Credit Valley Conservation

Terrestrial Monitoring Program Report
2005 - 2009

Monitoring Forest Integrity within the Credit River Watershed
Chapter 4: Forest Vegetation

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Monitoring Forest Integrity within the Credit River Watershed

Chapter 4: Forest Vegetation 2005-2009

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ABSTRACT

Forest Vegetation in the Credit River Watershed
Summary of Monitoring Results 2005-2009

Temporal Trends: Only two of the thirteen vegetation parameters examined for trends exhibited a significant change over the monitoring period. Ground vegetation species richness and diversity increased between 2005 and 2009. Several other vegetation parameters exhibited yearly fluctuations, including combined vegetation, ground vegetation and tree regeneration richness, ground vegetation and regeneration evenness, ground vegetation diversity, the combined proportion of native species, tree stems in all height classes, FQI, weedy species richness and the number of -3 weedy species. In addition, the occurrence of Brown-seed Dandelion increased in the ground vegetation layer, and White Ash decreased in the regeneration layer. Overall, it appears that vegetation in the Credit River Watershed is stable.

Spatial Trends: Two of twenty-four vegetation parameters displayed spatial differences in the Credit River Watershed. The Upper watershed contained greater herbaceous ground vegetation richness than the Lower watershed. In addition, the Lower watershed contained more -3 weedy species than the Upper watershed in 3/5 survey years. The remaining 22 vegetation parameters displayed no differences between physiographic zones.

Relationships with Landscape Metrics: Some vegetation parameters in the Credit River Watershed exhibited significant correlations with landscape metrics. Habitat patch size, percent natural cover, percent urban cover, percent agricultural cover and matrix quality were each correlated with between one and seven of the twenty two vegetation parameters examined. In addition, the probability of the occurrence of Brown Seed Dandelion and Garlic Mustard increased with greater urban cover. No vegetation parameters or selected species displayed a significant relationship with the distance to the nearest road.

Recommendations: Forest vegetation in the Credit River Watershed appears to be relatively stable. This data provides a good basis for detecting future environmental change. Future analysis should integrate other forest health parameters, such as indicators of tree health, soil, and faunal species, to increase overall understanding of forest health in the Credit River Watershed.

Forest vegetation monitoring was conducted as part of the terrestrial component of an overall Integrated Watershed Monitoring Program established at Credit Valley Conservation. Vegetation was surveyed at 25 forest sites throughout the Credit River Watershed from 2005 to 2009. Monitoring was conducted according to protocols developed by Credit Valley Conservation, adapted from Environment Canada's Environmental Monitoring and Assessment Network (EMAN).

One hundred and thirty-four forest vegetation species were detected over the five year monitoring period. Eighty-nine percent of these species were native to Ontario, six of which were considered locally rare, and four of these were also considered regionally rare. In addition, two of the detected species were considered to be potentially problematic weedy species and are a possible threat to natural areas in the Credit River Watershed.

Most vegetation parameters in the Credit River Watershed did not display an increasing or decreasing trend over time. Ground vegetation species richness and diversity were the exception, as they increased between 2005 and 2009. Other parameters, including: combined vegetation and tree regeneration richness, ground vegetation and regeneration evenness, the combined proportion of native species, tree stems in all height classes, Floristic Quality Index (FQI), weedy species richness and the number of -3 weedy species, displayed yearly fluctuations but no consistent increasing or decreasing trend. No changes over time were observed for regeneration shrub richness, regeneration diversity, the proportion of ground vegetation native species, total shrub stem counts, shrub stems >95cm, mean Coefficient of Conservatism (mCC) and wetness. In addition, the occurrence of Brown-seed Dandelion increased in the ground vegetation layer, and the occurrence of White Ash decreased in the regeneration layer. In general, forest vegetation in the Credit River Watershed appears to have been stable over the five year monitoring period.

Very few differences in forest vegetation were observed between the three physiographic zones of the Credit River Watershed. This result was surprising, and may be attributed to greater variation among forests found within each zone than differences between each zone. Of the twenty-four vegetation parameters, two displayed spatial differences over the monitoring period. The Upper watershed contained greater herbaceous ground vegetation richness than the Lower watershed. In addition, the Lower watershed contained more -3 weedy species than the Upper watershed in 3/5 survey years. The remaining 22 vegetation parameters displayed no differences between physiographic zones.

Eight vegetation parameters were significantly correlated with landscape metrics, such as habitat patch size, percent natural cover, percent urban cover, percent agricultural cover and matrix quality. The occurrence of Brown Seed Dandelion (*Taraxicum officinale*) and Garlic Mustard (*Alliaria petiolata*) were also correlated with landscape metrics, as each increased with greater urban cover. None of the studied vegetation parameters or selected species displayed a significant relationship with the distance to the nearest road.

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1.0 INTRODUCTION

1.1 BACKGROUND

Ontario has undergone dramatic change since the arrival of European settlers. A landscape that was historically dominated by forest cover has experienced rapid removal of habitat and fragmentation of remaining natural areas by agriculture, residential 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, a ecological region encompassing the southern-most areas of the province, has seen a decrease in proportional forest cover from 80% pre-settlement to a mere 11% as of 1999 (Larson et al. 1999). During the mid-90's, changes in agricultural practices and reforestation increased forested lands south and east of the Canadian Shield by 5%. Despite this, the majority of re-naturalized wooded areas will never return to their original 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).

Forests provide numerous, irreplaceable ecological functions including the production of oxygen through photosynthesis, sequestration of carbon, and the moderation of climate through the transpiration of trees. Forests also play a role in reducing water flow-through rates, decreasing soil erosion, improving surface water quality, and creating habitat for flora and fauna (Larson et al. 1999). Despite these benefits, forests have historically been viewed as obstacles to progress or as sources of economic gain through logging.

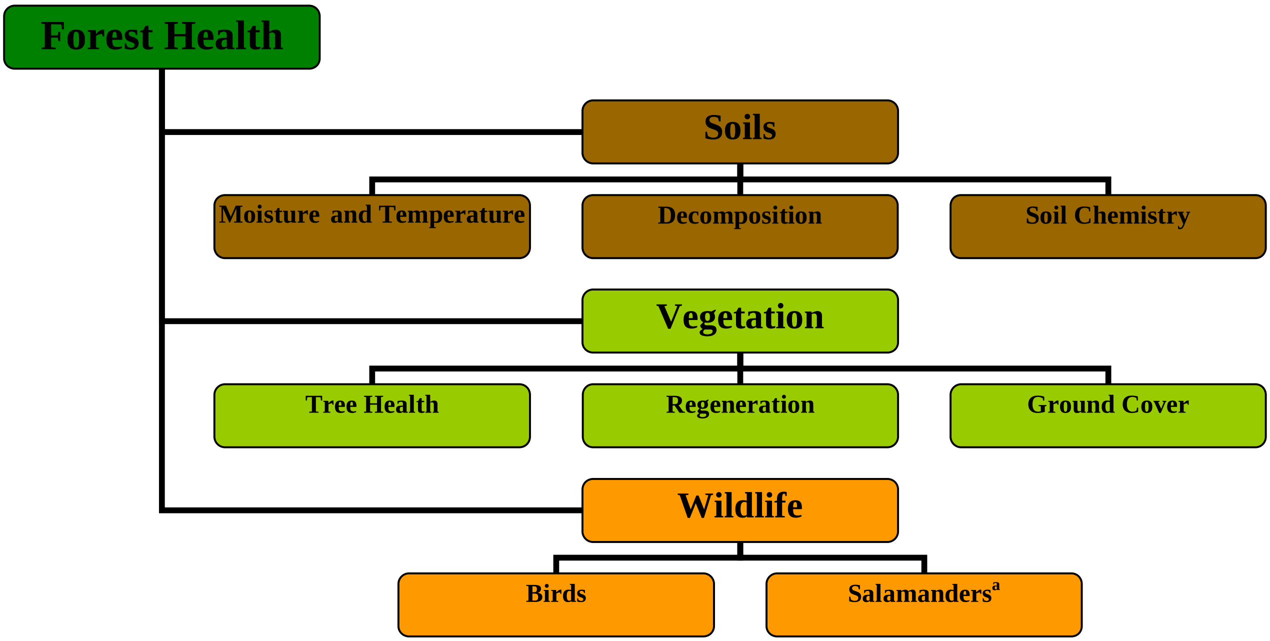
Forest removal has led to habitat loss and fragmentation. Fragmentation generally results in the reduction of total available habitat, the isolation of remaining patches, a decrease in patch size and often an increase in total patch number (Noss and Cooperrider 1994; Fahrig 2003). Plant and wildlife 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 neighbouring 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 hydrologic functioning of a forest, drastically altering the hydrologic patterns, such as peak flow and runoff, within a watershed (Lull and Sopper 1969; Duguay et al. 2007).

The relative impact of each of these effects on forest health within the watershed is still unknown. Through monitoring forests as part of the Terrestrial Monitoring Program, 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 for better accounting of the condition and health of the environment to determine whether conditions are improving or deteriorating (Niemi and McDonald 2004). An ecological monitoring program increases understanding of the trends and processes of a given ecosystem. A superior monitoring program should address both biotic and abiotic components, as well as function across multiple scales. Monitoring is useful in providing managers with information which can be used for long-term planning, because trends over time can be used to infer future conditions. 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).

In 2002 the Terrestrial Monitoring Program was initiated at Credit Valley Conservation (CVC) to examine the integrity of biotic and abiotic indicators in forest, wetland and riparian ecosystems throughout the watershed. The main goals of the Terrestrial Monitoring Program are to (1) measure indicators of the structure, composition and function of terrestrial ecosystems, to assess the ecosystem integrity of the Credit River Watershed, (2) identify status and trends in the integrity of terrestrial communities at the watershed scale, and link to overall watershed integrity, (3) identify spatial patterns in terrestrial community integrity and (4) provide meaningful data on which watershed management decisions can be based (Morris et al. 2002; CVC 2010a). Within the 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).



[a]monitoring to begin in 2011

Figure 1. Forest health parameters in the Credit River Watershed.

1.3 WHY MONITOR FOREST VEGETATION?

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). Monitoring herbaceous vegetation provides an early warning system for environmental degradation, including climate change, environmental pollution and land-use change (Roberts-Pichette and Gillespie 1999; Wolfe et al. 2005). Ground vegetation is an important element in forest monitoring programs due to the large diversity of understory vegetation in comparison to trees in the canopy layer (Gilliam 2007; Johnson et al. 2008). Ground vegetation species tend to have shorter lifespans and different survival tactics than species in the regeneration and canopy layers. This can result in rapid turnover rates and changes in ground vegetation community composition when compared to the other forest vegetation (Roberts-Pichette and Gillespie 1999; Johnson et al. 2008). Ground vegetation may be affected by changes in the concentrations of airborne pollutants, amount of received UV-B radiation and temperature and moisture regimes (Roberts-Pichette and Gillespie 1999). In addition, ground vegetation monitoring allows for tracking of rare and invasive species, most of which are herbaceous. Ground vegetation is also useful for estimating habitat quality and quantity for many fauna species. Therefore, long-term shifts driven by environmental change and short-term natural cyclic population variation may be differentiated through continued monitoring of ground vegetation species (Roberts-Pichette and Gillespie 1999).

The tree canopy layer has received the majority of attention in monitoring programs in Canada, and as a result, there is limited information about the population dynamics of canopy-tree species in the ground vegetation layer (Roberts-Pichette and Gillespie 1999). Monitoring will yield information about the rate of germination, growth and development of seedlings, and their interactions with the herbaceous species that make up the remainder of the ground vegetation layer. Furthermore, monitoring seedling and sapling regeneration indicates the quantity and composition of established tree seedlings and consequently the future canopy composition of the forest (Tierney et al. 2009). Regeneration data can also assist in estimating the extent of deer browse in the watershed. Seedling height ratios may be used to infer browse pressure, as deer preferentially browse vegetation in particular height classes (Tierney et al. 2009). Therefore, the collection of information from the understory layers may reveal information about the long-term development of the studied forest stands.

Monitoring forest vegetation also allows for early detection of the impacts of climate change. As climate change progresses, it is expected that forests will increasingly be stressed by drought and affected by forest fires and new pest infestations. It is predicted that as the climate becomes warmer the water table will lower resulting in a reduction in soil moisture. Grasslands may replace the driest forests and drought intolerant species will regenerate poorly leading to the establishment of drought tolerant species (Natural Resources Canada 2006).

1.4 FOREST VEGETATION IN A CHANGING LANDSCAPE

The Credit River Watershed encompasses 950 square kilometres of land in southern Ontario, Canada (Credit Valley Conservation 2003) (Fig. 2). The Credit River flows southeast for nearly 100 kilometres from its headwaters in Orangeville to its drainage point at Lake Ontario. The watershed is comprised of 23% natural communities, 11% successional communities, 37% agricultural land use, and 29% urban area (Credit Valley Conservation 2007a).

In 1851, it was estimated that forests covered approximately 67% of the Credit River Watershed (Fig. 3). 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%. Currently woodland area accounts for approximately 21% of land use in the watershed (11.6% upland forest, 4.2% treed swamp and 4.9% cultural woodland and plantation; CVC 2007a). This is currently below the 30% forest cover recommended by the Canadian Wildlife Service (Environment Canada 2004) for adequate wildlife habitat.

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*) (Fig. 4). The Deciduous Forest Region extends only a few miles into the watershed from the mouth of the river. Characteristic associations in this region include Black and White Oaks (*Quercus alba* and *Q. velutina*), Sassafras (*Sassafras albidum*) and Shagbark Hickory (*Carya ovata*) (Credit Valley Conservation 1956).

Though encompassing many unique landscape formations, the Credit River Watershed can be divided into three main physiographic zones based on topography, physiographic regions and subwatershed boundaries (Fig. 2) (Credit Valley Conservation 2007b). The Lower physiographic zone is highly urbanized, containing over 85% of the population of the watershed. The topography of this area is relatively flat with a gentle slope towards Lake Ontario and has been significantly altered by human development. The Lower watershed is comprised of lower permeability sediments, such as silt to clay till, lying on top of Georgian Bay and Queenston shales (Credit Valley Conservation 2007b). The soils in the Lower zone are comprised of clay loam soils associated with the Peel Plain and the South Slope (Credit Valley Conservation 2007b). These soils have low permeability in relation to the rest of the watershed; however localized pockets of sand and gravel exist. When compared against government standards (Environment Canada 2004), the amount of both wetland and forest cover in the Lower watershed is classified as poor.

