eastern White Cedar	Stable	24.0	596	294	193	16.72 SD	Poor
	Improved		348	169	110	9.86 SD	Poor
	Declined		654	322	212	18.31 SD	Poor
Eastern Hemlock	Stable	21.8	119	55	34	3.87 SD	Poor
	Improved		196	93	59	6.21 SD	Poor
	Declined		101	46	27	3.33 SD	Poor
Trembling Aspen	Stable	18.5	134	63	39	5.11 SD	Poor
	Improved		471	231	151	17.09 SD	Poor
	Declined		125	58	36	4.77 SD	Poor
American Elm	Stable	16.0	126	59	36	5.54 SD	Poor
	Improved		139	65	40	6.07 SD	Poor
	Declined		413	202	132	17.30 SD	Poor
Red/Green Ash	Stable	11.0	159	75	47	9.91 SD	Poor
	Improved		126	59	36	7.99 SD	Poor
	Declined		77	34	20	5.11 SD	Poor
White Oak	Stable	14.8	39	14	7	2.12 SD	Medium
	Improved		38	14	6	2.08 SD	Medium
	Declined		93	42	25	4.50 SD	Poor
Red Oak	Stable	14.3	80	36	20	4.08 SD	Poor
	Improved		59	25	13	3.09 SD	Poor
	Declined		121	56	34	5.95 SD	Poor

[a] The minimum detectable effect size is based on the current sample size (number of trees) associated with each test.

3.3 SPATIAL ANALYSES OF TREE AND SAPLING INDICATORS

3.3.1 Mortality

Monitoring Question: Are there spatial differences in the mortality rate of trees and saplings in forests of the Credit River Watershed?

- No significant spatial trends in annual mortality were detected among the three Physiographic Zones of the Watershed for trees or saplings.
- Highest tree mortality rates occurred in the Middle Physiographic Zone.
- Highest sapling mortality rates occurred in the Lower Physiographic Zone.

3.3.1.1 Tree Mortality: According to the hierarchical log-linear analysis, there were no differences in mortality rates among the Physiographic Zones in either the Dominant/Co-dominant category (X^2=2.154, df=6, p=0.455; Table 7) or Intermediate/Suppressed crown class (X^2=8.862, df=6, p=0.200; Table 8). Mortality rates were generally similar to those found by Busing (2005) in Appalachian forests over a ten year period.

Though not tested statistically, it appears that mortality rates were slightly higher in the Intermediate/Suppressed layer than the Dominant/Co-dominant layer both Watershed-wide and within each of the Physiographic Zones. This is expected, as Intermediate and Suppressed trees have limited access to direct sunlight and must compete for resources with larger, more established individuals. Ultimately, this competitive disadvantage can leave individuals more susceptible to disease, insect defoliation, and drought (Sajan 2006b).

The highest mortality rates for both crown class categories occurred in the Middle Physiographic Zone. For all zones combined, the highest mortality (2.5%) for Dominant/Co-dominant trees occurred between 2007 and 2008, while the highest rate in the Intermediate/Suppressed category (6.7%) occurred between 2005 and 2006. Although the mortality rate threshold recommended by Sajan (2006a) was established for Dominant/Co-Dominant trees, it is useful to also apply it to Intermediate/Suppressed trees for general comparisons between the groups. There is evidence that Intermediate/Suppressed trees were struggling in the Middle Zone between 2005 and 2006 when mortality rates exceeded the 5% threshold. This was unexpected, as the Middle Physiographic Zone is considered to be the most natural part of the Watershed. The possibility exists that the thin soils and relatively steep slopes associated with the escarpment areas of the Middle zone can negatively influence tree health by exacerbating existing temporary stresses in the Watershed (*e.g.* drought years, insect outbreaks). However, the temporally isolated nature of these mortality spikes suggests that the higher rates observed in the Middle zone were anomalies and not representative of patterns over the entire monitoring period.

Table 7. Year-to-year percent Annual Mortality Rate of Dominant/Co-dominant deciduous trees in three Physiographic Zones and Watershed-wide between 2005 and 2008.

	Mortality Rates (%)			
Years	Lower Zone	Middle Zone	Upper Zone	Watershed Wide
2005-2006	1.4	0	0.9	0.7
2006-2007	0	1.1	0	0.3
2007-2008	1.4	2.5	0.9	1.5
2008-2009	0	1.1	0	0.5

Table 8. Year-to-year percent Annual Mortality Rate of Intermediate/Suppressed deciduous trees in three Physiographic Zones and Watershed-wide between 2005 and 2008.

	Mortality Rates (%)			
Years	Lower Zone	Middle Zone	Upper Zone	Watershed Wide
2005-2006	1.6	6.7	2.1	2.9
2006-2007	0	2.1	3.1	1.7
2007-2008	2.5	1.3	1.3	1.7
2008-2009	4.4	1.2	3.1	2.4

3.3.1.2 Sapling Mortality: According to the hierarchical log-linear analysis, there were no differences in sapling mortality rates among the three Physiographic Zones (X^2=9.414, df=6, p=0.17; Table 9). Although not tested statistically, mortality rates of saplings were lower than for Intermediate/Suppressed trees.

Unlike trends observed in trees, the highest sapling mortality rates occurred in the Lower Physiographic Zone. Although mortality rates never exceeded 5% for saplings, conditions may have been more stressful between 2006 and 2007 than other periods during the monitoring program, as mortality rates were highest during this two year interval.

Table 9. Year-to-year percent Annual Mortality Rate deciduous saplings in three Physiographic Zones and Watershed-wide between 2005 and 2008.

	Mortality Rates (%)			
Years	Lower Zone	Middle Zone	Upper Zone	Watershed Wide
2005-2006	1.3	0.8	0.4	0.9
2006-2007	0.9	0.6	2.6	1.3
2007-2008	1.3	0.3	0.8	0.8
2008-2009	0.6	0.6	0	0.4

3.3.2 Crown Vigour

Monitoring Question: Are there spatial or temporal differences in the crown health of trees and saplings in forests of the Credit River Watershed?

- Higher proportion of healthy Dominant/Co-dominant trees in the Upper than Lower Watershed. Lower zone had higher proportions of moderately declining trees than the Middle and Upper zones. A higher proportion of trees declined in the Lower and the Middle than the Upper Physiographic zone.
-Healthy Intermediate/Suppressed trees were more abundant in the Lower than the Middle and Upper Physiographic Zones. The Middle and Upper Watersheds also had a higher proportion of dead trees than the Lower region.
-Sapling crowns were healthier in the Middle than the other two Physiographic Zones.
-Overall, tree and saplings appear to be healthier in the Middle and Upper than the Lower Watershed.

3.3.2.1 Tree Crown Vigour: Based on the thresholds established by Sajan (2006a), there is no evidence that serious problems are occurring in tree canopies within either of the crown classes. This is because the proportion of trees exhibiting severe crown decline was always well below the proposed threshold of 25% for both Dominant/Co-dominant and Intermediate/Suppressed trees.

The majority of Dominant/Co-dominant tree crowns were assessed as healthy in each Physiographic Zone. Values ranged from 82% healthy crowns in the Lower Watershed to 89% healthy crowns in the Upper watershed. Hierarchical Log-linear spatial analysis revealed that there was a significantly higher proportion of trees with healthy crowns in the Upper compared to the Lower Watershed (X^2=147.63, df=26, p<0.0001; Table 10). Moderately declining trees were also more abundant in the Lower than the Middle and Upper Physiographic Zones. Similar to temporal trends, there were a greater proportion of healthy trees in 2007 to 2009 than 2005 to 2006. Moderately declining trees were also less abundant in 2007 to 2009 than 2005 to 2006.

The proportions of Intermediate/Suppressed trees assessed as exhibiting healthy crowns during each survey year (Fig. 18b) were noticeably lower than those of the Dominant/Co-dominant trees, ranging from about 51% in the Middle Watershed to about 55% in the Lower Watershed. As with trends across years, the proportion of dead Intermediate/Suppressed trees was dramatically higher than the proportion of Dominant/Co-dominant trees with the same classification. Hierarchical Log-linear spatial analysis revealed that there was a higher proportion of healthy trees in the Lower Watershed compared to the Middle and Upper Physiographic Zones (X^2=139.03, df=26, p<0.0001; Table 10). Moderately declining trees were most abundant in the Lower Watershed, followed by the Middle Physiographic Zone and lowest in the Upper zone. Dead trees were also more abundant in the Middle and Upper than the Lower Watershed. Similar to trends observed for Dominant/Co-dominant trees, healthy trees were more abundant in 2009 than all previous monitoring years. The higher abundance of dead trees in the Middle and Upper zones is likely due to the fact that they are not removed as frequently for health and safety purposes in the less populated regions. It is difficult however, to explain why Intermediate/Suppressed trees appear to be healthier in the

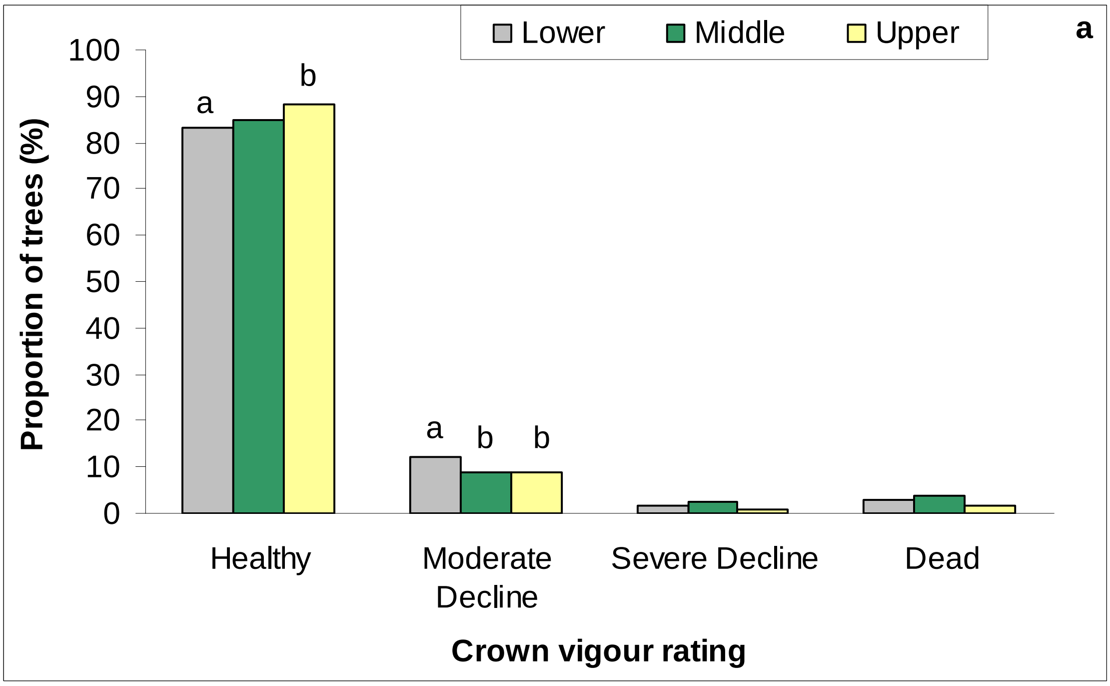
Lower Physiographic Zone when compared to the less urbanized Upper and Middle zones. It is probably related to the fact that Dominant/Co-dominant trees in the upper zones are healthier, resulting in reduced light and increased competition to the Intermediate/Suppressed trees. Increased stress on the Intermediate/Suppressed trees makes them more susceptible to disease and pests, ultimately resulting in reduced crown health. Further monitoring will provide further insight into the inverse relationship observed between Dominant/Co-dominant and Intermediate/Suppressed crown health (Table 10).