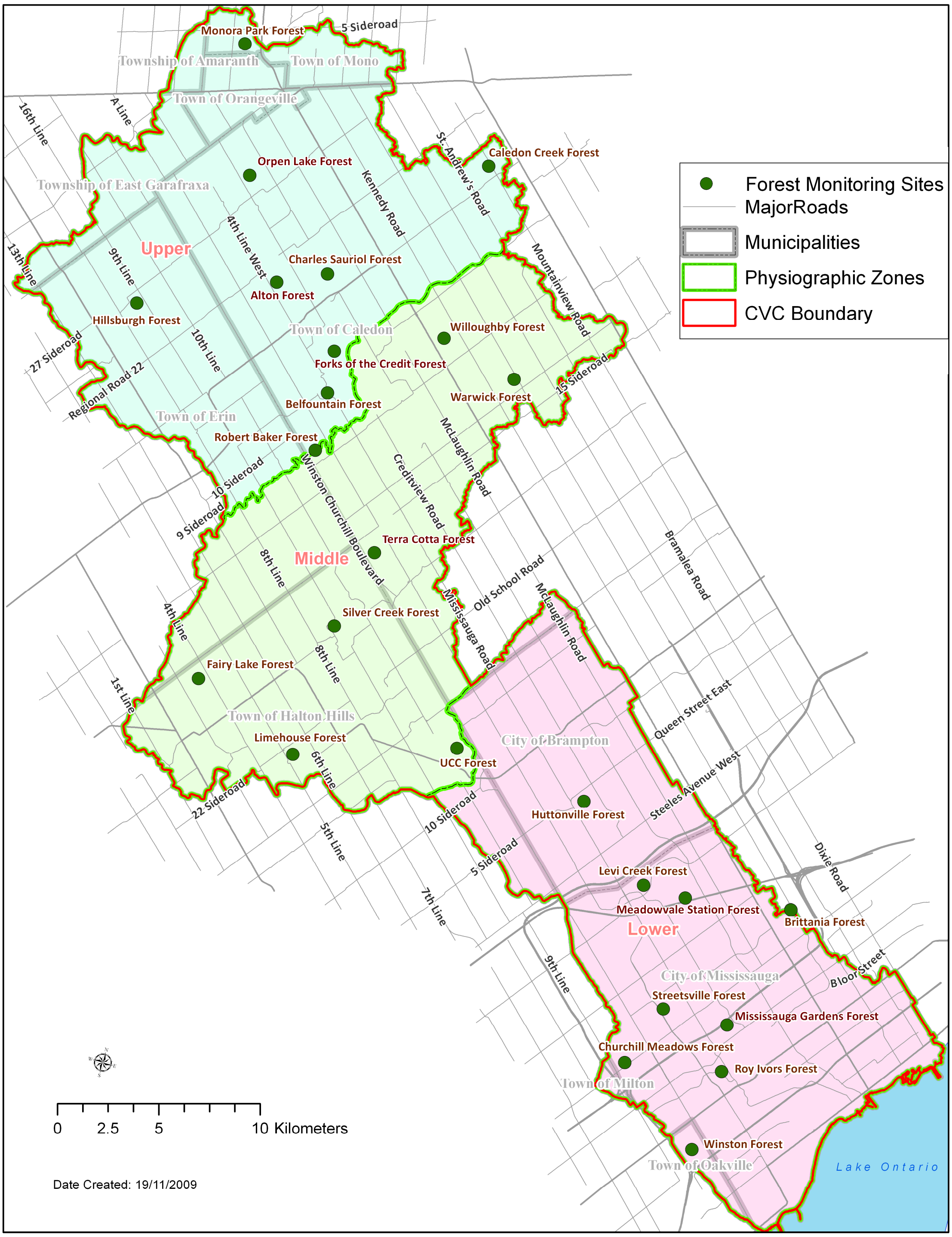


Figure 2. Forest monitoring sites in the Credit River Watershed.

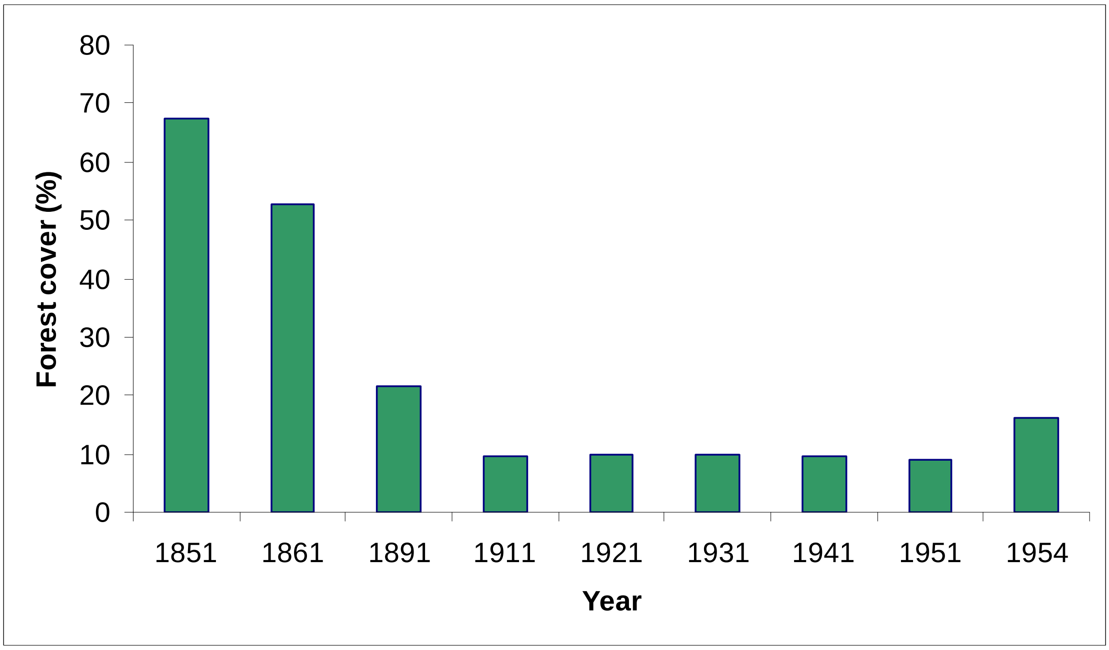


Figure 3. Estimated forest coverage in the Credit River Watershed from 1851-1954 (Credit Valley Conservation 1956).

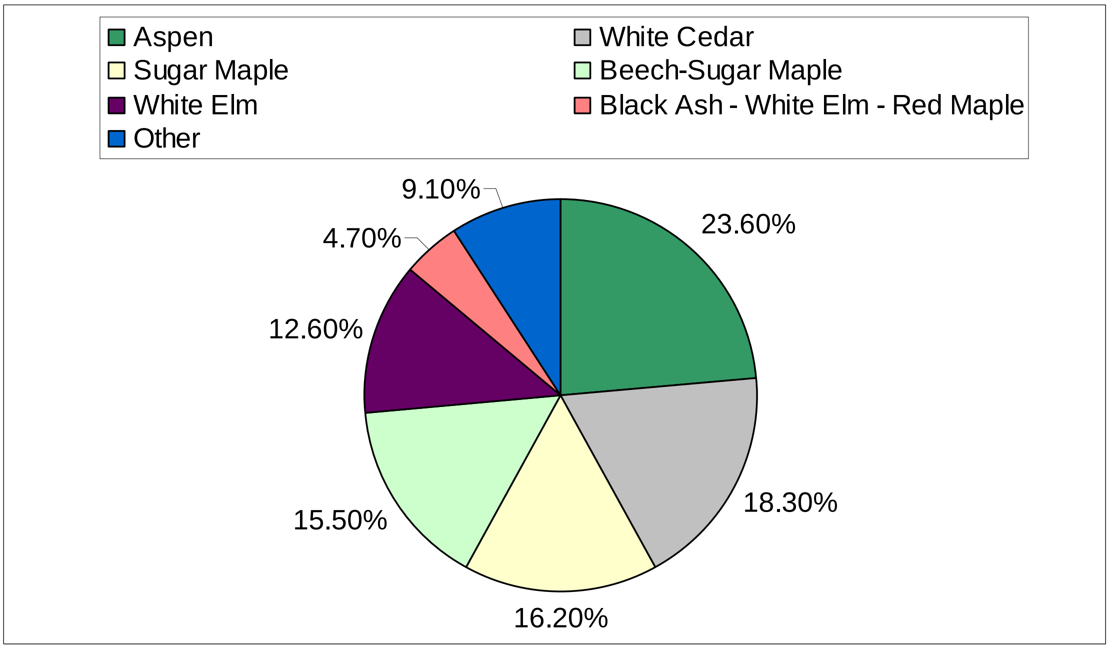


Figure 4. Forest cover types in the Credit River Watershed in 1954 (Credit Valley Conservation 1956).

The Middle zone contains the Niagara Escarpment, a landform comprised of steep slopes, rocky outcrops, and thin soil (Credit Valley Conservation 2005). Much of this zone is protected under the Greenbelt Plan (OMMAH 2005). The steep topography of this area leads to relatively high runoff volumes and velocities; however, high forest cover slows runoff and increases infiltration. Soils in this zone are variable as a result of the changing physiography between the Upper and Lower zones (Credit Valley Conservation 2007b). The east portion of this zone is underlain by Queenston Shale, whereas the west portion is underlain by dolomite of the Amabel/Lockport Formation. Surface geology is dominated by silt to clay tills and silty sand to sandy silt, with pockets of ice-contract stratified drift and bedrock or bedrock drift (Credit Valley Conservation 2007b). 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 till plains, moraines and glacial spillways (Credit Valley Conservation 2007b). This area is dominated by sandy loam soils that are associated with the Guelph drumlin field and the Hillsburgh Sandhills (Credit Valley Conservation 2007b). The high groundwater recharge rates in the Upper watershed are supported by the relatively high permeability rates of these soils. The Amabel/Lockport Formation is the dominant bedrock type in this area with pockets of the Guelph and Manitoulin dolostones (Credit Valley Conservation 2007b). Surficial geology is dominated by Ice-contact stratified drift, silty sand to sandy silt and galciofluvial gravel. Agricultural land use dominates portions of the Upper watershed, though it also contains several large wetland complexes and numerous headwater streams (Credit Valley Conservation 2007b).

Urbanization leads to both habitat loss and habitat fragmentation in forests (Lindenmayer and Franklin 2002). The population dynamics of species within fragmented forests are affected by four interrelated processes: habitat loss, subdivision of habitat, patch isolation and edge effects (Fig. 5). These processes can lead to weed invasions, the alteration of microclimate factors (e.g. wind speeds, light fluxes and temperature regimes), destabilization of population dynamics, increased vulnerability of populations to catastrophic events, alteration of gene frequencies in populations, disruption of ecological processes (e.g. pollination), and the increased potential for disturbance (e.g. windthrow) (Lindenmayer and Franklin 2002). Forests situated in urban landscapes have been shown to have 40% more introduced vegetation species compared to forests situated in natural or agricultural landscapes (Duguay et al. 2007). When forests are stressed the populations of opportunistic species increase; disturbance tends to favour communities dominated by rapidly reproducing, hardy species (Odum 1985).

Overall the extent and configuration of natural cover in the landscape can have the ability to alter ecosystem processes, nutrient availability, water availability, and dispersal. All of these changes can alter forest vegetation communities in the watershed. Therefore observed trends in forest vegetation will be considered in the context of the changing landscape of the Credit River Watershed.

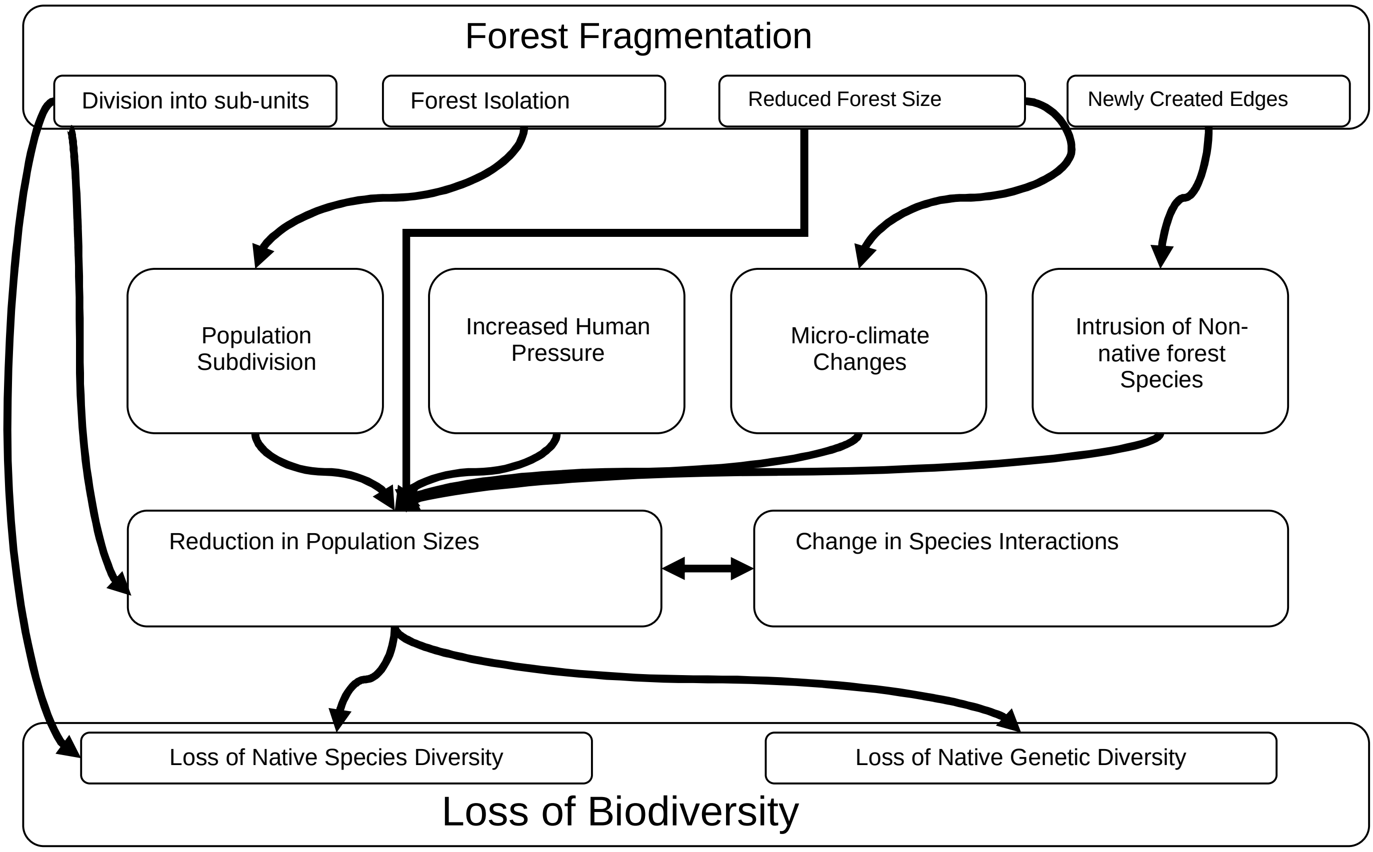


Figure 5. Graphical summary of the interacting effects of habitat loss and habitat fragmentation (after Lindenmayer and Franklin 2002).

1.5 OBJECTIVE: MONITORING FORMAT

Several measures of forest vegetation are currently being monitored to examine the ecosystem integrity of forest communities within the Credit River Watershed (Roy et al 2010). This report examines the integrity of the ground vegetation and regeneration layers using a variety of vegetation parameters, including: species richness, evenness and diversity, and measures of floristic quality (mean Coefficient of Conservatism [mCC], Floristic Quality Index [FQI], wetness and weediness). In addition, vegetation parameters were compared to several landscape measures because reliable indicators of ecosystem integrity are expected to be sensitive to anthropogenic disturbance (Noss 1999). Finally, several individual species were examined to determine if their presence was changing over time and to determine if they are sensitive to anthropogenic disturbance. The overall monitoring question being examined in this report is:

ARE INDICATORS OF HEALTHY FOREST VEGETATION IN THE CREDIT RIVER WATERSHED STABLE?

More specifically, 1) are species richness, diversity and evenness changing through time or spatially across the watershed; 2) does vegetation community similarity differ spatially or temporally through the watershed; 3) are indicators of floristic quality differing spatially or temporally throughout the watershed; 4) do any plant groups differ spatially or temporally through the watershed; 5) are there relationships between forest vegetation and landscape metrics in the watershed; and 6) are there relationships between selected forest vegetation species and landscape metrics in the watershed (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. Plant groups examined include the number of species with a low tolerance for disturbance (high conservatism scores [CC=8-10]), the number of locally and regionally rare species, and the number of potentially problematic weedy species (Weediness Score = -3) (See methods for details).

Table 1. Forest vegetation monitoring framework for the Credit River Watershed.

Monitoring Question	Monitoring Variable [a]	Unit of Measurement	Vegetation Layer [b]	Analysis Method
Trend Analyses				
Is species richness changing over time in the Credit River Watershed?	Number of species	Count	Combined vegetation Ground vegetation, Regeneration	- Linear Regression - Power Analysis
Is species diversity changing over time in the Credit River Watershed?	Shannon-Weiner Function	Index	Ground vegetation, Regeneration	- Linear Regression - Power Analysis
Are the number of regenerating trees changing over time in the Credit River Watershed?	Number of stems	Count	Regeneration	- Linear Regression - Power Analysis
Is the mean Coefficient of Conservatism changing over time in the Credit River Watershed?	Mean Coefficient of Conservatism value	Index	Combined vegetation	- Linear Regression - Power Analysis
Is the Floristic Quality Index changing over time in the Credit River Watershed?	Floristic Quality Index	Index	Combined vegetation	- Linear Regression - Power Analysis
Is the wetness index changing over time in the Credit River Watershed?	Mean wetness score	Index	Combined vegetation	- Linear Regression - Power Analysis
Temporal Analyses				
Did species richness differ among years in the Credit River Watershed?	Number of species	Count	Ground vegetation, Combined vegetation, Regeneration	- Repeated Measures ANOVA - Friedman Test
Did species diversity differ among years in the Credit River Watershed?	Shannon-Weiner Function	Index	Ground vegetation, Regeneration	- Repeated Measures ANOVA - Friedman Test
Did species evenness differ among years in the Credit River Watershed?	Simpson's Dominance Index	Index	Ground vegetation, Regeneration	- Friedman Test
Did the proportion of native species differ among years in the Credit River Watershed?	Proportion native species	Percent (%)	Ground vegetation, Combined vegetation, Regeneration	- Friedman Test
Did the number of regenerating trees differ among years in the Credit River Watershed?	Number of stems	Count	Regeneration	- Repeated Measures ANOVA

Monitoring Question	Monitoring Variable [a]	Unit of Measurement	Vegetation Layer [b]	Analysis Method
Temporal Analyses (Continued)				
Did the number of regenerating shrubs differ among years in the Credit River Watershed?	Number of stems	Count	Regeneration	- Friedman Test
Did the mean Coefficient of Conservatism differ among years in the Credit River Watershed?	Mean Coefficient of Conservatism value	Index	Combined vegetation	- Repeated Measures ANOVA
Did the Floristic Quality Index differ among years in the Credit River Watershed?	Floristic Quality Index	Index	Combined Vegetation	- Repeated Measures ANOVA
Did the mean wetness index differ among years in the Credit River Watershed?	Mean wetness score	Index	Combined vegetation	- Repeated Measures ANOVA
Did weedy species richness differ among years in the Credit River Watershed?	Number of weedy species	Count	Combined vegetation	- Friedman Test
Did the number of species with a weediness score of -3 differ among years in the Credit River Watershed?	Number of species with a weediness score of -3	Count	Combined vegetation	- Friedman Test
Spatial Analyses				
Did species richness differ among physiographic zones in the Credit River Watershed?	Number of species	Count	Ground vegetation, Combined vegetation, Regeneration	- Repeated Measures ANOVA - Power Analysis
Did total species diversity differ among physiographic zones in the Credit River Watershed?	Shannon-Weiner Function	Index	Ground vegetation	- Repeated Measures ANOVA - Power Analysis
Did species evenness differ among physiographic zones in the Credit River Watershed?	Simpson's Dominance Index	Index	Ground vegetation, Regeneration	- Kruskal-Wallis Test
Did the proportion of native species differ among physiographic zones in the Credit River Watershed?	Proportion native species	Percent (%)	Ground vegetation, Combined vegetation, Regeneration	- Kruskal-Wallis Test

Monitoring Question	**Monitoring Variable** [a]	**Unit of Measurement**	**Vegetation Layer** [b]	**Analysis Method**
Spatial Analyses (Continued)				
Did the number of regenerating trees differ among years in the Credit River Watershed?	Number of stems	Count	Regeneration	- Repeated Measures ANOVA - Power Analysis
Did the number of regenerating shrubs differ among years in the Credit River Watershed?	Number of stems	Count	Regeneration	- Kruskal-Wallis Test
Did the mean Coefficient of Conservatism differ among physiographic zones in the Credit River Watershed?	Mean Coefficient of Conservatism value	Index	Combined vegetation	- Repeated Measures ANOVA - Power Analysis
Did the Floristic Quality Index differ among physiographic zones in the Credit River Watershed?	Floristic Quality Index	Index	Combined vegetation	- Repeated Measures ANOVA - Power Analysis
Did the mean wetness index differ among physiographic zones in the Credit River Watershed?	Mean wetness score	Index	Combined vegetation	- Repeated Measures ANOVA - Power Analysis
Did weedy species richness differ among physiographic zones in the Credit River Watershed?	Number of weedy species	Count	Combined vegetation	- Repeated Measures ANOVA - Power Analysis
Did the number of species with a weediness score of -3 differ among physiographic zones in the Credit River Watershed?	Number of species with a weediness score of -3	Count	Combined vegetation	- Kruskal-Wallis Test

Monitoring Question	Monitoring Variable [a]	Unit of Measurement	Vegetation Layer [b]	Analysis Method
Landscape Analysis				
Were forest vegetation parameters correlated with landscape metrics in the Credit River Watershed?	All above vegetation parameters compared to habitat patch size, distance to the nearest road, % urban, % natural, % agricultural and matrix quality	Variable	Ground vegetation, Combined vegetation, Regeneration	- Spearman Rank Correlation
Species Level Analyses				
Was there a relationship between selected species and landscape metrics in the Credit River Watershed	Several selected species compared to habitat patch size, distance to the nearest road, % urban, % natural, % agricultural and matrix quality	Presence / Absence	Ground vegetation, Regeneration	- Logistic Regression
Did site occupancy of selected species change over time in the Credit River Watershed?	Proportion of sites occupied by several selected species	Percent (%)	Ground vegetation, Regeneration	- Cochrane-Armitage (trend analysis for proportions) - Power Analysis

[a] All monitoring variables were summarized for each individual site in each year across the monitoring period.
[b] Ground vegetation includes all herbaceous plants, woody vines, and shrubs and trees <16cm. Regeneration includes trees and shrubs ≥ 16cm and < 4cm in diameter at breast height (DBH). Combined vegetation includes data from both the ground vegetation and regeneration layers.

2.0 METHODS

2.1 FOREST HEALTH MONITORING

Twenty-five permanent forest monitoring sites were established in 2002 throughout the Credit River Watershed (Appendix A). These sites have been monitored annually for changes in vegetation, following modified plot-based methodologies developed by Environment Canada's Environmental Monitoring and Assessment Network (EMAN) and CVC. All vegetation parameters are measured annually or bi-annually at the monitoring sites. Forest monitoring sites consist of a 20x20 m plot used to monitor tree health and five subplots used to monitor ground vegetation and regeneration established within and around the 20x20 m plot (Fig. 6). The plots were oriented north-south with a minimum distance of three times the canopy height away from any forest edge. At each subplot a 1x1 m ground vegetation subplot was nested within a 2x2 m regeneration subplot, which shares the same centre point. Additional parameters such as downed woody debris, salamanders, decomposition, breeding bird surveys and soil temperature, moisture and chemistry are also measured in proximity to the established forest plots.

2.1.1 Ground Vegetation

At each 1x1 m monitoring subplot, species identification was recorded for all herbaceous vegetation (forbs, grasses, sedges, ferns) and trees and shrubs with a height of <16cm. Each species was also assigned to one of the following cover classes: <1%, 1-5%, 6-15%, 15-30%, 31-50%, 51-75% and 76-100%. In 2008, methodology was revised for assessing forest vegetation abundance from "percent cover" classes to the actual percent cover a species occupies in a subplot. This was done to enable better analysis of data as the cover classes were found to be too coarse to yield meaningful statistical results. However, for analysis in this report, 2008 and 2009 percent cover data was reassigned to the appropriate cover class for consistency in data presentation across all years. Ground vegetation was monitored bi-annually, in spring and late summer, to ensure accurate identification of species and to capture plants blooming throughout the season. Methodology follows standardized EMAN protocol (Roberts-Pichette and Gillespie 1999).

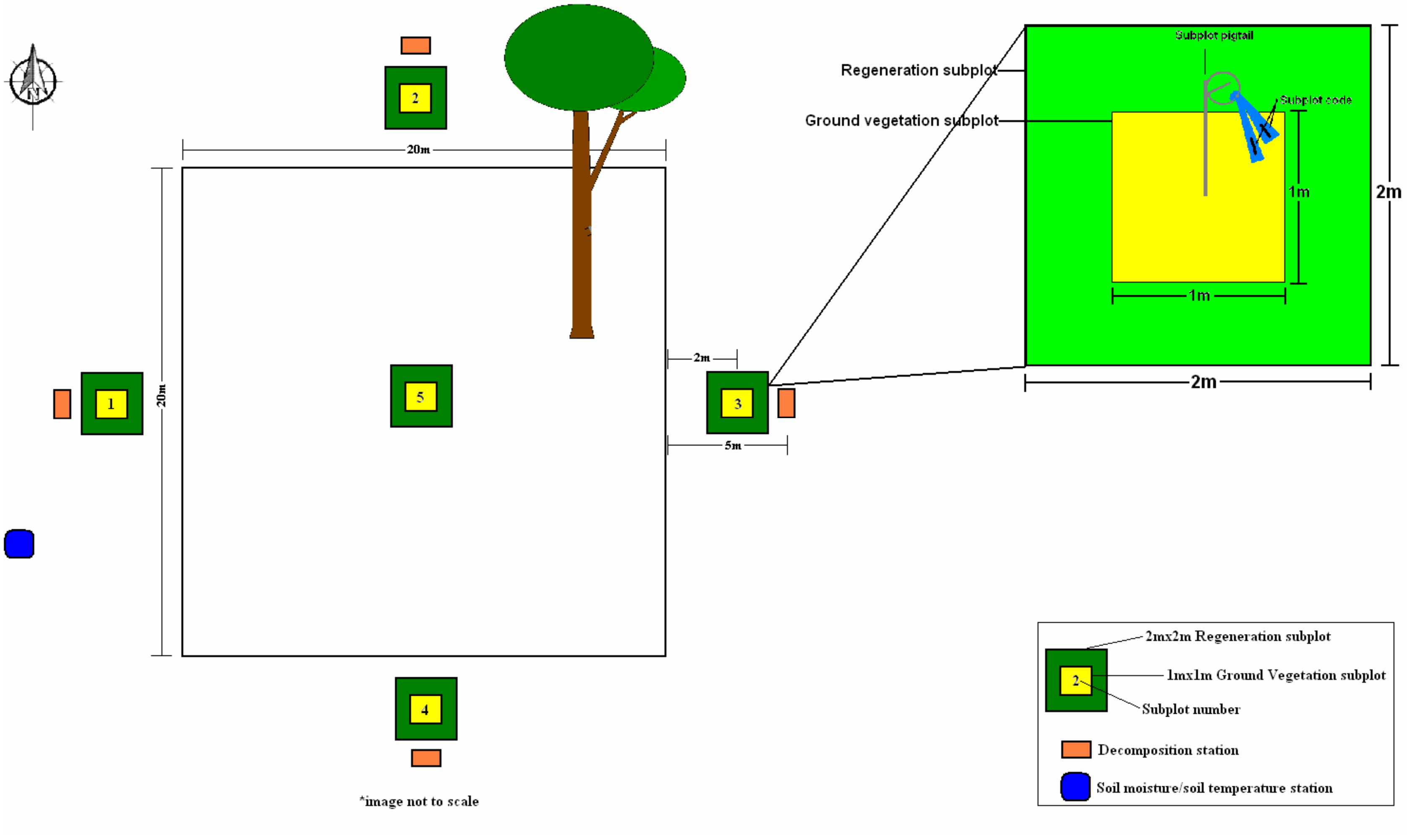


Figure 6. Forest monitoring site layout.