Spatial patterns of improvements and declines among the three Physiographic Zones were only present in the Dominant/Co-dominant trees (Fig. 18). A higher proportion of trees declined in the Lower and Middle Physiographic Zones than in the Upper Watershed (X^2=80.53, df=16, p<0.0001; Fig. 19a). The greatest change towards improved crown health occurred in the Lower zone (12%), whereas the greatest change towards crown decline occurred in the Middle zone (10%). According to Hierarchical Lon-linear analyses, a higher proportion of Dominant/Co-dominant trees improved and a lower proportion declined between 2006 and 2007 than between all other monitoring years. Although no spatial trends for crown improvements or declines were detected for Intermediate/Suppressed trees (Fig. 19b), similar to Dominant/Co-dominant trees, a higher proportion improved and lower proportion declined between 2006-2007 and 2008-2009 than between all other monitoring years. As with the trend analysis of improvement and decline, the deficit of between-year comparisons makes it premature to form any substantial conclusions concerning these apparent spatial patterns (Table 10).

Table 10. Comparison of Tree Health metrics among three Physiographic Zones of the Credit River Watershed between 2005 and 2008.

Parameter	Pearson Chi-Square		Degrees of Freedom		*p*-Value		Significant Differences [a]
	2-way interaction	3-way interaction	2-way interaction	3-way interaction	2-way interaction	3-way interaction	
Dominant/ Co-dominant							
Crown Vigour	147.63	21.26	26	24	<0.0001	0.338	Higher proportion of healthy trees in Upper than Lower Watershed. Higher proportion of trees with moderate decline in Lower than Middle and Upper Watersheds. Greater proportion of healthy trees in 2007 to 2009 than 2005 & 2006. Higher proportion of trees in moderate decline in 2005 & 2006 than 2007 to 2009.
Crown Improvements and Declines	80.53	17.96	16	12	<0.0001	0.165	A higher proportion of trees declined in the Lower and Middle than the Upper Watershed. A higher proportion of trees improved and lower proportion declined between 2006-2007 than between all other monitoring years.
Intermediate/ Suppressed							
Crown Vigour	139.03	14.57	26	24	<0.0001	0.661	Higher proportion of healthy trees in Lower than Middle and Upper watersheds. Higher proportion of dead trees in Middle and Upper than Lower Watershed. 2007 had a higher proportion of dead trees than all other years. Higher proportion of trees with moderate decline in Lower than Middle and Upper Watersheds. Higher proportion of trees with moderate decline in Middle than Upper Watershed. 2009 had a higher proportion of healthy trees than all previous years.
Crown Improvements and Declines	32.37	14.36	16	12	0.043	0.074	Higher proportion of trees improved and lower proportion declined between 2006-2007, and 2008-2009 than between all other monitoring years.

[a] Spatial and temporal differences were determined with Hierarchical Lon-linear Analysis.



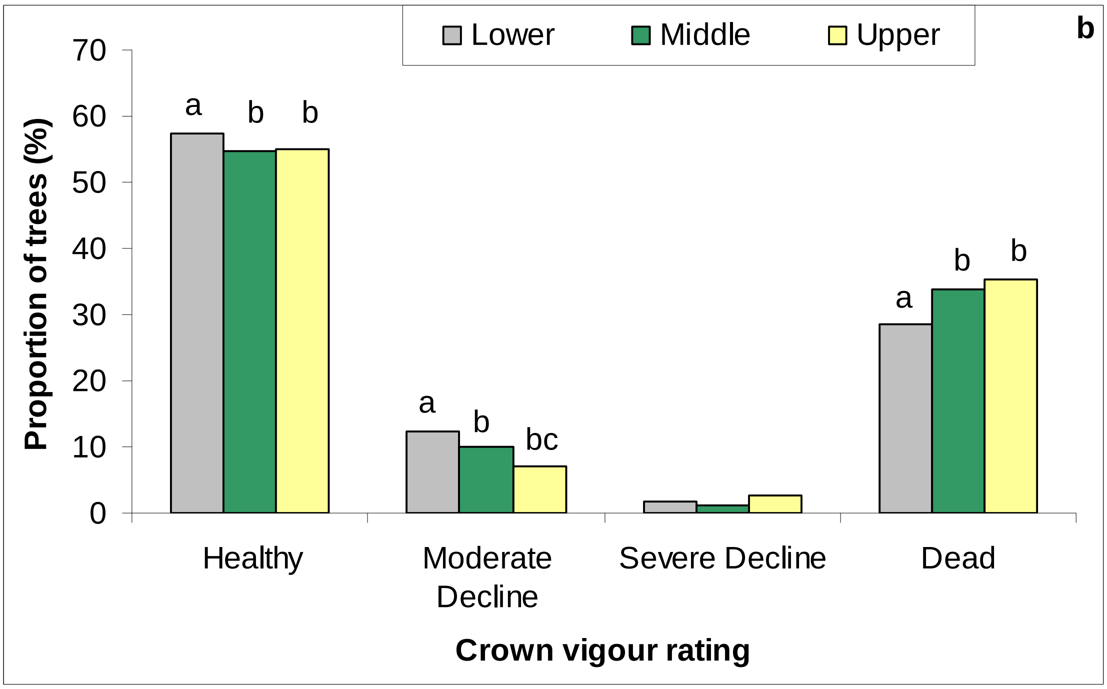


Figure 18. Comparison of the proportion of a) Dominant/Co-dominant trees and b) Intermediate/Suppressed trees from all tree health monitoring plots in each of the four crown vigour rating categories in the Credit River Watershed. Within rating categories, bars with different letters indicate a significant difference according to Log-linear analysis.

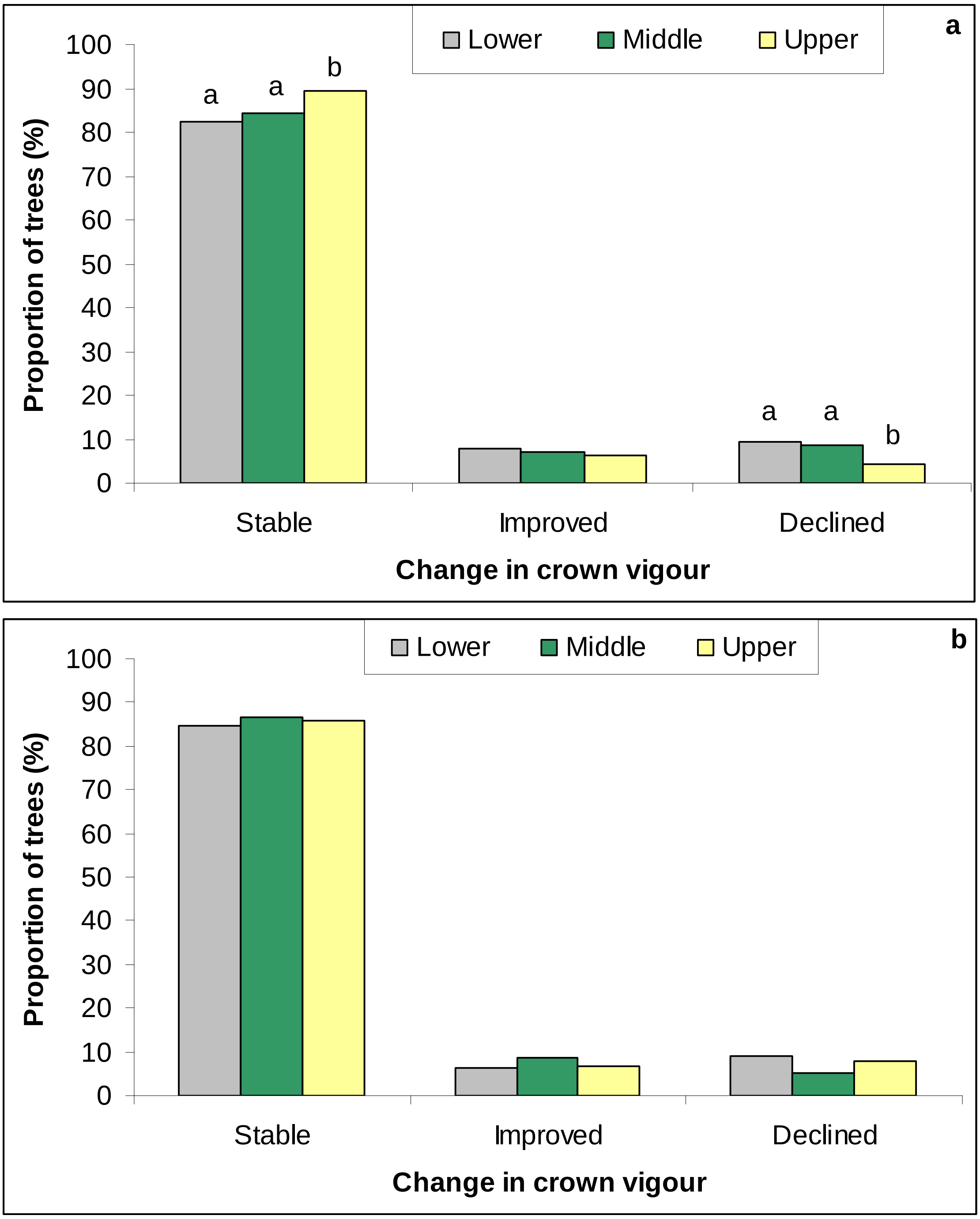


Figure 19. Proportional improvement or decline in canopy vigour of a) Dominant/co-dominant trees and b) Intermediate/Suppressed trees from 2005 to 2008 in three Physiographic Zones of the Credit River Watershed. Within "Improved" and "Declined" categories, bars with different letters indicate a significant difference according to Log-linear analysis.

3.3.2.2 Sapling Crown Vigour: Similar to Intermediate/Suppressed trees, the proportion of saplings exhibiting healthy crowns during each survey year were lower than those of the Dominant/Co-dominant trees, ranging from approximately 50% in the Upper Watershed to 59% in the Middle Watershed. Proportions of dead saplings were also higher than observed for Dominant/Co-dominant trees.

According to Hierarchical Log-linear spatial analysis, saplings were healthier in the Middle Physiographic Zone than the other zones (Table 11, Fig. 20). The Middle Watershed had higher proportions of healthy saplings and lower proportions of declining saplings than the Lower and Upper regions (X^2=142.67, df=21, p<0.0001; Table 11). Dead saplings were also more abundant in the Lower and Middle zones than the Upper Watershed. It is unclear why dead sapling proportions did not mirror those observed for the Suppressed/Intermediate trees. Temporally, saplings exhibiting severe decline were less abundant in 2007 and healthy saplings were more abundant in 2005 than all other monitoring years.

Similar to tree crown vigour, the deficit of between-year comparisons makes it premature to form any substantial conclusions concerning these spatial patterns. However, the apparent healthier conditions in the Middle Physiographic Zone are consistent with expectations based on percent natural cover and land-use in the region.

Table 11. Comparison of Sapling crown vigour ratings among three Physiographic Zones of the Credit River Watershed between 2005 and 2008.