2.1.2 Regeneration

As a measure of forest succession, regeneration monitoring provides insight into what trees will comprise the future forests of the Credit River Watershed. Regeneration is monitored annually during mid summer. Following modified EMAN protocols, tree and shrub stems ≥16cm in height and <4cm Diameter at Breast Height (DBH) originating within each subplot were identified to species, counted and placed in one of six height categories (16-35cm, 36-55cm, 56-75cm, 76-95cm, 96-200cm and >200cm). The six height categories were monitored to identify potential stresses on seedling and sapling development that target different stages of development (e.g. excessive deer browse vs. competition for nutrients and water) (Sajan 2000).

2.2 DATA PREPARATION

Forest ground vegetation and regeneration data collected between 2005 and 2009 were included in the analyses. All vascular plants identified to species were included in the dataset. Although non-vascular plants also provide valuable information about ecosystem health, due to resource constraints and the specialized knowledge required for their identification only vascular plants were included in analyses. Therefore, any observations of mosses, liverworts and algae were removed from the dataset. Plants identified to genus were included in a grouping if no other plant of that genus was identified to species within the group in question, unless otherwise noted below. These genus-only records were included to provide an accurate representation of the number of species within a site, even if species-level identification was not possible.

Woody species excluded from the regeneration survey included woody vines such as Poison Ivy (*Toxicodendron radicans ssp. negundo*) and woody species that do not have the potential to contribute to the dominant canopy layer in the future, such as Running Strawberry Bush (*Euonymus obovatus*). A complete list of all woody species not included in the regeneration analyses is presented in Table 2. These species were instead included in the ground vegetation analyses.

Table 2. List of woody species removed from the regeneration analyses.

Scientific Name	Common Name
Celastrus scandens	American Bittersweet Vine
Euonymus obovatus	Running Strawberry Bush
Lonicera hirsuta	Hairy Honeysuckle
Parthenocissus inserta	Thicket Creeper
Rubus pubescens	Dwarf Red Raspberry
Solanum dulcamara	Climbing Nightshade
Toxicodendron radicans ssp. negundo	Poison Ivy
Vitis riparia	Riverbank Grape

2.2.1 Vegetation Parameters

Data summaries were conducted for several vegetation parameters described below. Data were summarized for the ground vegetation and regeneration layers separately, as well as for combined vegetation that incorporates data from both the ground vegetation and regeneration layers.

2.2.1.1 Most Common Species: Lists of the most common species in the watershed were developed using only plants identified to species level. The lists were determined by summing the total number of monitoring sites in which each species was observed per year, regardless of the abundance of the species at each site.

2.2.1.2 Species Richness: Richness was calculated by counting the number of unique vegetation species identified watershed-wide, and at each site per year (Table 3). In addition, the proportion of native species (combined and ground vegetation) was determined watershed-wide, and at each site per year. Proportion of native species was calculated using plants identified to species-level, as:

$$\mathbf{P} = \frac{\mathbf{N}}{\mathbf{T}}$$

Where P = Proportion of native species
N = Number of native species
T **= Total number of species (native + non-native).**

2.2.1.4 Species Diversity: Vegetation species diversity in the Credit River Watershed was calculated using the Shannon-Wiener Function:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where H' = Index of species diversity
s = Number of species
p_i = Proportion of total sample belonging to ith species determined by percent cover

Diversity values at each monitoring site were calculated separately for ground vegetation and regeneration species. Diversity was calculated separately for each subplot, and then averaged to obtain the diversity score for each site. p_i was calculated using the same method described above for evenness. Diversity for each subplot was then calculated using the formula described above.

It is important to note that for ground vegetation, because p_i was calculated using percent cover, opposed to abundance, H' values in this study cannot be compared to other Shannon diversity indices for vegetation within the literature. In a community with only one species $H' = 0$. As H' increases, communities increase in diversity (Krebs 1999). This index was calculated for each site per year.

Table 3. Summary of temporal and spatial analyses used for vegetation parameters within the Credit River Watershed.

Vegetation Parameters	Parametric Trend Analysis	Parametric Temporal and Spatial Analyses	Non-Parametric Temporal and Spatial Analyses
Ground Vegetation			
Total Species Richness	X	X	
Woody Species Richness		X	
Herbaceous Species Richness		X	
Total Species Evenness			X
Total Species Diversity	X	X	
Proportion of Native Species Richness			X
Regeneration			
Total Species Richness	X	X	
Tree Species Richness	X	X	
Shrub Species Richness	X	X	
Species Evenness			X
Species Diversity	X	X	
Proportion of Native Species			X
Shrub Stem Count – All			X
Shrub Stem Count – 16-95cm			X
Shrub Stem Count – >95cm			X
Tree Stem Count – All	X	X	
Tree Stem Count – 16-95cm	X	X	
Tree Stem Count – >95cm	X	X	
Combined Vegetation[a]			
Species Richness	X	X	
Proportion of Native Species Richness			X
Mean Wetness Index	X	X	
mCC[b]	X	X	
FQI[b]	X	X	
Total Weediness Score			X
Weediness -3 Species			X

[a] Combined vegetation incorporates both ground vegetation and regeneration layers
[b] mCC = mean Coefficient of Conservatism; FQI = Floristic Quality Index

2.2.1.5 Regeneration Stem Count: The number of regenerating stems was analyzed separately for shrubs and trees, as they have different functions in the canopy of the future forest. The total number of stems was summarized for each site, per year. In addition, the number of stems 16-95cm and the number of stems >95cm in height were also summarized, as small stems are expected to be under greater threat from mortality than larger stems.

2.2.1.6 Floristic Quality Assessment: Plants can reflect the quality or condition of an ecosystem. This relationship between vegetation and site quality was assessed using the Ontario Ministry of Natural Resources Floristic Quality Assessment System for southern Ontario (Oldham et al. 1995). This system assigned each vegetation species known to occur in southern Ontario several values, including a wetness index, coefficient of conservatism and weediness score. Each index is based on species habitat requirements and these scores were used to calculate several vegetation parameters described below.

Wetness Index

Mean wetness index was calculated for each site using the species specific wetness values listed in the Floristic Quality Assessment System for Southern Ontario (Oldham et al. 1995). Wetness values were assigned to species based on their requirement for wet habitats on a scale of -5 (obligate wetland) to 5 (obligate upland). The mean wetness index was calculated by averaging the wetness scores for each species detected at a given site, per year.

Coefficient of Conservatism

Coefficient of Conservatism (CC) scores have been assigned to native vegetation species in the Floristic Quality Assessment System for Southern Ontario (Oldham et al. 1995), and are based on a species tolerance to disturbance and habitat fidelity. These scores were used to calculate three vegetation parameters, including the mean Coefficient of Conservatism (mCC), Floristic Quality Index (FQI) and the number of species with CC values of 8-10. Coefficient of Conservatism scores for each species range from 0 (low conservatism) to 10 (high conservatism). A conservatism value of 8, 9 or 10 indicates that a species is a habitat specialist (Ontario Ministry of Natural Resources 2008). Mean Coefficient of Conservatism was calculated by averaging the CC scores for each species detected at a given site. In addition to mCC, the total number of species with a CC value of 8-10 was also calculated for each site. Finally, the Floristic Quality Index was calculated as follows:

$$\mathbf{FQI = mCC} \times \sqrt{\mathbf{N}}$$

where mCC is the mean Coefficient of Conservatism and N is native species richness.

Mean Coefficient of Conservatism and FQI are both measures of the floristic integrity of a given site. Mean Coefficient of Conservatism is solely based on the habitat requirements of detected species, whereas FQI incorporates species richness into its calculation. Both parameters are useful for examining vegetation integrity, as a site with a high FQI may have a low mCC value and vice versa. For example, a relatively degraded site may have a high FQI value if a large number of disturbance-tolerant native species are present (Taft et al. 1997). Given that mCC and FQI have the potential to rank sites differently, it is important to consider both when examining the overall quality of a given location. Mean Coefficient of Conservatism, FQI and CC 8-10 were calculated for each individual site, per year.

Weediness Score

Weediness was evaluated using the weediness scores provided for non-native species in the Floristic Quality Assessment System for Southern Ontario (Oldham et al. 1995). Weediness scores have been assigned to all non-native species and range from -1 (low impact of the species on natural areas) to -3 (high impact of the species on natural areas). Weedy species richness was calculated for each site by totalling the number of species with a weediness score of either -1, -2 or -3 at a given site. Also, in order to quantify the impact of non-native species that may have serious effects on natural areas in the watershed, the total number of species with a weediness score of -3 was calculated. These weediness parameters were calculated for each individual site, per year.

2.2.1.7 Locally and Regionally Rare Species: In order to understand the composition of rare species within the watershed, the number of both locally and regionally rare species was determined using plants identified to species-level watershed-wide and at each site per year. Local and regional rareness designations were based on Kaiser (2001). The criteria used for determining if a plant was locally or regionally rare were as follows:

- Locally Rare - a species that occurred fewer than 10 times in the Region of Peel (Kaiser 2001).
- Regionally rare - a species that occurred fewer than 40 times in the Greater Toronto Area

2.2.1.8 Community Similarity: Vegetation community change was calculated with plants identified to species-level using Jaccard's Similarity Index (Krebs 1999):

$$S_j = \frac{a}{a + b + c}$$

Where S_j = Jaccard's similarity coefficient
a = number of species in year 1 and year 2 (joint occurrences)
b = number of species in year 2 but not in year 1
c = number of species in year 1 but not year 2

Jaccard's Similarity Index is a calculated value used to compare species composition between two samples or locations. The index was calculated watershed-wide for the combined vegetation data for 2005 vs. 2006, 2006 vs. 2007, 2007 vs. 2008, 2008 vs. 2009 and 2005 vs. 2009. In addition, Jaccard's Similarity Index was also determined across all years between the physiographic zones, including Lower zone vs. Middle zone, Lower zone vs. Upper zone, and Middle zone vs. Upper zone.

2.3 STATISTICAL ANALYSES

2.3.1 Trend and Temporal Analyses

Population trends between 2005 and 2009 were analyzed using linear regression in STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $p<0.05$. Prior to analyses, data were tested for normality and homogeneity of variance using the Shapiro-Wilks test and Levene's test, respectively. If required, data were transformed in order to improve normality and homogeneity (Appendix B). Trend analysis was completed for the vegetation parameters indicated in Table 3. Trends could not be determined in the species evenness or the proportion of native species parameters due to the ordinal nature of the data, which necessitated the use of non-parametric tests (McDonald 2009). The number of regeneration shrub stems, weedy species richness and weediness count -3 were analyzed with non-parametric methods due to the large numbers of zeros in these datasets. Too few species were detected at each site to analyze the number of locally rare species, regionally rare species, and species with CC values of 8-10.

In addition, data were also examined to determine if differences occurred between years. Differences between years were determined with either the parametric repeated measures ANOVA (Analysis of Variance) or the non-parametric Friedman test, depending on the parameter. Although a one-way ANOVA would have been sufficient to test for differences between years, the repeated measures ANOVA was used because this test was already being used to determine spatial differences in the data and provided equivalent temporal comparisons to a one-way ANOVA. Tukey's test for unequal sample sizes was used for post-hoc comparisons when significant differences were detected between years with a repeated measures ANOVA. In lieu of post-hoc analysis, which is not available for the Freidman test, differences between groups were inferred through visual examination of the data.

A select group of forest vegetation species were also examined for trends using the Cochrane-Armitage test (Agresti 2002) in XLStat (Addinsoft). This test is often used to examine linear trends in binomial proportions of response across increasing levels of dosage in medical studies. In this study the test has been used to examine if proportional site occupancy of species was increasing or decreasing over time. Vegetation species chosen for this analysis were selected due to interest in a species distribution and the suitability of its distribution for the required statistical tests. Species were considered for selection if they were of some interest to the program either because they were non-natives, uncommon in the watershed or a common native plant. In addition, the species' distribution needed to be appropriate as the statistical analyses would not be meaningful if the species were present at very few or almost all of the sites. Based on the preceding criteria, ground vegetation species examined included: Garlic Mustard, Canada Mayflower (*Mainanthemum canadense*), Brown-seed Dandelion, and Trillium species (*Trillium spp.*). In addition, two regeneration species were examined: White Ash and Common Buckthorn (*Rhamnus cathartica*).

2.3.2 Spatial 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.

Data were analyzed with STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $p<0.05$ (Zar 1999). Data were tested for normality and homoscedasticity using Shapiro-Wilks and Levene's test for homogeneity of variance, respectively. If required, data were transformed in order to improve normality and homogeneity of the residuals (Appendix B). Where variances could not be normalized, the equivalent non-parametric test was used to complete analyses. Tukey's test for unequal sample sizes was used for post-hoc comparisons in order to compensate for the larger number of sites in the Lower zone compared to the Middle and Upper zones (Zar 1999).

The Kruskal-Wallis test was conducted on annual data sets to identify differences among the three physiographic zones for the non-normalized data. This is a non-parametric version of a one-way ANOVA in which treatment levels of an independent variable (e.g. physiographic zone) are independent of one another. Zone effects were analysed on a year by year basis because Kruskal-Wallis cannot account for year effect when all survey years are used in the same analysis. An associated post-hoc test was subsequently run to determine which zone relationships were significant.

2.3.3 Landscape Analysis

To increase understanding of the relationships between forest vegetation populations and the landscape which surround them, Spearman Rank correlations were used to determine if monotonic associations exist between vegetation parameters and landscape metrics. Monotonic associations are instances where one variable increases or decreases with the other variable but not necessarily in a linear manner. Correlations were run pairing the mean of each vegetation parameter across the monitoring period (parameters listed in Table 3), to habitat patch size, distance to nearest road, matrix quality, and finally percent agriculture, natural and urban area within a 2km radius. Landscape parameters were based on orthophotography collected between 2005 and 2007 over the Credit River Watershed. Aerial photographs were interpreted and analysed using ArcGIS, a software package capable of generating information on patterns, structure, and change within a landscape (Credit Valley Conservation 2007a).