Pearson Chi-Square		**Degrees of Freedom**		***p*-Value**		
2-way interaction	**3-way interaction**	**2-way interaction**	**3-way interaction**	**2-way interaction**	**3-way interaction**	**Significant Differences** [a]
142.67	20.52	21	18	<0.0001	0.243	Higher proportion of healthy saplings in Middle than Upper Watershed. Moderately declining saplings more abundant in Lower than Middle and Upper Watersheds. Higher proportion of declining saplings in Upper than Middle Watershed. Dead saplings more abundant in Upper than Lower and Middle Zones. Healthy saplings more abundant in 2005 and severely declining saplings lower in 2007 than all other monitoring years.

[a] Spatial and temporal differences were determined with Hierarchical Lon-linear Analysis.

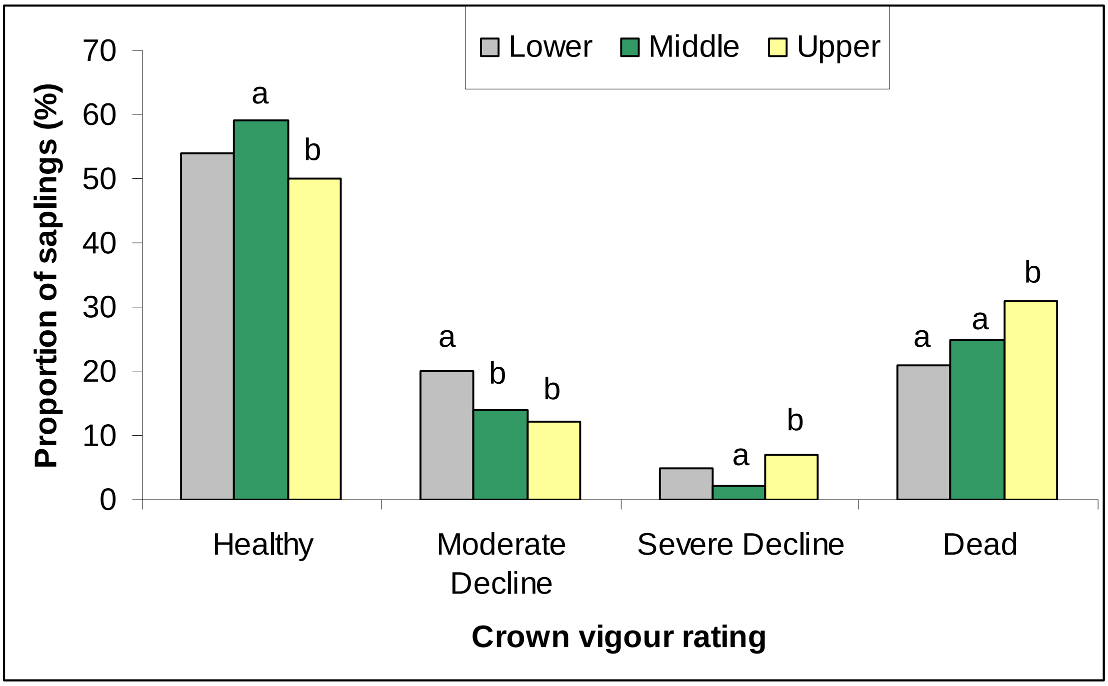


Figure 20. Comparison of the proportion of saplings from all tree health monitoring plots in each of the four crown vigour rating categories in the Credit River Watershed. Within rating categories, bars with different letters indicate a significant difference according to Log-linear analysis.

3.3.3 Tree Stem Defects

Monitoring Question: Are there spatial differences in the occurrence of stem defects in forests of the Credit River Watershed?

- Five of the top-ten diseases or pests of Credit River Watershed were detected in 2009.
- Watershed-wide, defect frequency occurred below established concern thresholds.
- Defects were most abundant in the Lower Zone, meeting concern thresholds for fungus occurrence and exceeding thresholds for canker detection.
-There was a higher proportion of Dominant/Co-dominant trees with cankers in the Lower zone than in the Middle and Upper zone and a higher proportion of these trees with fungus/fruiting bodies in the Lower zone compared to the Middle zone.
- There were a higher proportion of Intermediate/Suppressed trees with fungus/fruiting bodies in the Lower zone than in the Middle and Upper zones.
- Beech bark disease was detected in over three-quarters of monitored American Beech trees.

Pathogens and pests can affect ecological patterns and processes in a forested landscape through alterations in species composition and successional pathways (Costello et al. 1995; Loo 2009). Impacts are often most significant when invading pathogens attack foundation species (Loo 2009) because effects can cascade through all dependant ecosystems processes. Fruiting bodies and underlying fungal infections such as Coal Fungus (*Hypoxylon deustum*) and Shoestring Root-rot (*Armillaria sp.*) often target the lower portions of a stem and result in root and root-collar decay (Anderson and Rice 1993). The two common cankers observed during the surveys – Target canker and Cobra canker – are stem deformities resulting from parasitic disease infection (Anderson and Rice 1993). The defect category of "open wounds" includes any physical damage to the surveyed stems that have not closed or healed. These wounds may allow water or nutrients to seep from the tree, and may even function as an entry point for further infections.

Only half of the top-ten tree diseases or pests impacting the Credit River Watershed were detected in 2009. Shoestring-root rot (*Armillaria mellea*) was detected in only five trees throughout the plots. Butternut Canker (*Sirococcus clavigignenti-juglandacearum*), Dutch elm disease (*Ceratocystis ulmi*) and White Pine blister rust (*Cronartium ribicola*) were not detected on any monitored trees. Watershed-wide, Gypsy moth (*Lymantria dispar L.*), was detected on only 3% of trees, while cankers were present on less than 5% of all monitored trees. Proportionally, beech bark disease was the most commonly detected 'top-10 diseases', observed in 78% of all monitored American Beech trees.

Defect types were analyzed separately for live versus dead trees to get a better understanding of potential threats to tree and forest health, which would otherwise be biased if dead trees were not removed. Decay fungus and fruiting bodies were more common on dead than live trees, due to infestation by scavenger fungus that only target dead trees (Fig. 21). These scavenger-fungi are of no threat to live trees from an infection perspective and contribute to nutrient cycling and healthy forest function by hastening tree decay. As expected, closed wounds were more commonly observed in live trees, since dead trees are unable to heal newly created wounds. Dead trees had much higher rates of insect damage than live trees. Over 80% of all monitored dead trees had insect damage caused by wood borers, relative to 4% of live trees. Defoliation was evident in 21% of monitored trees ranging from slight to severe. The sugar maple borer was detected for the first time at two monitored trees. Further monitoring will determine whether this pest is becoming more abundant in the Watershed. Gypsy Moth (*Lymantria dispar*) was detected on 3% of all monitored trees. These infection rates are lower than previous years, which may be related to the wetter, cooler spring conditions in 2009. A fungus (*Entomophaga maimaiga*) responsible for gypsy moth larvae mortality is more abundant in years with wetter spring conditions (Hajek et al. 1997). Future monitoring of Gypsy Moth abundance and evidence of larvae mortality will evaluate the potential of the fungus to naturally regulate Gypsy Moth populations in the Credit River Watershed. Non-native insect pests Emerald Ash Borer (*Agrilus planipennis*), Asian Long-horned Beetle (*Anoplophora glabripennis*) and Sirex Wood Wasp (*Sirex noctilio*) were not observed in monitoring sites. The native Two-lined Chestnut Borer (*Agrilus bilineatus*), Fall Canker Worm (*Alsophila pometaria*) and Pine Weevil (*Hylobius abietis*) were also not detected on any of the monitored trees. However, the Forest Tent Caterpillar (*Malacosoma disstria*) was detected on a single tree in the Middle Watershed.

Based on studies in the Bruce Peninsula (Boyle 2003), the concern threshold for proportion of live Dominant and Co-dominant trees with decay fungus/fruiting bodies or cankers was set at 10%. Live trees in Credit Watershed forests fell below this concern threshold in most cases (Fig. 22 & Fig. 23). Exceptions were that at 15%, canker occurrence in the Lower Physiographic Zone exceeded the threshold and, at 10%, the occurrence of fungus/fruiting bodies in the same zone equaled the threshold value. No individual species had at least 10% of individuals with decay fungus or cankers, however, Beech Bark Disease was present in 78% of beech trees, and accounted for an additional 4% of all trees with evidence of disease. Further monitoring of all tree species is needed to determine whether infection rates will remain below concern thresholds with increasing pressures of urbanization and climate change.

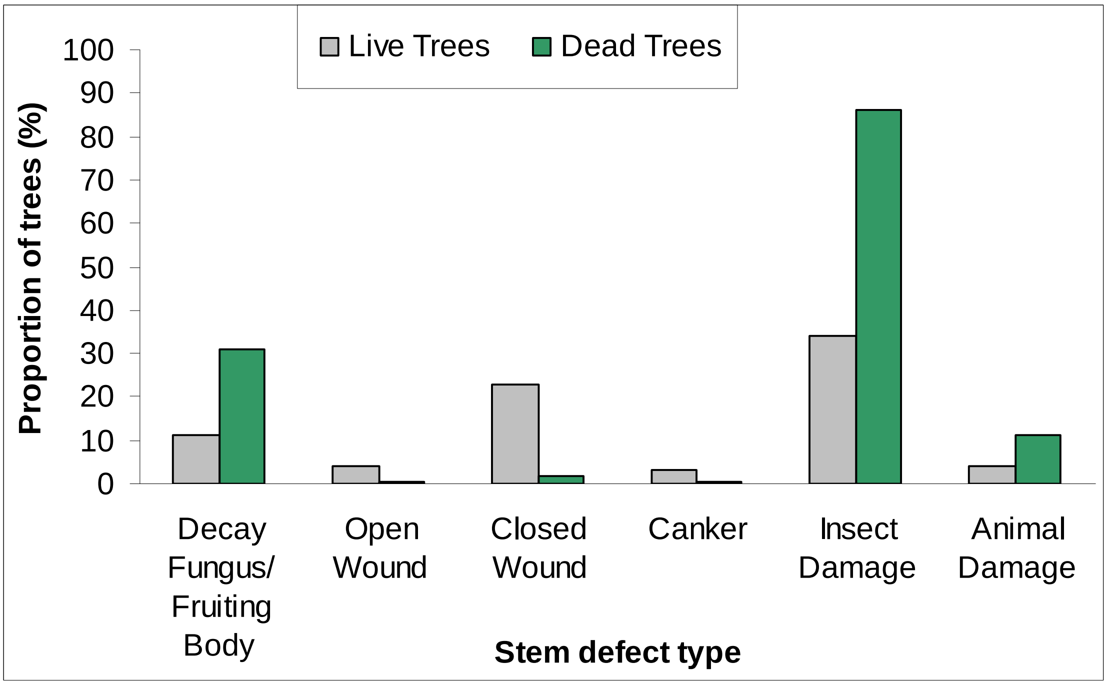


Figure 21. Comparison of proportion (%) of live and dead trees in 2009 with six stem defect types in the Credit River Watershed.

One of the biggest threats to forest health in the Credit River Watershed is beech bark disease. Over three-quarters of monitored beech trees had signs of the disease. Beech bark disease has been in Ontario for approximately 10 years. It can cause severe disfigurement and ultimately death. Beech trees are attacked by beech scale (*Cryptococcus fagisuga* Lind), which feed on liquid from bark cells. The damage created through feeding activities provides entry wounds for *Nectria* fungus (cankers) which is usually observed 3 to 6 years following scale infestation. If large areas are infected, a tree can be girdled, which ultimately results in death. For surviving trees, substantial disfigurement can develop as the tree attempts to fight infection from *Nectria* fungus. All infected trees in our plots showed some disfigurement and 68% had scale insects. Ten of the infected trees had evidence of *Nectria*, suggesting that the disease has been present in the Watershed for at least 3 years. Natural Resources Canada reports that up to 1% of beech trees are resistant to the disease (Sage 1996). Such a low resistance rate in the natural population is unlikely to prevent the disease from causing population level reductions in reproductive rates of beech trees. Further monitoring of beech trees in forest plots will provide insight into how tree species composition and forest structure will change as they age and become more susceptible to infection and ultimately death.

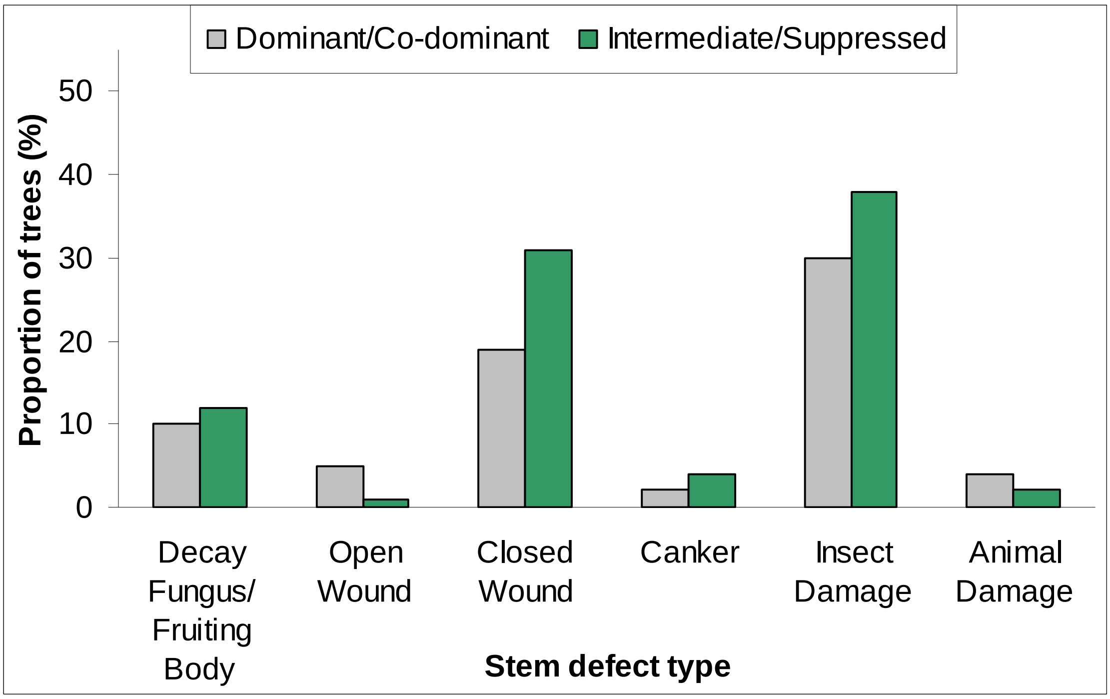


Figure 22. Comparison of proportion (%) of live Dominant/Co-dominant and Intermediate/Suppressed trees in 2009 with six stem defect types in the Credit River Watershed.

Each defect type was most commonly detected in the Lower Watershed for Dominant/Co-dominant trees, with cankers being the most prevalent defect in that zone (15% of trees). Cankers were also the most prevalent defect detected in the Middle Zone (7%), while fungus/fruiting bodies were the type most often detected in the Upper Zone (8%). Spatial comparisons found a higher proportion of Dominant/Co-dominant trees with cankers in the Lower Zone than in the Middle and Upper zones (X^2 = 12.1,df=2, p = 0.002) and a higher proportion of trees with fungus/fruiting bodies in the Lower Zone compared to the Middle Zone (X^2 = 5.84,df=2, p = 0.044). No significant spatial differences were found for the proportion of trees with open wounds in 2009 (X^2 = 3.82, df=2, p = 0.148). Defects were likely more prevalent in the urbanized Lower Physiographic Zone due to the anthropogenic stressors that often accompany highly fragmented and developed regions.

Studies suggest that stem defects should be more prevalent in Intermediate and Suppressed than Dominant and Co-dominant trees, which was not the case in our plots (Sajan, 2006b). Stem defect rates were very similar between the two groups, with all crown categories exhibiting values that were usually slightly below established concern thresholds (Fig. 22 & Fig. 23). Fungus/Fruiting bodies was the most common stem defect in the Lower Zone (11% of trees) while cankers were the most frequently observed defect in the Middle (10%) and Upper (9%) Zones. Intermediate/Suppressed trees in the Lower Zone had a higher proportion fungus/fruiting bodies than trees in the Middle and Upper zones (X^2 = 7.92, df=2, p = 0.019). No significant spatial differences were found for the proportion of trees with cankers (X^2 = 0.133, df=2, p = 0.936) or open wounds (X^2 = 3.63, df=2, p = 0.163).

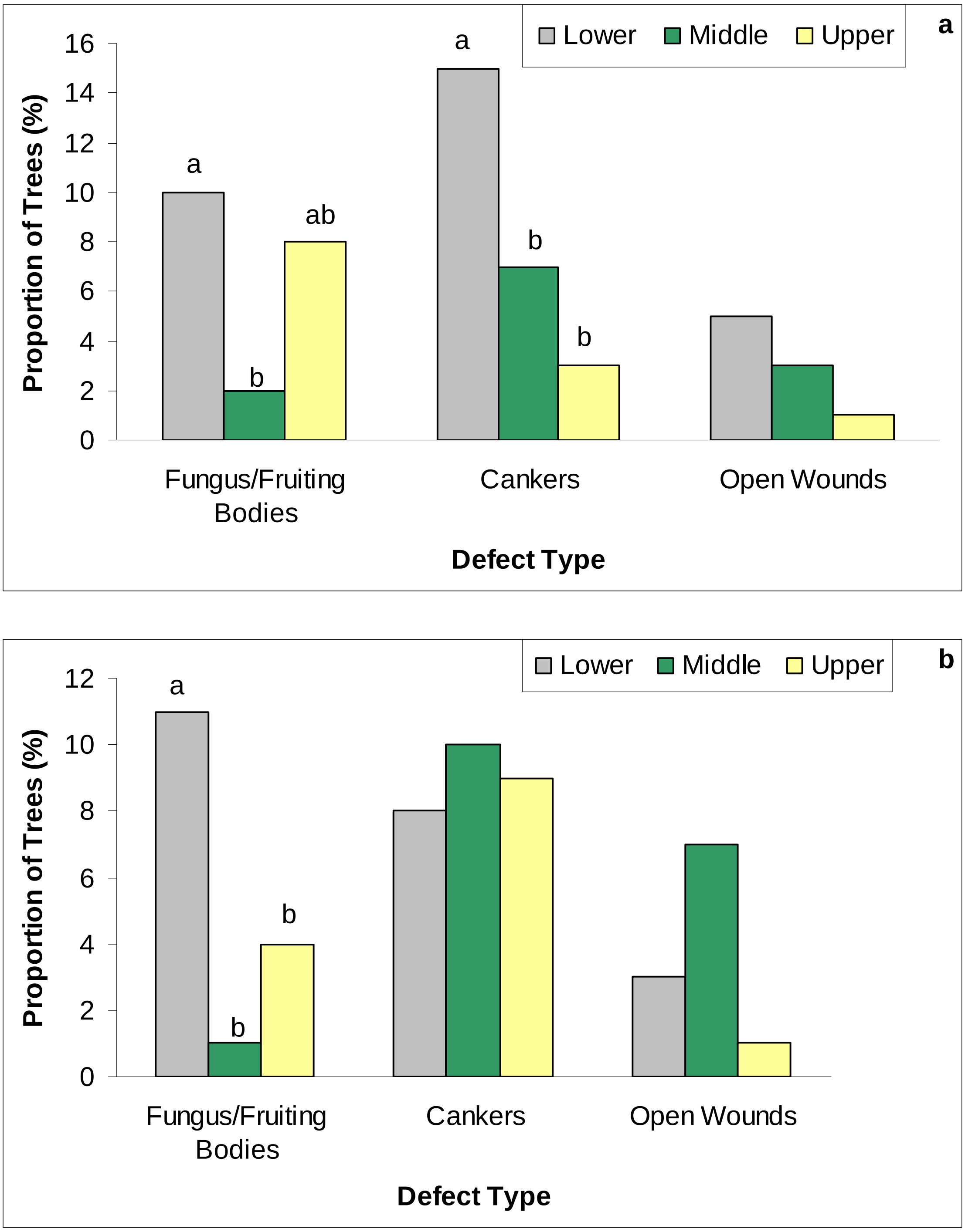


Figure 23. Comparison of proportion of live a) Dominant/Co-dominant and b) Intermediate/Suppressed trees in 2009 exhibiting three stem defect types in three Physiographic Zones of the Credit River Watershed. Within defect types, bars with different letters indicate a significant difference according to Pearson Chi-Square analysis.

It is important to note that live saplings had a much lower frequency of stem defects than canopy trees (Fig. 24). Disease and insect infestation that target canopy trees are not as prevalent in saplings, which are more sensitive to microclimatic and habitat conditions such as lack of sunlight or water.

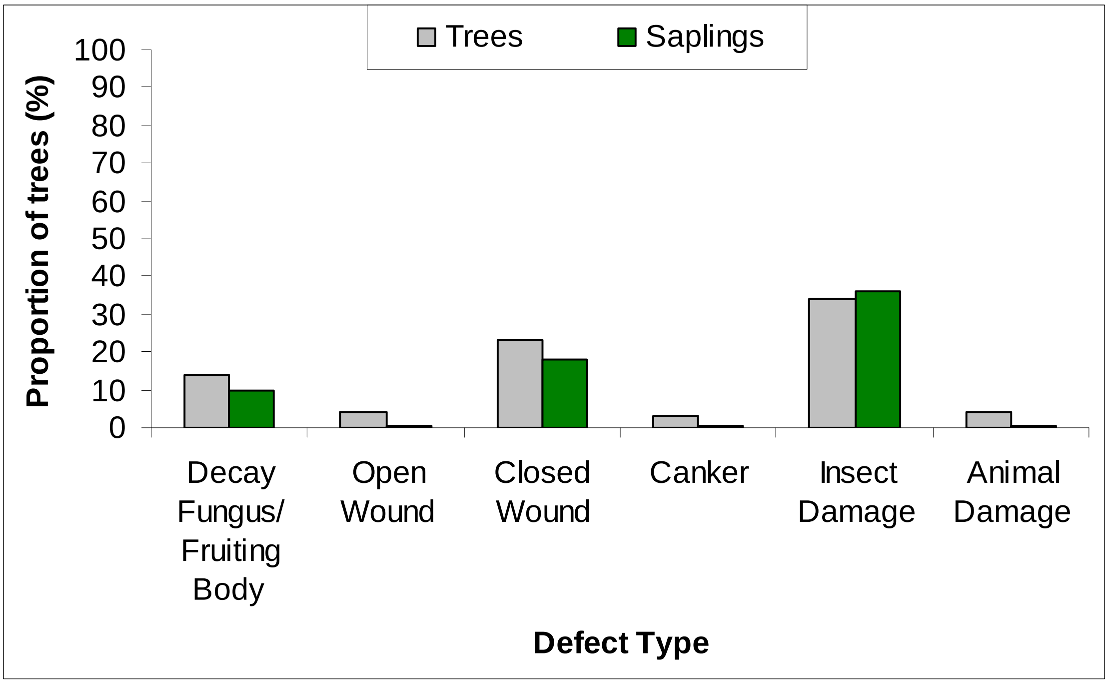


Figure 24. Comparison of proportion of live trees and saplings in 2009 exhibiting 6 stem defect types in the Credit River Watershed.