Spearman Rank correlations were completed using STATISTICA 7.0 (Statsoft Inc.), with results considered significant when $p<0.05$. Habitat patch size and distance to the nearest road were included as metrics in the analysis as research has shown that they both tend to negatively affect vegetation communities (Findlay and Houlahan 1997; Hooftman and Diemer 2002). A radius of 2km was chosen for the scope of the above landscape composition parameters because Findlay and Houlahan (1997) found that landscape effects on wetland taxa richness were strongest when considering landscape composition at this distance. In addition, this distance has been used in other monitoring studies to examine matrix influence, as it is the distance within which most species dispersal can be expected for most floral and faunal species (Toronto and Region Conservation Authority 2007).

Habitat patch is defined as a continuous patch of natural land cover in a given area, in which the monitored forest area is included, and is comprised of forests, wetlands and successional communities. A 30m buffer was developed around the centre of the monitoring site, and the percentage of natural, urban and agricultural land use was calculated within a 2km radius from the edge of the buffer. Finally, matrix quality is an index developed to account for the amount of varying types of land uses in an area, with higher matrix quality values indicating more natural land cover in the area. Matrix influence is calculated by summing percent natural area multiplied by positive one, with percent agricultural area multiplied by zero, and percent urban area multiplied by negative one (Toronto and Region Conservation Authority 2007).

In addition, relationships were examined between selected species at each site and selected landscape metrics. Relationships were examined using simple logistic regression with one continuous predictor. Though still considered a parametric option, logistic regression is a non-linear estimation method in which the binary response variable is assumed to follow a binomial distribution (Quinn and Keough 2002). The assumptions of normality and homoscedasticity do not apply as with linear regression. For logistic regression, tests were performed between the site occupancy (presence/absence) of selected species and landscape metrics. A site was considered occupied if the species in question was detected in at least two of the five survey years. Species examined include: Brown-seed Dandelion, Canada Mayflower, Garlic Mustard and Trillium species. Brown-seed Dandelion and Garlic Mustard are of interest because they are examples of commonly encountered non-native species in the watershed, with Dandelion being moderately invasive (Weediness Score -2) and Garlic Mustard being a potentially problematic species (Weediness Score -3). In contrast, Canada Mayflower and Trillium species (*Trillium grandiflorum* and *T. erectum*), are commonly encountered native species in the watershed, which are more likely to be found in high quality habitats than degraded areas.

2.3.4 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.).

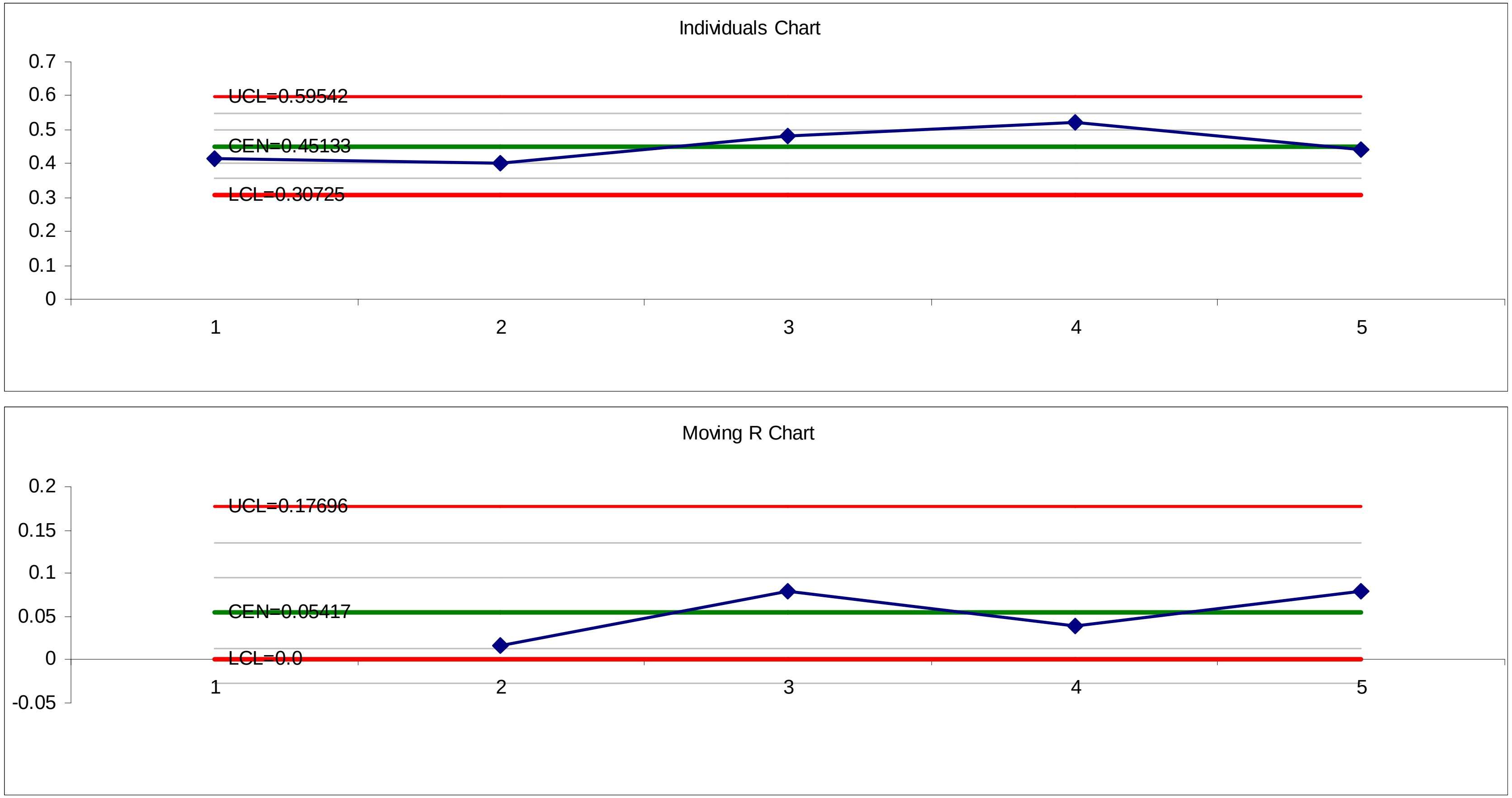


Figure 7. Statistical Process Control charts for Weedy Species Richness. Both the individual moving average chart (showing the parameter values for each year) and the Moving Range chart (showing the amount of change in the parameter between years) are "in control" from 2005 to 2009. The green line indicates 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.

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 (Fig. 7) (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 vegetation 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 recognise 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.

2.3.5 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 vegetation parameters. Power analysis also assessed the ability of the current monitoring program to detect statistical differences in forest vegetation parameters among physiographic zones and among years, given the number of established monitoring sites. 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. 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. Changes in a parameter of ± 3 SD represent instability and situations in which causal factors must be investigated. 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. Currently, five years of in control data are being used to determine the five year effect size.

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 analysis. These results were used to determine the quality of current monitoring data. Data quality was assessed according to Table 4, developed by Dobbie et al. (2006) and CVC.

Although these rules are subjective, they are not arbitrary and are based on emerging common practice among conservation agencies, personal experience, and logistical considerations (Dobbie et al. 2006). For linear regression, the upper effect size limit (data are “red”) is set to 40% because changes above this point are too coarse to provide early warning of decline in a parameter (Dobbie et al. 2006). The lower effect size limit (data are “green”) is set to 20% because a smaller effect size is too fine and would likely result in an unaffordable monitoring program. An effect size of less than 20% may be reasonable for some parameters, but this is likely not the case for all monitored parameters. And although smaller effect sizes may allow for the detection of significant differences more often, without knowledge regarding natural variability in the parameter it may be difficult to determine if these changes are meaningful (Dobbie et al. 2006). It is important to note that the data quality rules developed by Dobbie et al. (2006) were set according to power analysis of a paired *t*-test. This test does not reflect changes in trends but changes in status and usually requires a smaller sample size to achieve the same power and confidence as a regression test (Dobbie et al. 2006). Therefore, data quality assessment is appropriate, if not more stringent than necessary, for analyses completed in this report.

Table 4. Rule set for assessing data quality in monitoring measures (adapted from Dobbie et al. 2006).

Data Quality	**Effect size**			**Confidence**	**Power**
	Linear Regression	**Cochrane-Armitage**	**Logistic Regression**		
Green	<20% change	<2 SD	Currently have enough sites to detect a significant relationship	80%	90%
Yellow	>20% <40% change	2-3 SD	N/A	80%	90%
Red	>40% change	>3 SD	Currently do not have enough sites to detect a significant relationship	80%	90%

For the Cochrane-Armitage test, percent change effect sizes could not be calculated; therefore, SD was used to determine data quality instead (Table 4). The upper effect size limit (data are red) is set to 3 SD because that is the critical warning limit in statistical process control. Therefore, data in this quality range are not capable of detecting the most important ecological changes. The lower effect size limit (data are green) is set to <2 SD because 2 SD is the early warning limit in statistical process control. Data in this quality range can therefore detect both early and critical warming limits and should be able to provide managers with necessary information for making informed management decisions. 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 (e.g. requires a smaller sample size) to detect a 2 SD change in mortality when the underlying variability of the mortality data is high. If variability was low, 2 SD would represent a very small change in proportion. Smaller changes are innately more difficult to detect than larger changes over the same time period.

Currently, no type of effect size could be calculated for logistic regression. For that reason, two data quality groupings were developed for this analysis. Data were considered green if enough site-years were available to detect a significant logistic relationship between parameters. Data were considered red if not enough site-years were available to detect a significant logistic relationship between parameters. No yellow data category was used.

Confidence and power levels are also subjectively, but not arbitrarily, selected. Although research standards typically set confidence to 95% and power to 80%, this may not be appropriate for ecological monitoring (Dobbie et al. 2006). Confidence refers to the probability of not committing a Type I statistical error. In ecological monitoring, this may be considered a “false alarm”. Power refers to the probability of not making a Type II error, which may be considered a “missed signal”. In ecological monitoring, missing a signal has more severe management implications than raising a false alarm. For that reason, power is usually set higher than confidence in this type of monitoring (Dobbie et al. 2006).

3.0 RESULTS AND DISCUSSION

3.1 DESCRIPTIVE RESULTS

3.1.1 Most Common Species

Monitoring Question: What vegetation species were most commonly encountered in the Credit River Watershed?

- The most common forest vegetation species in the Credit River Watershed were: Alternate-leaf Dogwood, Canada Mayflower, Choke Cherry, Garlic Mustard, Intermediate Enchanter's Nightshade, Jack-in-the-Pulpit, Sugar Maple, White Ash, Wild Black Cherry, and Yellow Trout-lily

The ten most common combined forest vegetation species across all years are presented in Table 5 in descending order. Most of these species are native to Ontario, and span a large range of wetness values, from facultative wetland species to obligate upland species (-2 to +5). They also occupy a range of Conservation Coefficients, between 2 and 6, indicating that they tolerate major to mild disturbance.

One of the most common species, Canada Mayflower (*Maianthemum canadense*), is a Species of Urban Interest. This designation is specific to Credit Valley Conservation, which has ranked species inhabiting the watershed according to their sensitivity to environmental change and disturbance. Species in the watershed may be ranked as Species of Conservation Concern (SoCC; Tier 1), Species of Interest (SoI; Tier 2), Species of Urban Interest (SoI; Tier 3), Secure (Tier 4) or Non-native (Tier 5). Species of Conservation Concern are designated at risk either federally and/or provincially or are provincially rare according to Ontario Ministry of Natural Resource's Natural Heritage Information Centre. According to a draft version of the ranking, a total of 87 species in the Credit River Watershed have been designated SoCC to date. Species of Interest are either uncommon in the watershed and/or have exhibited a significant population decline in the past 25 years. Finally, Species of Urban Interest are exhibiting some form of decline within urban areas due to some sensitivity, but are thought to be relatively secure in more natural environments.

When the ground vegetation layer was examined alone, the most common forest vegetation species remains similar, with the exception that and Blue Cohosh (*Caulophyllum thalictroides*) and Brown-seed Dandelion (*Taraxacum officinale*) replace Alternate-leaf Dogwood (*Cornus alternifolia*) and Wild Black Cherry (*Prunus serotina*) as the ninth and tenth most common species across the watershed (Table 6). Blue Cohosh has been designated by CVC as a Species of Interest.

The five most common non-native forest vegetation species across all years were Garlic Mustard, Brown-seed Dandelion, Herb-robert (*Geranium robertianum*), Climbing Nightshade (*Solanum dulcamara*), and Common Buckthorn (Table 7). In 2009, Credit Valley Conservation ranked priority invasive vegetation species into five categories. Species in Category 1, or Transformer species, have the ability to exclude all other species, dominate sites indefinitely and provide a threat to natural areas. Category 2 consists of Highly Invasive Species, which tend to dominate certain niches or that are problematic but do not spread rapidly from major concentrations. These species can persist in dense populations for long periods. Category 3 consists of Moderately Invasive species that can become locally dominant under specific conditions. Category 4 species are considered Minimally Invasive, and do not pose an immediate threat to natural areas but compete with native species. Finally, Category 5 species are Potentially Invasive, and are known to reproduce aggressively on occasion, but have not yet posed a serious threat to natural areas in Ontario (Credit Valley Conservation 2009).

Of the most common non-native species recorded in the surveys, Garlic Mustard and Common Buckthorn are both considered Transformer species, and have a weediness score of -3 according to the Floristic Quality Assessment System for Southern Ontario (Oldham et al. 1995). Unlike many other herbaceous invasive species, Garlic Mustard is a biennial forb that is shade tolerant and capable of thriving in forest understory. Community disturbance is also not required for Garlic Mustard to become established at a site (Rodgers et al. 2008). In addition, Garlic Mustard produces a variety of secondary compounds that make it unpalatable to many herbivores, affect seed germination and growth of surrounding native plants, and alter the activity of soil biota (Rodgers et al. 2008). Common Buckthorn has many physiological traits which confer advantages over native species. Common Buckthorn is shade tolerant, has rapid growth rates and high photosynthetic rates (Knight et al. 2007). It also has a large range of habitat tolerances, high fecundity, high germination rates, grows well in drought and moisture rich environments, and bird dispersal of fruit which allows the shrub to spread rapidly and successfully (Knight et al. 2007). Climbing Nightshade is considered a Moderately Invasive species by CVC, as it is known to invade forests and wetlands. Brown-seed Dandelion and Herb-robert have not been ranked by CVC, but are considered -2 species by the Floristic Quality Assessment System.

The ten most common forest regeneration species across all years are presented in Table 8 in descending order. The most common species are a mixture of trees and shrubs, all of which are native to Ontario. Wetness values ranged from -3 to 5 and CC values ranged from 2 to 6. Both American Beech and Balsam Fir (*Abies balsamea*) are classified as Species of Urban Interest.

Table 5. The ten most common combined vegetation species across all years in the Credit River Watershed. [a]

Common Name	Scientific Name	Native	Wetness Index	SCC Tier	CC Value	Plant Type	Mean # of Sites per Year [b]
Sugar Maple	*Acer saccharum ssp. saccharum*	Native	3	4	4	Tree	23.8
Yellow Trout-lily	*Erythronium americanum ssp. americanum*	Native	5	4	5	Forb	19.4
White Ash	*Fraxinus americana*	Native	3	4	4	Tree	17.6
Choke Cherry	*Prunus virginiana ssp. virginiana*	Native	1	4	2	Shrub	13.8
Canada Mayflower	*Maianthemum canadense*	Native	0	3	5	Forb	13
Jack-in-the-pulpit	*Arisaema triphyllum*	Native	-2	4	5	Forb	12.8
Intermediate Enchanter's Nightshade	*Circaea lutetiana ssp. canadensis*	Native	3	4	3	Forb	10.2
Garlic Mustard	*Alliaria petiolata*	Non-native	0	5	NA	Forb	9.8
Alternate-leaf Dogwood	*Cornus alternifolia*	Native	5	4	6	Shrub	9.6
Wild Black Cherry	*Prunus serotina*	Native	3	4	3	Tree	8.2

[a] Combined vegetation includes data from both the ground vegetation and regeneration layers.
[b] 25 forest sites were monitored between 2005 and 2009.

Table 6. The ten most common ground vegetation species across all years in the Credit River Watershed.

Common Name	Scientific Name	Native	Wetness Index	SCC Tier	CC Value	Plant Type	Mean # of Sites per Year [a]
Yellow Trout-lily	*Erythronium americanum ssp. americanum*	Native	5	4	5	Forb	19.4
Sugar Maple	*Acer saccharum ssp. saccharum*	Native	3	4	4	Tree	17
Canada Mayflower	*Maianthemum canadense*	Native	0	3	5	Forb	13
Jack-in-the-pulpit	*Arisaema triphyllum*	Native	-2	4	5	Forb	12.8
White Ash	*Fraxinus americana*	Native	3	4	4	Tree	10.4
Intermediate Enchanter's Nightshade	*Circaea lutetiana ssp. canadensis*	Native	3	4	3	Forb	10.2
Garlic Mustard	*Alliaria petiolata*	Non-native	0	5	NA	Forb	9.8
Choke Cherry	*Prunus virginiana ssp. virginiana*	Native	1	4	2	Shrub	8
Blue Cohosh	*Caulophyllum thalictroides*	Native	5	2	6	Forb	6.8
Brown-seed Dandelion	*Taraxacum officinale*	Non-native	3	5	NA	Forb	6.6

[a] 25 forest sites were monitored between 2005 and 2009.

Table 7. Non-native forest vegetation species detected in the Credit River Watershed between 2005 and 2009, from most to least common.

Common Name	Latin Name	CVC Invasive Priority Category	Wetness Index	Weediness Score	Mean # of Sites per Year [a]
Garlic Mustard	*Alliaria petiolata*	1	0	-3	9.8
Brown-seed Dandelion	*Taraxacum officinale*	NA	3	-2	6.6
Herb-robert	*Geranium robertianum*	NA	5	-2	4.4
Climbing Nightshade	*Solanum dulcamara*	3	0	-2	2.2
Common Buckthorn	*Rhamnus cathartica*	1	0	-3	1.8
Eastern Helleborine	*Epipactis helleborine*	NA	5	-2	1.6
Manitoba Maple	*Acer negundo*	1	-2	NA	1.2
Woods Bluegrass	*Poa nemoralis*	NA	0	-1	1
Stinging Nettle	*Urtica dioica ssp. dioica*	3	-1	-1	1
Gypsy-weed	*Veronica officinalis*	NA	5	-2	1
Yellow Hawkweed	*Hieracium caespitosum*	3	5	-2	0.8
Tall Buttercup	*Ranunculus acris*	NA	-2	-2	0.4
European Columbine	*Aquilegia vulgaris*	NA	3	-1	0.2
Common Burdock	*Arctium minus ssp. minus*	NA	5	-2	0.2
Brittle-stem Hempnettle	*Galeopsis tetrahit*	NA	5	-1	0.2

[a] 25 forest sites were monitored between 2005 and 2009.

Table 8. The ten most common regeneration species across all years in the Credit River Watershed.

Common Name	**Scientific Name**	**Native**	**Wetness Index**	**SCC Tier**	**CC Value**	**Plant Type**	**Mean # of Sites per Year** [a]
Sugar Maple	*Acer saccharum ssp. saccharum*	Native	3	4	4	Tree	22.4
White Ash	*Fraxinus americana*	Native	3	4	4	Tree	15.2
Choke Cherry	*Prunus virginiana ssp. virginiana*	Native	1	4	2	Shrub	13.4
Alternate-leaf Dogwood	*Cornus alternifolia*	Native	5	4	6	Shrub	8.8
Wild Black Cherry	*Prunus serotina*	Native	3	4	3	Tree	7.8
American Beech	*Fagus grandifolia*	Native	3	3	6	Tree	7
Bitter-nut Hickory	*Carya cordiformis*	Native	0	4	6	Tree	6.6
Green Ash	*Fraxinus pennsylvanica*	Native	-3	4	3	Tree	4.2
Prickly Gooseberry	*Ribes cynosbati*	Native	5	4	4	Shrub	4.2
Balsam Fir	*Abies balsamea*	Native	-3	3	5	Tree	4

[a] 25 forest sites were monitored between 2005 and 2009.

3.1.2 Species Richness and Composition

3.1.2.1 Combined Vegetation

Monitoring Questions: How many vegetation species were found in the Credit River Watershed? What proportion of forest vegetation species was native to Ontario?

- 134 vascular vegetation species were detected in the watershed.
- 89% of plant taxa detected were native to Ontario.

Over the four year monitoring period 134 woody and herbaceous vegetation species were identified to species level, representing 11% of the 1205 vascular vegetation species known to occur in the Credit River Watershed (Credit Valley Conservation 2002). Eighty-nine percent of the species detected were native to Ontario. Of the species identified 15% were shrubs, 17% were trees, and the remaining 62% were herbaceous plant types (ferns, grasses, forbs, etc.) (Fig. 8).

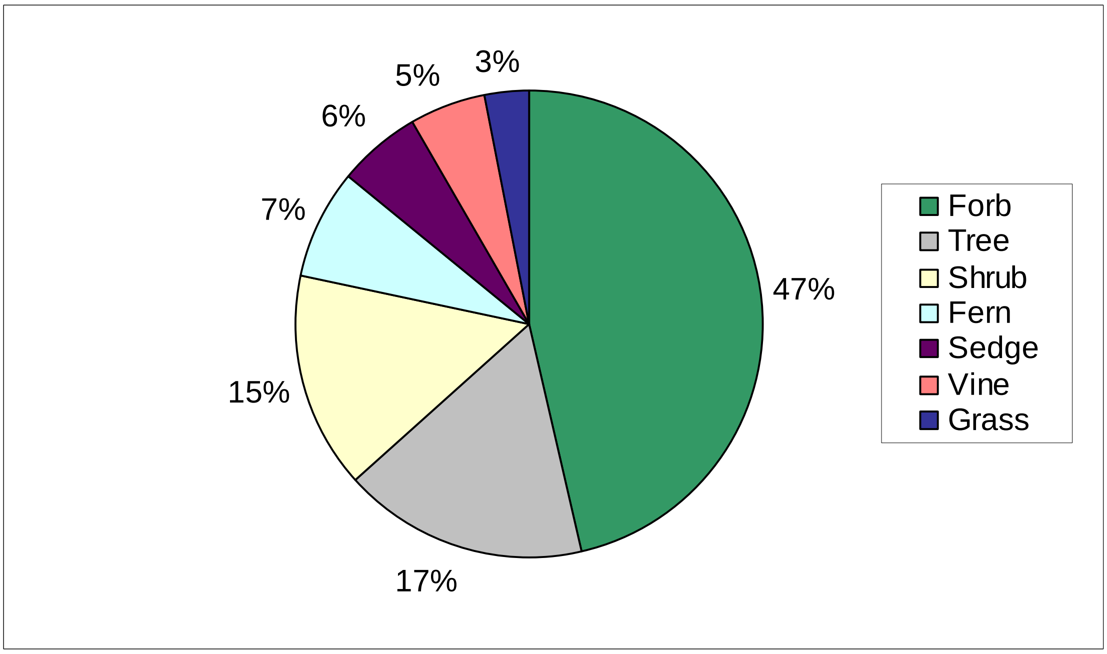


Figure 8. Species richness by plant type detected between 2005 and 2009 in the Credit River Watershed.

Combined vegetation species richness was highest at Fairy Lake Forest and Silver Creek Forest across the monitoring period. Fairy Lake Forest is located in the Middle watershed and is a swampy successional forest. Silver Creek Forest is also located in the Middle watershed and is located along the Niagara Escarpment. This monitoring site also contains many microhabitats that may have led to high species richness. The sites with the lowest richness were Britannia Forest and UCC Forest. These sites are mature deciduous forests located in the Lower and Middle watershed, respectively.

The combined proportion of native forest vegetation species watershed-wide ranged from 90.3% to 93.9% per year. Only native species were identified at the following six monitoring sites: Levi Creek Forest, Churchill Meadows Forest, Britannia Forest, Monora Park Forest, Caledon Creek Forest and Orpen Lake Forest. The first three aforementioned sites are located in the Lower watershed, and the following three sites are located in the Upper watershed. Sites with the lowest proportion of native species were Silver Creek Forest and Limehouse Forest, both located within the Middle watershed. The proportion of native species detected in forests was higher than the proportion of native species found in the watershed overall, as it is estimated that approximately 69% of the flora in the Credit River Watershed is native (CVC draft list 2009).

3.1.2.2. Ground Vegetation

Monitoring Questions: How many ground vegetation species were found in the Credit River Watershed? What proportion of these species was native to Ontario? How were ground vegetation species distributed among cover classes within the Watershed?

- 125 species were observed in the ground vegetation layer.
- 88% of ground vegetation species observed were native to Ontario.
- Forbs were the most dominant plant type in all cover classes.

From 2005 to 2009, 125 taxa identified to species-level were observed in the ground vegetation layer. Approximately 88% of these species were native to Ontario. The number of ground vegetation species occupying each cover class category ranged from 1 to 111, and decreased with increasing cover class (Fig. 9). In other words, forest ground vegetation species are more likely to occupy a low proportion of cover within a given area. Indeed, only 9 of the 125 taxa detected ever occupied >50% cover within a subplot. Forbs were the most dominant plant type in all cover classes, typically making up approximately 50% of the species (Fig. 9). Trees, shrubs and ferns were the next most prominent plant types.

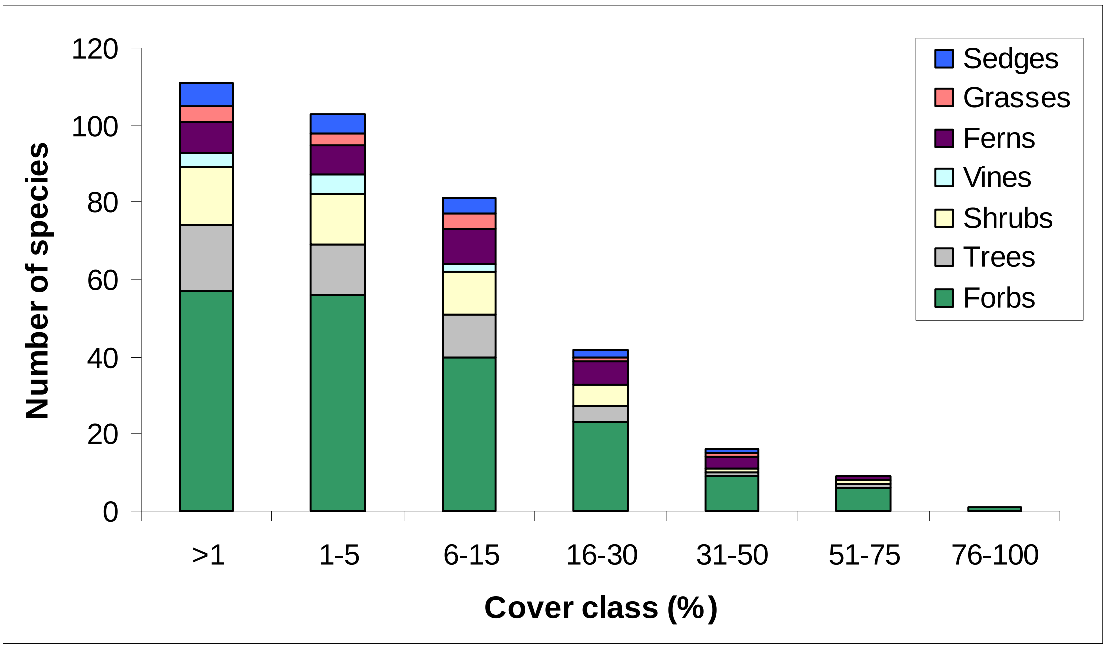


Figure 9. Number of species in each cover class by plant type for forest ground vegetation.

3.1.2.3 Regeneration

Monitoring Questions: How many regeneration species were found in the Credit River Watershed? What proportion of these species were native to Ontario? How were regeneration species distributed among height classes within the watershed?

- 37 regeneration species were observed in the forest regeneration layer.
- 95% of regeneration species were native to Ontario.
- Trees were the most dominant plant type in all cover classes.