Based on stem defects alone, Credit River Watershed forests appear to be healthy. Very few groups of trees exceeded the concern thresholds for canker and fungus occurrence in 2009. However, the health of American Beech trees in the Watershed is of concern. Beech Bark disease was widespread throughout the watershed, with few beech trees free of disease symptoms. With the recent arrival of the Emerald Ash Borer to southern Ontario, the future health of ash trees is also of great concern. Diseases targeting two co-dominant species within our forests can have potentially devastating effects on species composition and overall ecosystem health. The continued monitoring of tree health will not only provide information on the long-term persistence of tree species vulnerable to disease, but will also evaluate the capacity of forests in the watershed to perform important ecological functions and services.

4.0 CONCLUSIONS

Tree health in the Credit River Watershed appeared to be stable and, in some cases, improving over the four to five year monitoring period. Moreover, there were no signs of critical decline in any of the chosen health indicators. This is reflected most clearly in the fact that annual mortality rates did not even approach the critical threshold, nor show signs of increasing temporal trends. Annual tree mortality is a parameter that can be viewed as the ultimate indicator of non-vitality from the perspective of individual trees (Dobbertin and Brang, 2001). Improvements were primarily seen in crown vigour ratings, where the proportion of healthy crowns increased and the proportion of crowns in moderate decline decreased for both Dominant/Co-dominant and Intermediate/Suppressed trees between 2005 and 2009. Similar to mortality rates, proportions of trees with severely declining crowns did not approach the 25% concern threshold for any of the parameters throughout the whole monitoring period.

Despite the stable and possibly improving forest conditions, the high infection rate of American Beech trees by Beech Bark Disease (78% monitored trees infected) is alarming. With the recent arrival of the Emerald Ash Borer to southern Ontario, the future health of ash trees is also of great concern. Diseases targeting the two co-dominant species within our forests can have potentially devastating effects on species composition and overall ecosystem health.

From a spatial perspective, differences in tree health among the three Physiographic Zones were dependent on the specific health indicator being considered. No significant spatial differences in mortality were detected, though several spatial patterns were evident in the crown vigour and stem defect data. Crowns appeared to be exhibiting greater improvements in health in the Lower Zone when compared to the Upper and Middle zones judging by the proportion of trees that improved or declined in the Dominant/Co-dominant category. However, there were also a greater proportion of Dominant/Co-dominant trees with healthy crowns in the Upper and Middle than the Lower Watershed. Interestingly, sapling crowns appeared to be healthier in the Middle than the Lower and Upper Physiographic Zones.

Stem defect data revealed that forests in the Lower Watershed exhibited a higher proportion of trees with Fungus/Fruiting bodies and cankers than those in the Middle and Upper Zones. However, there was no significant difference in the frequency of open wounds among the physiographic zones. It is not surprising that defects were higher in the Lower Watershed, given the increased stress imposed by rapid urbanization in that area.

These results, though encouraging, must be viewed cautiously because only four to five years of monitoring data were available for analysis. This is compounded by the fact that sample sizes were too low for most parameters to detect critical and warning thresholds for changing tree health trends. Forests are complex and slowly shifting systems in which changes in structure, composition, and processes may be detectable only after an extended observation period. This is particularly true when considering the potential impacts of climate change on forests in the watershed. It is recommended that future analyses include comparisons between tree health at individual monitoring plots and measures of landscape composition and configuration surrounding those forest plots.

In addition, greater analytical integration between forest health indicators will be examined. This will involve the comparison of tree health characteristics to indicators such as ground vegetation diversity, the composition of regenerating species, and forest soil properties. Through this integration and a continued focus on program improvement, a more complete and holistic understanding of forest health in the Credit River Watershed can be gained. Furthermore, consideration will be given to strategically increasing sample sizes of target species to have the ability in the future to detect changes in tree health trends.

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APPENDIX A: FOREST MONITORING SITES

Table 1. Forest health monitoring sites established throughout the Credit River Watershed.

Site #	Site Name	Township	Municipality	Physiographic Region	Habitat Patch Size (Ha)	Ecological Land Classification Vegetation Type
F-16	Britannia Forest	Mississauga	Peel	Lower	5.19	Dry-Fresh Sugar Maple –Oak Deciduous Forest
F-13	Churchill Meadows Forest	Mississauga	Peel	Lower	5.89	Fresh-Moist Oak-Sugar Maple Deciduous Forest
F-10	Huttonville Forest	Brampton	Peel	Lower	18.36	Mixed Forest
F-11	Levi Creek Forest	Mississauga	Peel	Lower	24.2	Dry-Fresh Sugar Maple-Beech Deciduous Forest
I-05	Meadowvale Station Forest	Mississauga	Peel	Lower	45.70	Fresh-Moist Sugar Maple-Hardwood Deciduous Forest
I-01	Mississauga Gardens Forest	Mississauga	Peel	Lower	52.36	Dry-Fresh White Pine-Oak Mixed Forest
F-14	Roy Ivors Forest	Mississauga	Peel	Lower	24.73	Fresh-Moist Sugar Maple-Lowland Ash Deciduous Forest
F-12	Streetsville Forest	Mississauga	Peel	Lower	18.76	Fresh-Moist Oak-Sugar Maple Deciduous Forest
F-15	Winston Forest	Oakville	Halton	Lower	27.24	Deciduous Forest
F-18	Fairy Lake Forest	Halton Hills	Halton Hills	Middle	169.10	n/a
F-20	Willoughby Nature Reserve Forest	Caledon	Peel	Middle	93.25	Fresh-Moist Sugar Maple-Lowland Ash Deciduous Forest
F-08	Limehouse Forest	Halton Hills	Halton Hills	Middle	135.32	Dry-Fresh White Pine-Red Pine Coniferous Forest
F-05	Robert Baker Forest	Caledon	Peel	Middle	232.56	Deciduous Forest
F-07	Silver Creek Forest	Halton Hills	Halton Hills	Middle	370.14	Dry-Fresh Sugar Maple-White Ash Deciduous Forest
I-06	Terra Cotta Forest	Caledon	Peel	Middle	753.26	Dry-Fresh Sugar Maple-White Ash Deciduous Forest
F-09	UCC Forest	Halton Hills	Halton Hills	Middle	141.32	Mixed Forest
F-06	Warwick Forest	Caledon	Peel	Middle	191.18	Fresh-Moist Sugar Maple-Lowland Ash Deciduous Forest
I-03	Alton Forest	Caledon	Peel	Upper	185.75	Dry-Fresh Sugar Maple-Paper Birch-Poplar Deciduous Forest
F-19	Belfountain Forest	Caledon	Peel	Upper	439.15	Fresh-Moist Sugar Maple-Lowland Ash Deciduous Forest
F-04	Caledon Creek Forest	Caledon	Peel	Upper	134.21	Dry-Fresh Sugar Maple-Paper Birch-Poplar Deciduous Forest
F-03	Charles Sauriol Forest	Caledon	Peel	Upper	233.83	Mixed Forest
I-04	Forks of the Credit Forest	Caledon	Peel	Upper	534.18	Dry-Fresh Sugar Maple Deciduous Forest
F-02	Hillsburgh Forest	Erin	Wellington	Upper	60.43	Deciduous Forest
F-01	Monora Park Forest	Mono	Dufferin	Upper	112.06	Dry-Fresh Sugar Maple Deciduous Forest
I-02	Orpen Lake Forest	Caledon	Peel	Upper	323.18	Fresh-Moist Sugar Maple-Hardwood Deciduous Forest

APPENDIX B: TREE SPECIES PRESENT IN MONITORING PLOTS

Table 1. Common and latin names of the 32 tree species identified in monitoring plots throughout the Credit River Watershed.

Common Name	Latin Name	Type	Native Status
Deciduous			
American Beech	*Fagus grandifolia*	Deciduous	Native
American Elm	*Ulmus americana*	Deciduous	Native
Balsam Poplar	*Populus balsamifera*	Deciduous	Native
Basswood	*Tilia americana*	Deciduous	Native
Bitternut Hickory	*Carya cordiformis*	Deciduous	Native
Black Ash	*Fraxinus nigra*	Deciduous	Native
Black Maple	*Acer nigrum*	Deciduous	Native
Blue-Beech	*Carpinus caroliniana*	Deciduous	Native
Bur Oak	*Quercus macrocarpa*	Deciduous	Native
Butternut	*Juglans cinerea*	Deciduous	Native
Common Apple	*Malus sylvestris*	Deciduous	Non-native
Common Buckthorn	*Rhamnus cathartica*	Deciduous	Non-native
Downy Hawthorn	*Crataegus mollis*	Deciduous	Native
Freeman Maple	*Acer x freemanii*	Deciduous	Native
Ironwood	*Ostrya virginiana*	Deciduous	Native
Northern Red Oak	*Quercus rubra*	Deciduous	Native
Paper Birch	*Betula papyrifera*	Deciduous	Native
Red/Green Ash	*Fraxinus pennsylvanica*	Deciduous	Native
Red Maple	*Acer rubrum*	Deciduous	Native
Shagbark Hickory	*Carya ovata*	Deciduous	Native
Sugar Maple	*Acer saccharum ssp. saccharum*	Deciduous	Native
Swamp White Oak	*Quercus bicolor*	Deciduous	Native
Trembling Aspen	*Populus tremuloides*	Deciduous	Native
White Ash	*Fraxinus americana*	Deciduous	Native
White Oak	*Quercus alba*	Deciduous	Native
Wild Black Cherry	*Prunus serotina*	Deciduous	Native
Yellow Birch	*Betula alleghaniensis*	Deciduous	Native
Coniferous			
Balsam Fir	*Abies balsamea*	Coniferous	Native
Eastern Hemlock	*Tsuga canadensis*	Coniferous	Native
Eastern White Cedar	*Thuja occidentalis*	Coniferous	Native
Eastern White Pine	*Pinus strobus*	Coniferous	Native
White Spruce	*Picea glauca*	Coniferous	Native

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES

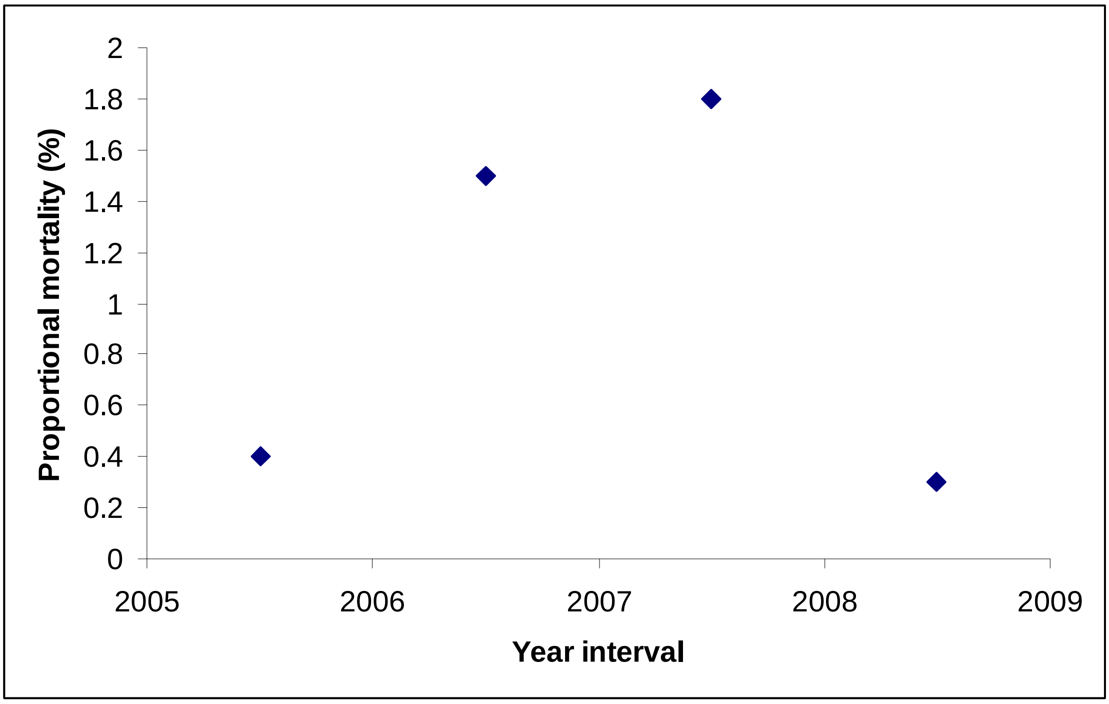

Figure 1. Between-year mortality rates of Sugar Maple trees over the 5-year monitoring period.

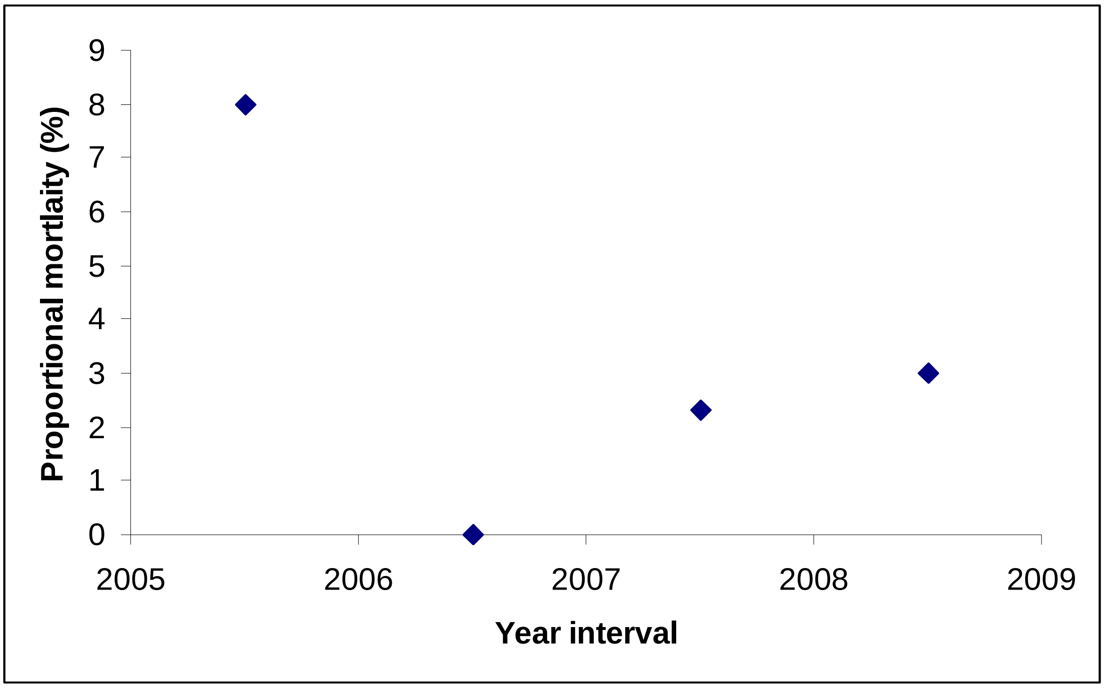

Figure 2. Between-year mortality rates of White Ash trees over the 5-year monitoring period.

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES (Cont'd)

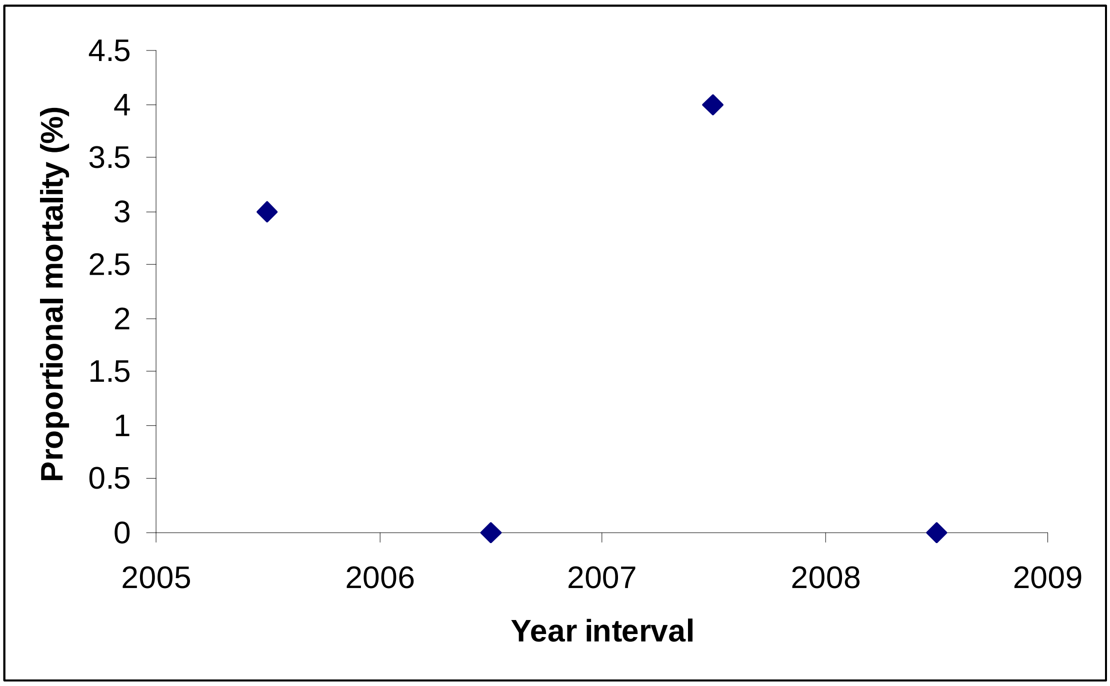

Figure 3. Between-year mortality rates of Paper and Yellow Birch trees over the 5-year monitoring period.

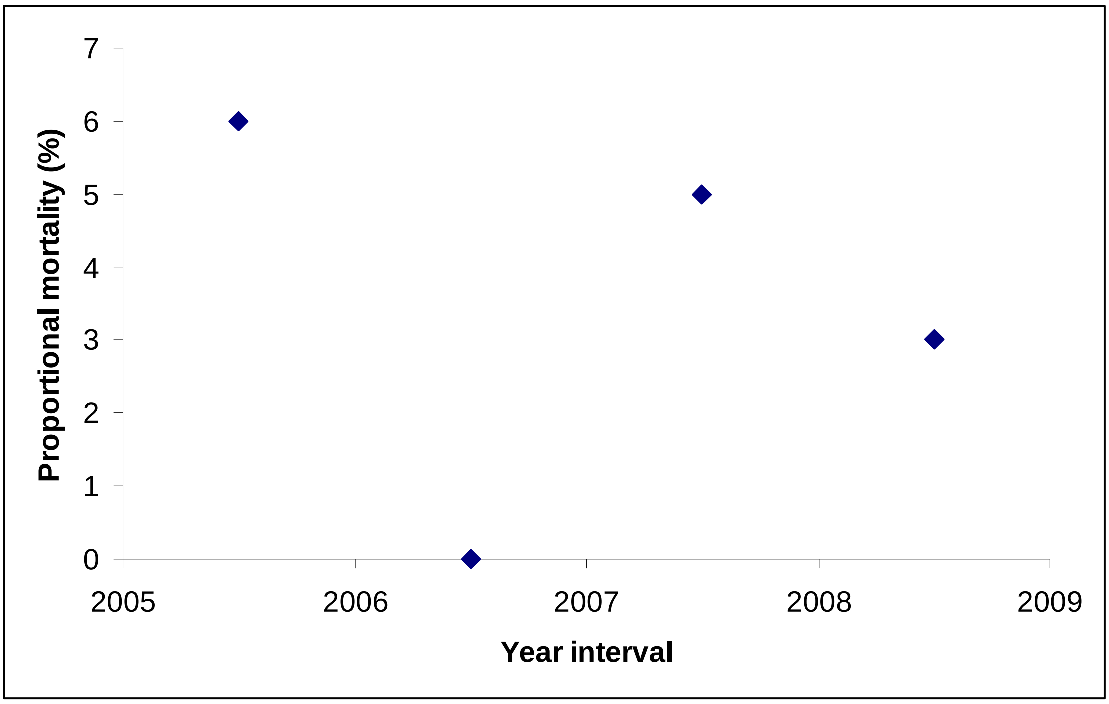

Figure 4. Between-year mortality rates of American Beech over the 5-year monitoring period.

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES (Cont'd)

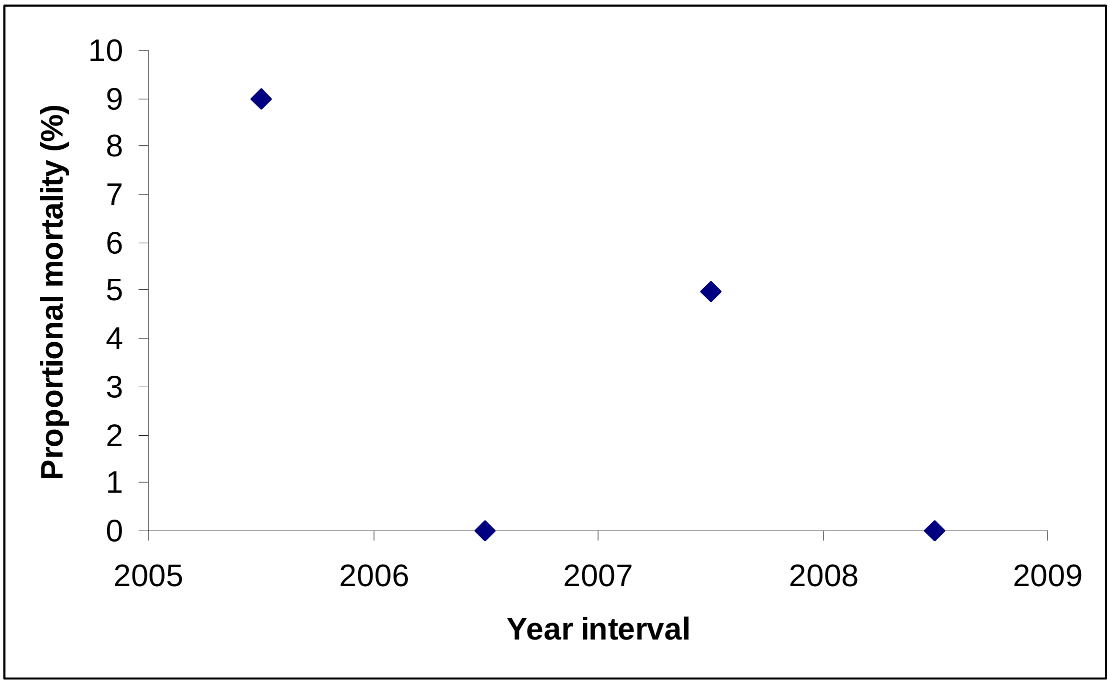

Figure 5. Between-year mortality rates of White Pine over the 5-year monitoring period.