Over the four year monitoring period 37 regeneration species (21 tree species and 16 shrub species) were identified, approximately 95% of which were native to Ontario. Only two non-native regeneration species were detected: Manitoba Maple (*Acer negundo*) and Common Buckthorn. The number of species in each height class ranged from 16 to 34, and decreased with increasing height class (Fig. 10). Trees accounted for 54-81% of the species in each height class, with trees becoming more dominant as height class increased (Fig. 10).

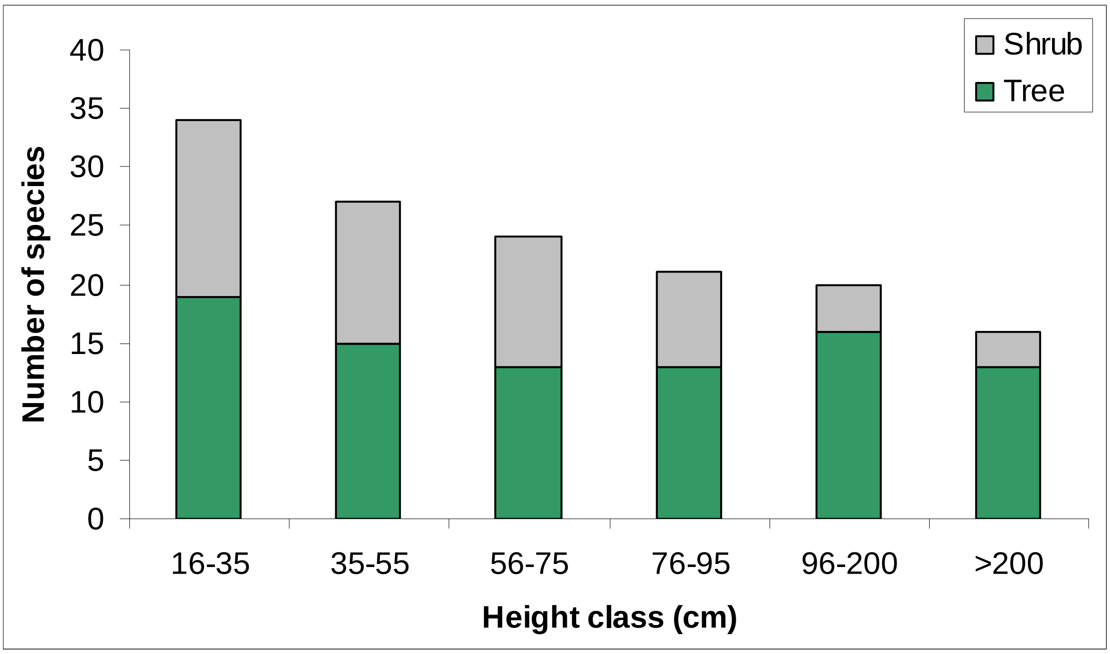


Figure 10. Number of species in each height class by plant type for regeneration.

Tree Regeneration

The total number of regenerating tree seedlings ranged from a low of 1207 seedlings in 2007, to a high of 1908 seedlings in 2005. Sugar Maple was the dominant species accounting for 69% of all regenerating trees across the monitoring period, and was the most abundant tree species in all six regeneration height classes (Fig. 11). White Ash was the second most abundant species, accounting for 16% of tree regeneration, with relatively high abundance in all regeneration growth stages. Only three additional species comprised greater than 1% of sampled seedlings: Green/Red Ash (*Fraxinus pennsylvanica*), Eastern White Cedar (*Thuja occidentalis*) and Wild Black Cherry. The remaining sixteen species cumulatively represented the remaining 7% of tree regeneration and individually represented less than 1% of observed species in the seedling layer.

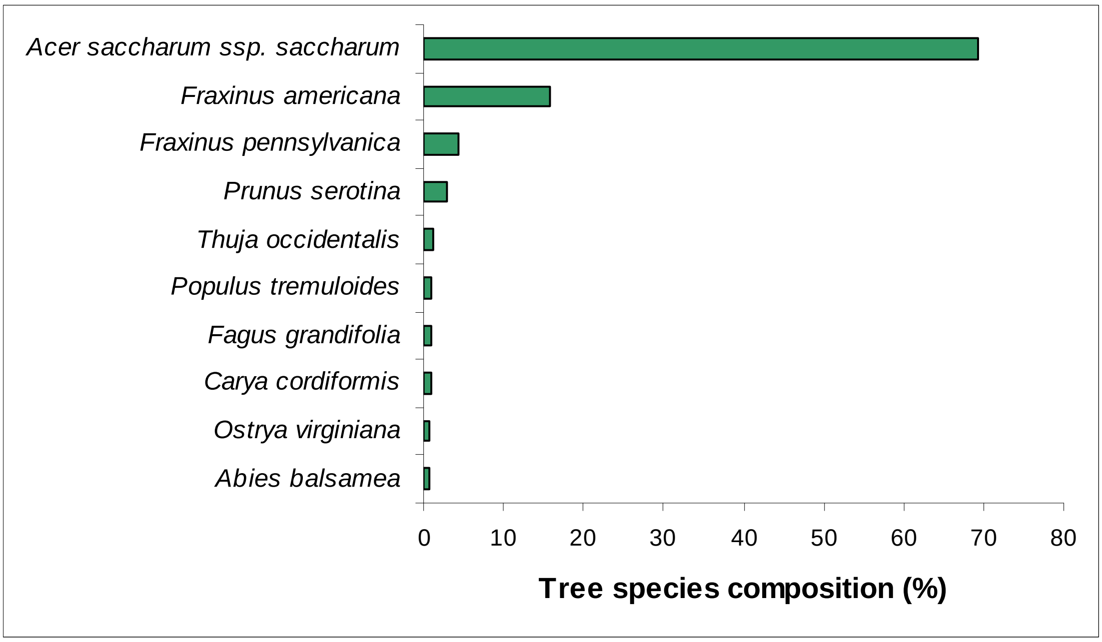


Figure 11. Percent species composition of dominant regenerating tree species across the monitoring period. Data pooled across all forest plots in the Credit River Watershed.

Eleven tree species known to account for 9% of the canopy layer were absent in the regeneration layer, namely Balsam Poplar (*Populus balsamifera*), Black Maple (*Acer saccharum ssp. nigrum*), Burr Oak (*Quercus macrocarpa*), Butternut (*Juglans cinerea*), Common Apple (*Malus sylvestris*), Downy Hawthorn (*Crataegus mollis*), Eastern White Pine, Freeman Maple (*Acer x freemanii*), Swamp White Oak (*Quercus bicolor*), White Oak (*Quercus alba*) and White Spruce (*Picea glauca*) (CVC 2010b). Conversely, Manitoba Maple was absent from the canopy layer but was identified in the regeneration layer. Monitoring regeneration species composition over the long-term will help determine whether the simpler community composition and additional non-native species are a cause for concern.

The smallest of the six height classes (16-35cm) had the greatest species richness and abundance of regenerating trees (Fig. 12). This pattern is expected, as most forests are flushed with seedlings in the smallest height class due to high germination rates. However, these numbers immediately decrease as seedlings naturally die off due to competition for resources, a process referred to as “natural thinning”.

In addition to natural mortality, deer herbivory also reduces the number of large seedlings in a forest (Cornett et al. 2000; Sweetapple and Nugent 2004), and has been cited as a threat to forest regeneration in Ontario (Gaston et al. 2008). Deer preferentially browse on seedlings between 30 and 120 cm in height (Cornett et al. 2000), and monitoring the ratio of small and large seedlings at forest sites can assist in identifying sites impacted by ungulates (Appendix C). However this matter is confounded by the fact that certain forest types, particularly mature forests, are expected to have low numbers of seedlings, as mature trees suppress the growth of new seedlings (Oliver and Larson 1996). Future monitoring of deer browse at forest sites within the Credit River Watershed will elucidate whether low seedling numbers in larger height categories are a cause for concern.

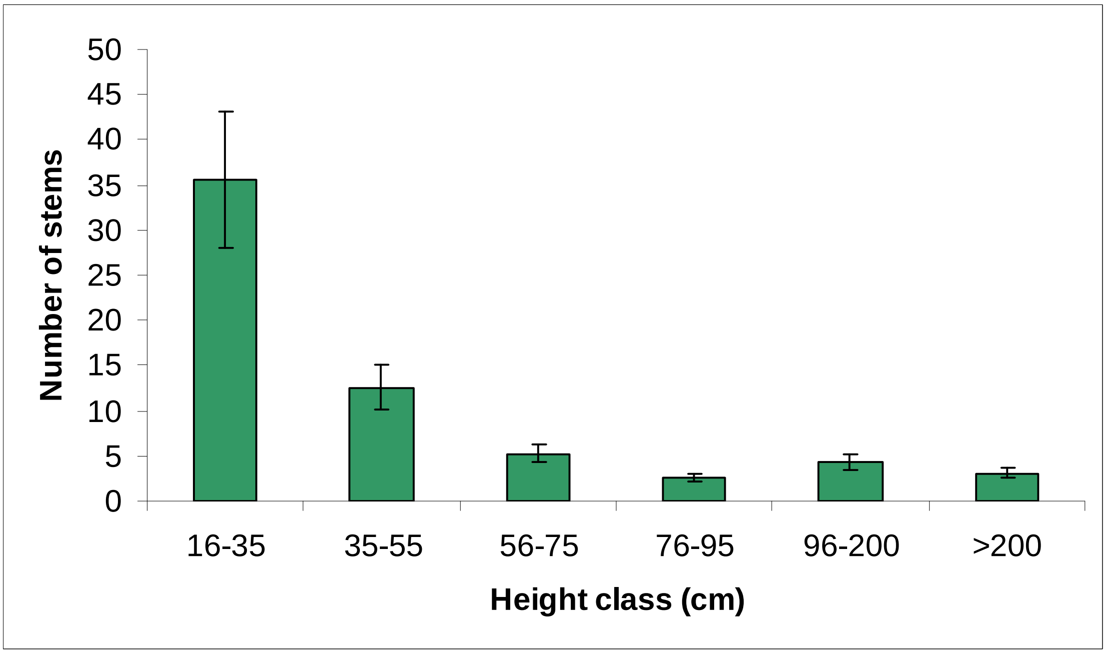


Figure 12. Mean number of stems within each regeneration height class across sites within the Credit River Watershed between 2005 and 2009. Error bars indicate +/- SE.

An additional concern is the absence of American Beech from two of the six regeneration height classes (36-55, 56-75cm). Although this may simply be attributed to a few poor mast years, the fact that beech canopy trees have been heavily inflicted with beech bark disease in forests of the Credit River Watershed raises concern over the mechanism behind low seedling regeneration. In the New York Adirondacks, beechnut production has declined 37% due to mortality of infected large trees and reduced vigour of smaller surviving beech trees (Sage 1996). This phenomenon may also be occurring in our watershed. As canopy trees die off and species in the regeneration layer take their place, species composition may change over the long-term from forests historically dominated by Sugar Maple-White Ash- American Beech, to a community with very few beech trees.

Shrub Regeneration

A total of 16 shrub species were documented at forest regeneration plots across the monitoring period. Chokecherry (*Prunus virginiana ssp. virginiana)* was the dominant shrub species in the Credit River Watershed, accounting for 53% of all identified shrub stems (Fig. 13). Except for the >200 cm height class, it was the most abundant shrub species in all remaining growth stages. Alternate-leaved Dogwood was the only other species that was found in large numbers, comprising 20% of all sampled shrubs in the regeneration layer. Seven additional shrub species each comprised 2-6% of shrubs: American Fly-honeysuckle (*Lonicera canadensis*), Common Red Raspberry (*Rubus idaeus ssp. melanolasius*), Maple-leaf Viburnum (*Viburnum acerifolium*), Northern Bush Honeysuckle (*Diervilla lonicera*), Prickly Gooseberry (*Ribes cynosbati*), Red Elderberry (*Sambucus racemosa ssp. pubens*), and Swamp Red Currant (*Ribes* *triste*). Seven other species cumulatively represented 5% of shrubs and individually represented less than 2%. Similar to the tree species in the regeneration layer, the smallest height class (16-35cm) had the greatest species richness and abundance of shrubs (not shown).

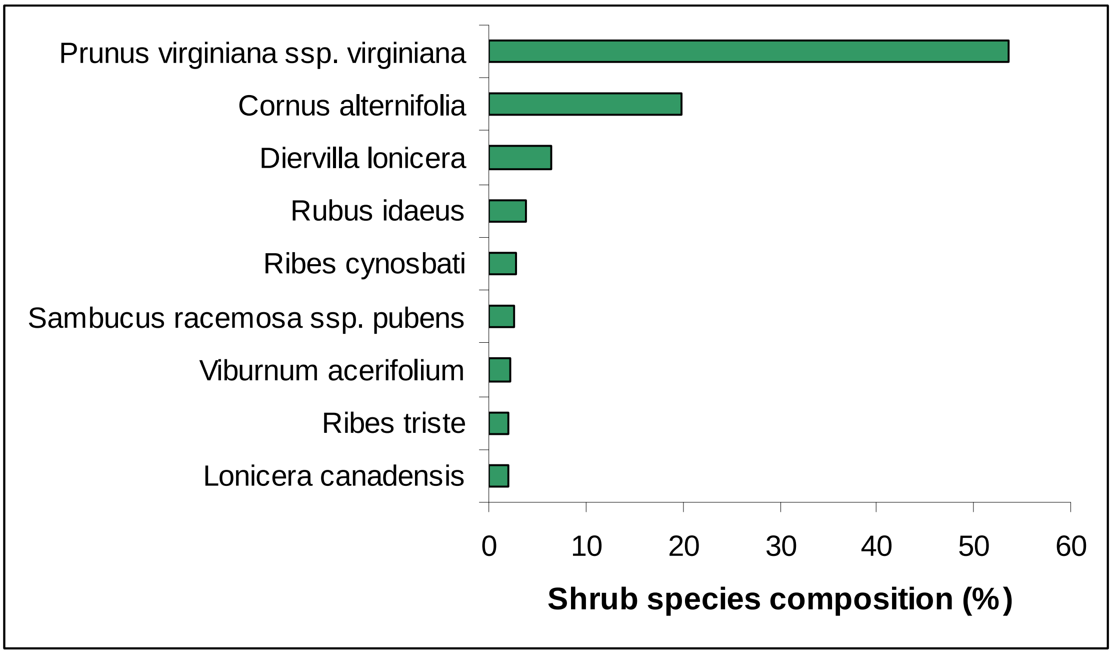


Figure 13. Dominant shrub species (>2% abundance) based on the total number of shrub stems detected in regeneration plots between 2005 and 2009. Data pooled across all forest plots in the Credit Watershed.