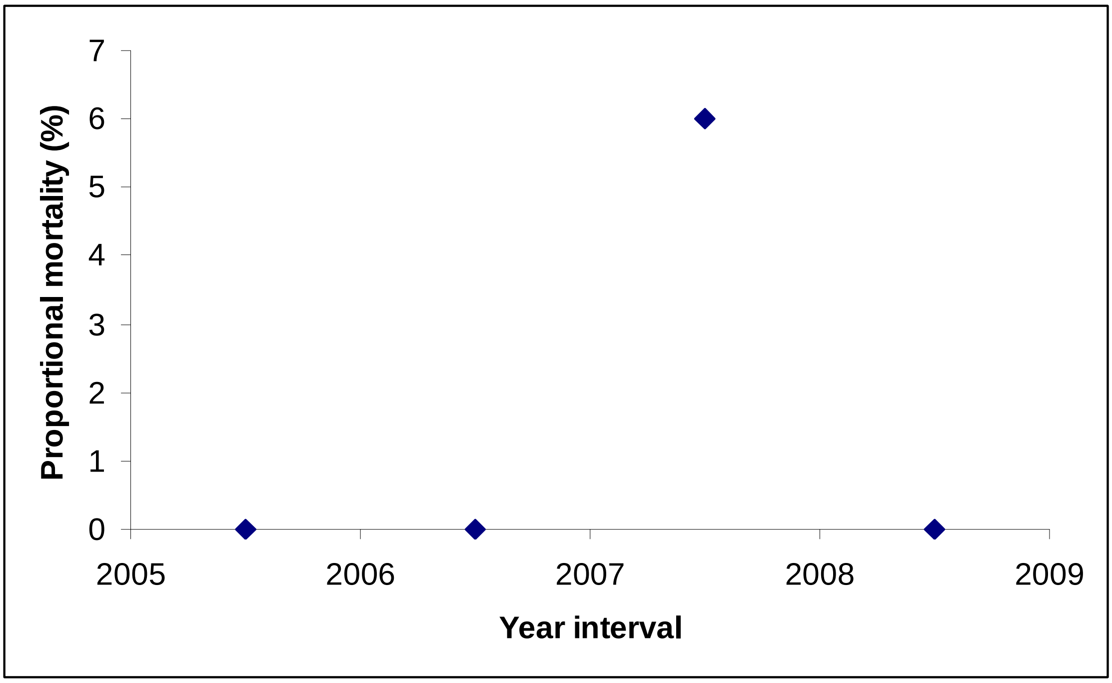

Figure 6. Between-year mortality rates of Eastern White Cedar over the 5-year monitoring period.

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES (Cont'd)

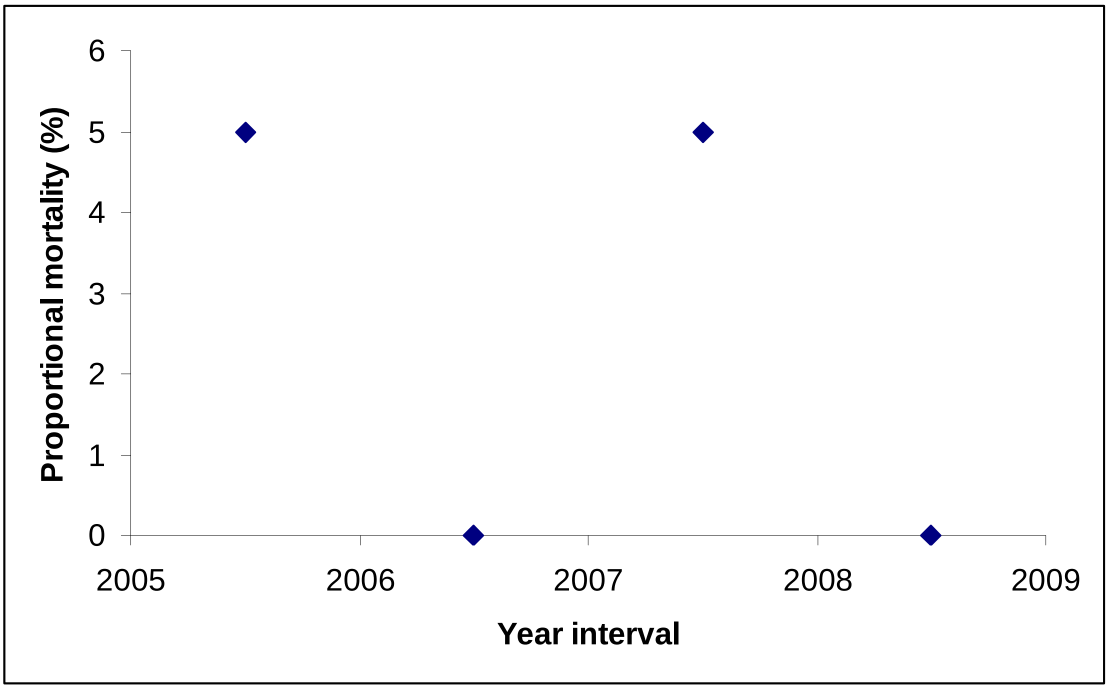

Figure 7. Between-year mortality rates of Eastern Hemlock over the 5-year monitoring period.

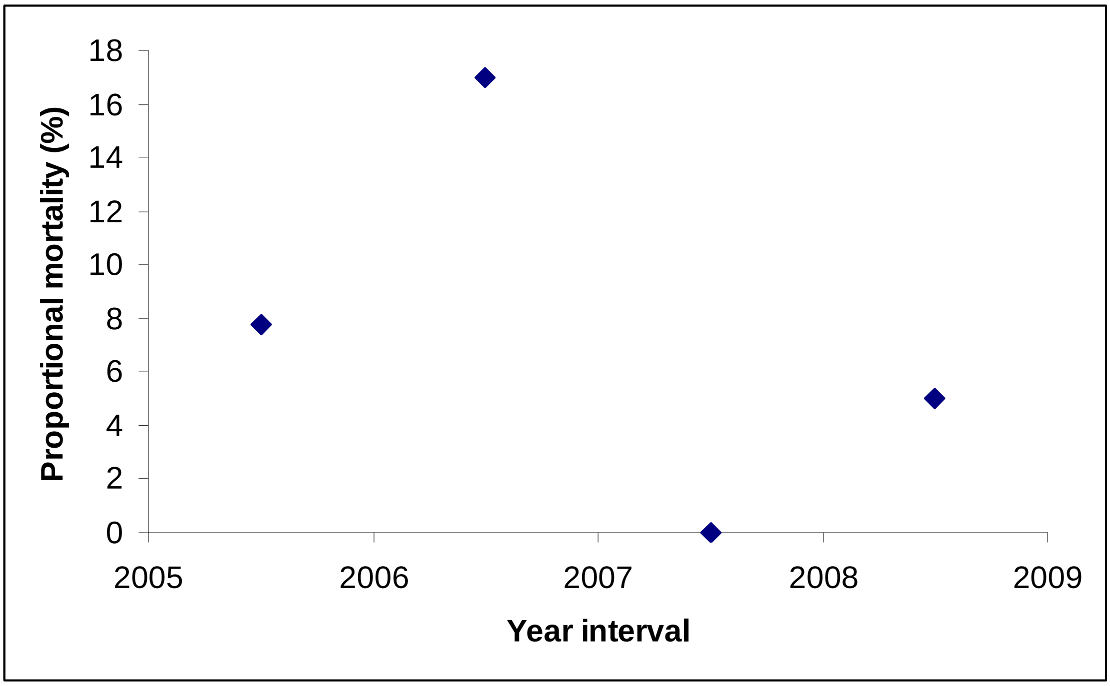

Figure 8. Between-year mortality rates of Trembling Aspen over the 5-year monitoring period.

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES (Cont'd)

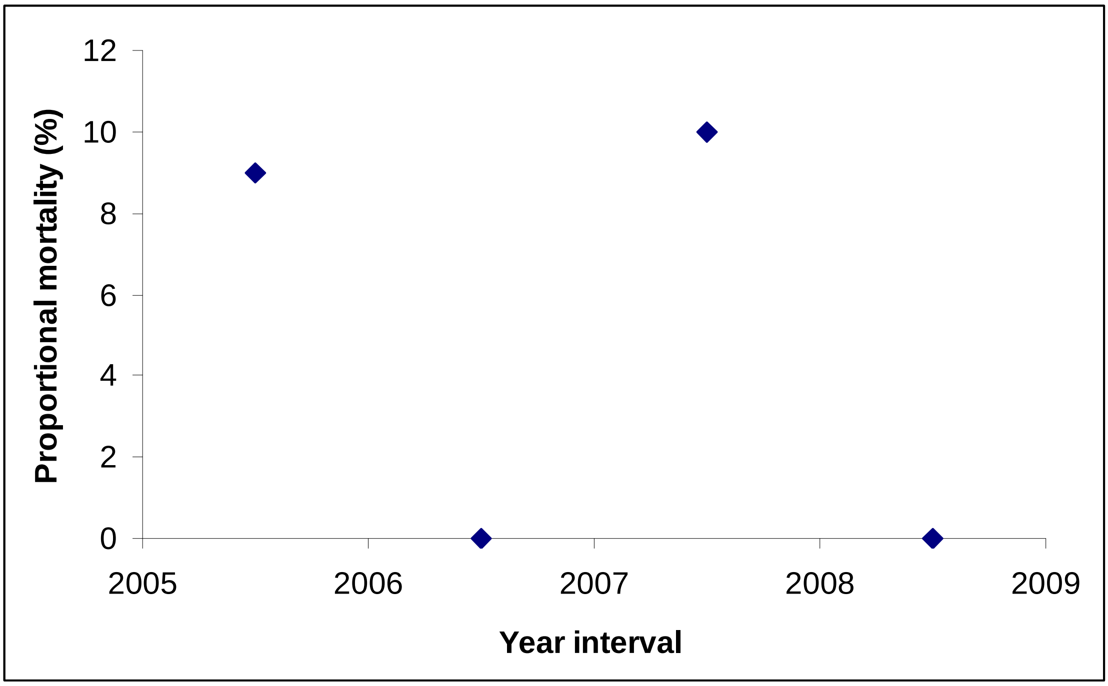

Figure 9. Between-year mortality rates of American Elm over the 5-year monitoring period.

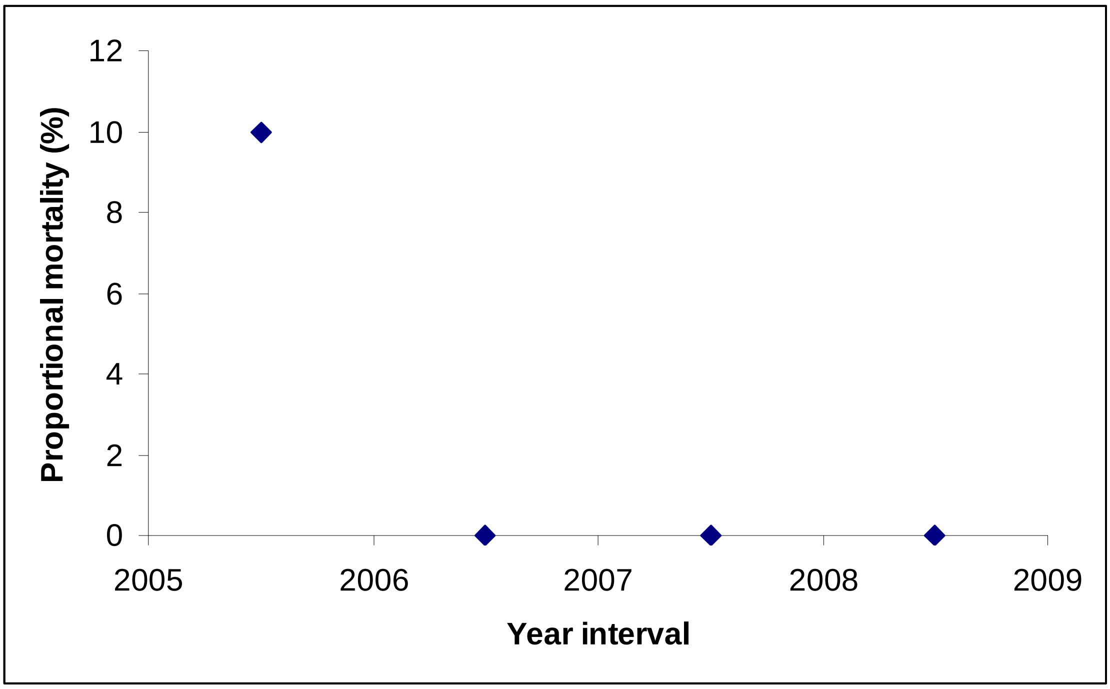

Figure 10. Between-year mortality rates of Red/Green Ash over the 5-year monitoring period.

APPENDIX C: PROPORTIONAL MORTALITY TRENDS OF SELECTED TREE SPECIES (Cont'd)

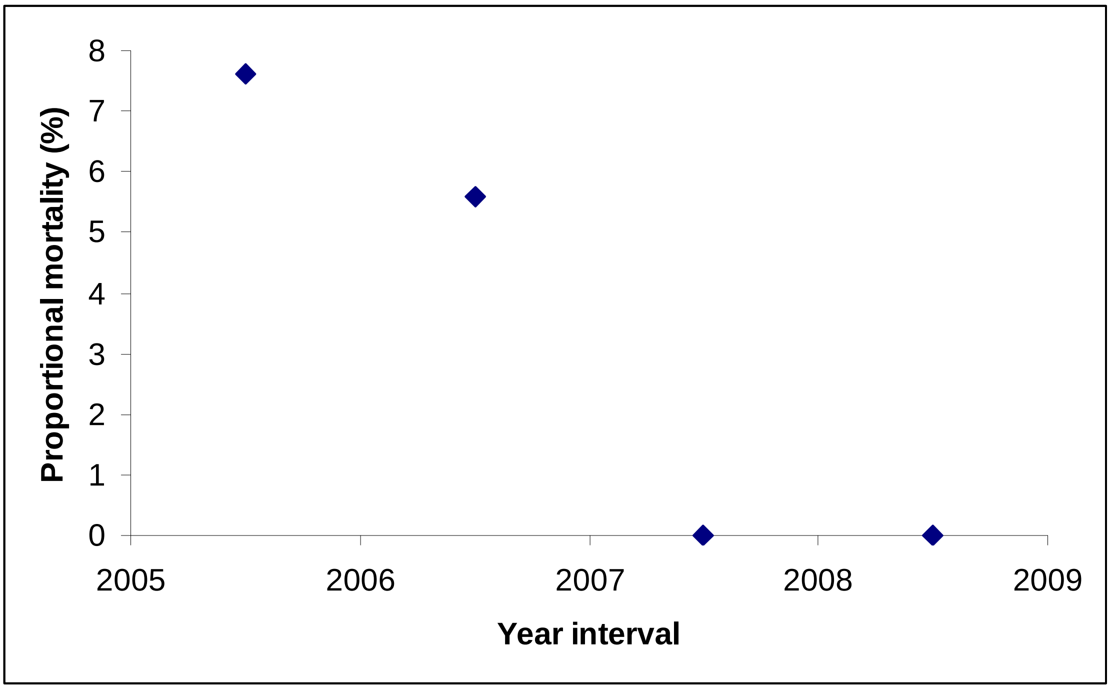

Figure 11. Between-year mortality rates of White Oak group over the 5-year monitoring period.

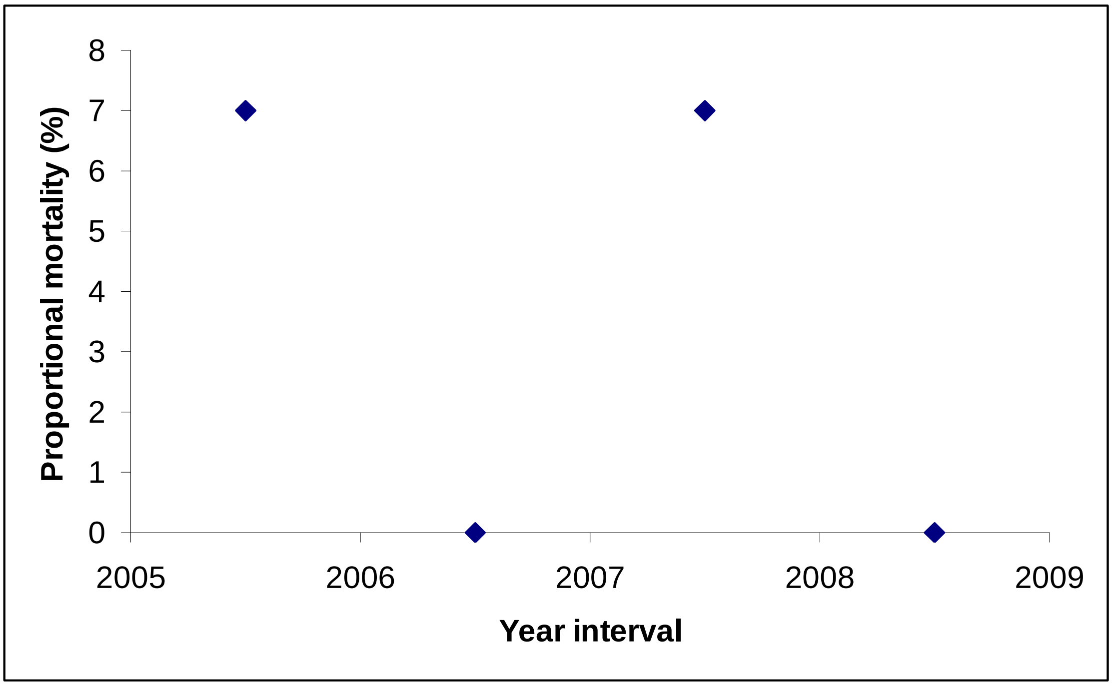

Figure 12. Between-year mortality rates of Red Oak group over the 5-year monitoring period.

APPENDIX D: POTENTIAL IMPROVEMENTS TO TREE HEALTH PROGRAM BASED ON POWER ANALYSIS RESULTS

Based on completed power analyses, the following theoretical changes to sample size would improve data quality in the listed categories. Sample size changes are only presented in situations where logistically possible as determined by current program resources. For example, mortality rates in the Watershed are very low, therefore an additional 836 Dominant/Co-dominant trees would have to be monitored in order to detect a critical threshold in mortality rates. Because such sample size increases are way beyond current program capabilities, any parameter that requires the addition of 200 trees or greater to improve threshold detection is not listed below.

Parameter	Increase in Sample Size	Health Category	Threshold Detected
Mortality			
White Ash	161	n/a	Critical
White Pine	128	n/a	Critical
Eastern White Cedar	100	n/a	Critical
Trembling Aspen	79/180	n/a	Critical/Warning
American Elm	106	n/a	Critical
Lowland Ash species	112	n/a	Critical
White Oak	154	n/a	Critical
Red Oak	147	n/a	Critical
Crown Vigour			
Saplings	169	Severe Decline	Warning
Crown Improvements and Declines			
Dominant/Co-dominant	5	Declining	Warning
Intermediate/Suppressed	12	Improving	Critical
	198	Declining	Critical
Sugar Maple	18	Improving	Warning
	195	Declining	Warning
White Ash	13/80	Declining	Critical/Warning
Paper/Yellow Birch	154	Improving	Critical
	147	Declining	Critical
American Beech	12/67	Improving	Critical/Warning
White Pine	85/148	Improving	Critical/Warning
	14/69	Declining	Critical/Warning
Eastern White Cedar	145	Improving	Critical
Eastern Hemlock	72/172	Improving	Critical/Warning
	25/80	Declining	Critical/Warning
Trembling Aspen	40/107	Declining	Critical/Warning
American Elm	49/123	Improving	Critical/Warning
	186	Declining	Critical
Red/Green Ash	48/115	Improving	Critical/Warning
	23/66	Declining	Critical/Warning
White Oak group	24	Improving	Critical
	28/79	Declining	Critical/Warning
Red Oak group	11/45	Improving	Critical/Warning
	42/107	Declining	Critical/Warning

APPENDIX E: TRENDS IN YEAR-TO-YEAR CROWN CHANGE FOR INDIVIDUAL SPECIES OR GROUPS

Table 1. Trends in year-to-year crown improvement, decline, and stability of individual species or groups between 2005 and 2009 in 25 forest plots across the Credit River Watershed, determined using Cochrane-Armitage analysis.

Species	Health Trend	Observed *z*	Critical *z*	*p*-Value [a]	Observed Trend
Sugar Maple	Stable	0.053	1.96	0.958	stable
	Improved	0.916	1.96	0.360	stable
	Declined	3.833	1.96	0.045	**decreasing**
White Ash	Stable	1.771	1.96	0.077	stable
	Improved	0.589	1.96	0.556	stable
	Declined	1.798	1.96	0.0.072	stable
Paper and Yellow Birch	Stable	0.558	1.96	0.557	stable
	Improved	0.924	1.96	0.356	stable
	Declined	1.091	1.96	0.577	stable
American Beech	Stable	1.453	1.96	0.146	stable
	Improved	1.569	1.96	0.117	stable
	Declined	0.307	1.96	0.759	stable
White Pine	Stable	0.648	1.96	0.517	stable
	Improved	0.560	1.96	0.575	stable
	Declined	1.314	1.96	0.189	stable
Eastern White Cedar	Stable	0.336	1.96	0.737	stable
	Improved	0.231	1.96	0.444	stable
	Declined	0.373	1.96	0.709	stable
Eastern Hemlock	Stable	0.023	1.96	0.982	stable
	Improved	1.483	1.96	0.138	stable
	Declined	1.414	1.96	0.157	stable
Trembling Aspen	Stable	0.257	1.96	0.797	stable
	Improved	0.263	1.96	0.636	stable
	Declined	0.473	1.96	0.361	stable
American Elm	Stable	0.377	1.96	0.707	stable
	Improved	1.257	1.96	0.209	stable
	Declined	0.883	1.96	0.377	stable
Red/Green Ash	Stable	0.375	1.96	0.707	stable
	Improved	1.050	1.96	0.294	stable
	Declined	0.624	1.96	0.533	stable
White Oak group	Stable	1.775	1.96	0.076	stable
	Improved	1.168	1.96	0.243	stable
	Declined	2.374	1.96	0.018	**decreasing**
Red Oak group	Stable	1.534	1.96	0.125	stable
	Improved	0.604	1.96	0.546	stable
	Declined	1.511	1.96	0.131	stable

[a] p significant at <0.05