3.1.3 Species Evenness

Monitoring Question: What was the species evenness for ground vegetation and regeneration within the Credit River Watershed?

- Ground vegetation evenness ranged from a mean of 0.66 to 0.75 across the monitoring period.
- Regeneration diversity evenness from a mean of 0.80 to 0.86 across the monitoring period.

Evenness was calculated separately for ground vegetation and regeneration, as evenness calculations for ground vegetation were dependant on cover class estimations and regeneration calculations were dependant on stem counts. The mean evenness value across sites ranged from 0.66 to 0.75 for ground vegetation species and ranged from 0.80 to 0.86 for regeneration species, across the monitoring period (Fig. 14). Regeneration species were more evenly distributed than ground vegetation species, likely because there were only a few regeneration species detected at each monitoring plot.

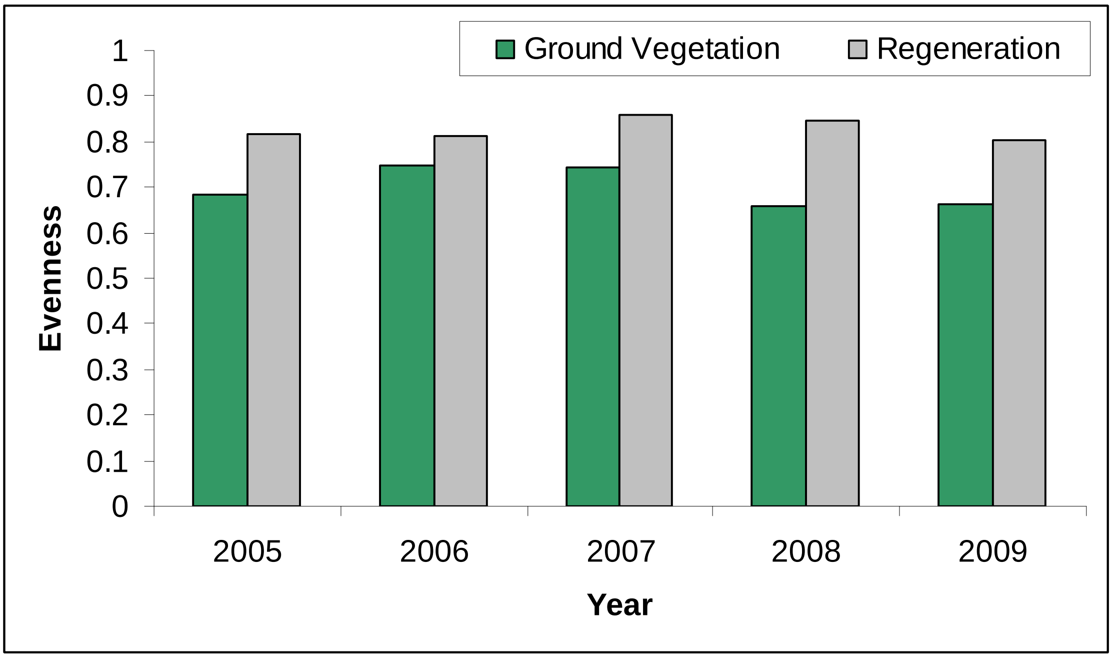


Figure 14. Mean species evenness across sites throughout the Credit River Watershed over the monitoring period for ground vegetation and regeneration.

3.1.4 Species Diversity

Monitoring Question: What was the species diversity for ground vegetation and regeneration within the Credit River Watershed?

- Ground vegetation diversity ranged from a mean of 0.78 to 1.10 units per site across the monitoring period.
- Regeneration diversity ranged from a mean of 0.44 to 0.52 units per site across the monitoring period.

Similar to evenness, diversity was calculated separately for ground vegetation and regeneration. The mean diversity score across sites for ground vegetation species ranged from 0.78 to 1.10 across the monitoring period (Fig. 15). The sites that had the greatest ground vegetation diversity were Silver Creek Forest (*H'* = 1.97) and Fairy Lake Forest (*H'* = 1.63), both within the Middle watershed. This is consistent with the high species richness recorded at these sites. The sites with the lowest ground vegetation diversity were Britannia Forest (*H'* = 0.02) and Churchill Meadows Forest (*H'* = 0.15), both within the Lower watershed.

The mean diversity score per site for regenerating species ranged from 0.44 to 0.52 across the monitoring period (Fig. 15). The sites which had the greatest regeneration diversity were Fairy Lake Forest (*H'* = 1.34) and Charles Sauriol Forest (*H'* = 1.16), located in the Middle and Upper watershed, respectively. The sites with the lowest regeneration diversity were Britannia Forest (*H'* = 0.00) and UCC Forest (*H'* = 0.12) located in the Lower and Middle watershed, respectively. Low regeneration at these sites may be attributed to the maturity of both forests.

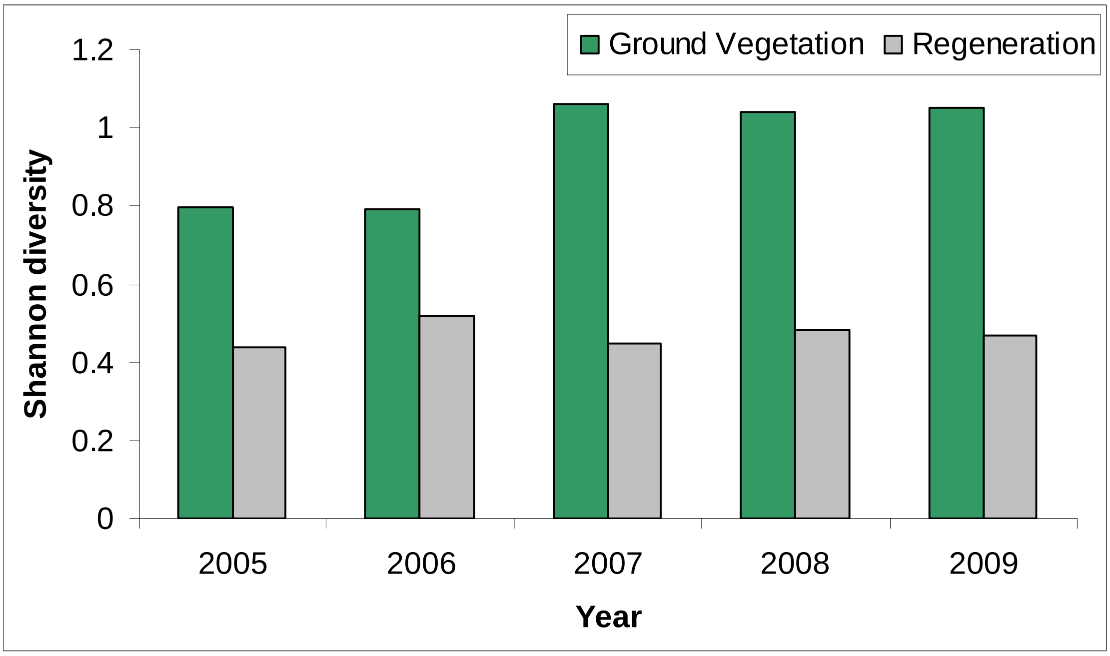


Figure 15. Mean diversity across sites throughout the Credit River Watershed over the monitoring period for ground vegetation and regeneration.

3.1.5 Coefficient of Conservatism

Monitoring Questions: What is the average mean Coefficient of Conservatism (mCC) and Floristic Quality Index (FQI) distributed throughout the watershed?

- The average mCC ranged from 4.44 to 4.58 across the monitoring period.
- The average FQI ranged from 14.97 to 16.25 across the monitoring period.

Coefficient of Conservatism scores indicates a species ability to tolerate disturbance (Oldham et al. 1995). Species with a score of 0-3 are indicative of taxa found in a range of habitats, and tolerate disturbed sites. Taxa which tolerate mild disturbance have CC rankings of 4-6. Species that are found in communities in an advanced successional stage have rankings of 7-8. Finally taxa which tend to be found in pristine communities are assigned a ranking of 9-10. Native forest plants detected in the Credit River Watershed ranged in Coefficients of Conservatism from 0 to 8, with no detected species having a CC value of 9 or 10 (Fig. 16).

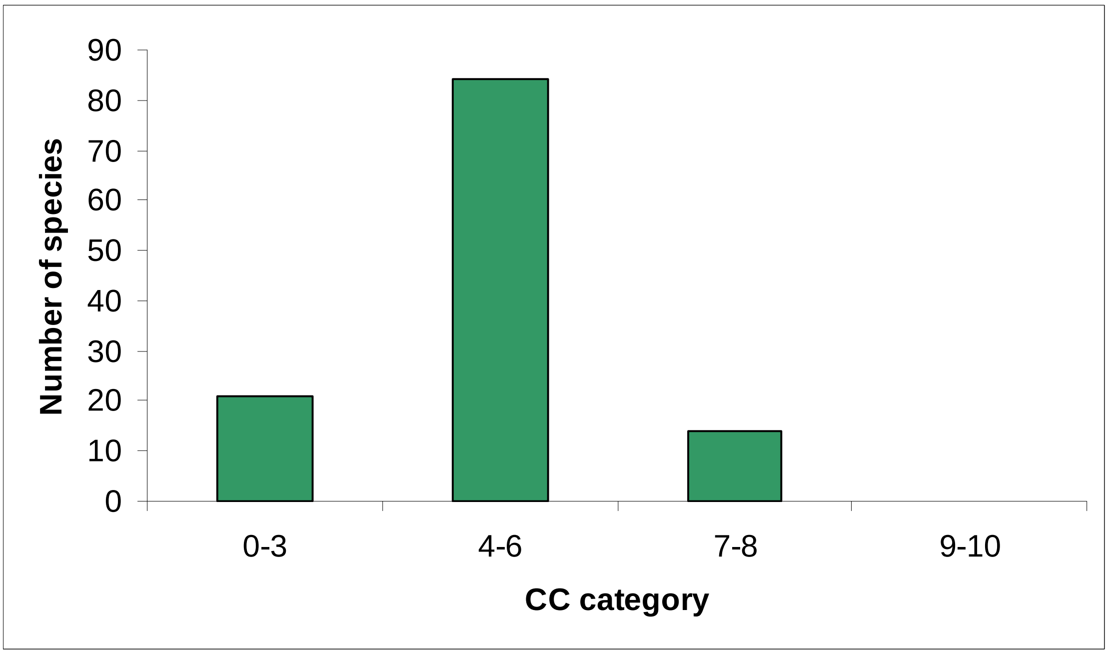


Figure 16. Number of species within each CC category for plants detected during the monitoring period in the Credit River Watershed.

The coefficient of conservatism scores for taxa detected across the watershed was used to determine the mean Coefficient of Conservatism for each site (mCC), as well as the Floristic Quality Index (FQI) of each site. The mean mCC for sites in each year ranged from 4.44 to 4.58 across sites, and the mean FQI across sites in each year range from 14.97 to 16.25. Although these two parameters both rely on CC values for their calculation, they were not correlated with each other among forests plots (Spearman correlation, ρ=0.308, *p*=0.135). This is in contrast to other studies using mCC and FQI, which have shown that these two parameters are highly correlated in natural areas (Bourdaghs et al. 2006; Bowers and Boutin 2008). Mean Coefficient of Conservatism and FQI were also correlated among wetland sites within the Credit River Watershed over the same monitoring period (CVC 2010c).

Sites ranged in mCC values from 3.71 to 5.22, and FQI scores from 5.89 to 24.68 across the monitoring period. Fairy Lake Forest contained the lowest mCC (3.71), but had the seventh highest FQI score (19.74). Conversely, Orpen Lake Forest, containing the highest mCC (5.22), had a moderate FQI score (16.33). The site with the lowest FQI was Britannia Forest (5.89), which had a moderate mCC score of 4.40. Finally, the site with the highest FQI was Silver Creek Forest (24.68), had a correspondingly high mCC score of 4.88. In practice, if a site is degraded or recently disturbed it may still support relatively high species richness and thus have a correspondingly large FQI (Taft et al. 1997). This appears to be the case at Fairy Lake Forest, an early successional forest supporting a large number of species. The high species richness at Fairy Lake results in a high FQI; however, because the forest is in the early stages of succession, the majority of the species present tolerate mild to major disturbances, resulting in a low mCC score. Given that mCC and FQI ranked sites differently in terms of their floristic integrity, it was important to consider both when examining the overall quality of a given site.

3.1.6 Rare and Highly Conservative Species

Monitoring Question: How many regionally and locally rare species were found watershed-wide? How many highly conservative species were detected watershed-wide?

- A total of six rare species were detected in forests over the monitoring period.
- Two species with a CC value of 8 were detected in the watershed.

A total of six locally rare vegetation species were detected in forests throughout the monitoring period. Four of species were also regionally rare (Table 9). In addition, two of the detected species had high conservatism scores (CC = 8), indicating that they are habitat specialists (Ontario Ministry of Natural Resources 2008). Each of the rare or specialist species were detected at only a single site throughout the monitoring period, with the exception of Carolina Spring-beauty (*Claytonia caroliniana*), found at three sites. Six of the 25 monitoring sites contained at least one rare species (Table 9). Species with the highest possible conservatism scores of 9 or 10 were not detected in forest plots throughout the watershed.

In addition to examining rare and highly conservative species, the Conservation Concern rankings of detected forest vegetation species were also summarized. To date, none of the species detected in forest monitoring plots are considered Species of Conservation Concern (SoCC) by CVC. Approximately 36% of forest vegetation species detected in the watershed falls within one of the other two concern categories (SoI or SoUI; Table 10). The remaining 64% of forest vegetation species are considered to be stable or non-native.

Table 9. Rare species and species with high conservatism values (CC = 8-10) detected between 2005 and 2009 in the Credit River Watershed.

Latin Name	Common Name	Locally Rare	Regionally Rare	CC Value	Years of Detection	Location
Claytonia caroliniana	Carolina Spring-beauty	X		7	4	Orpen Lake Forest Terra Cotta Forest Silver Creek Forest
Galium aparine	Catchweed Bedstraw	X		4	5	Terra Cotta Forest
Lonicera hirsuta	Hairy Honeysuckle	X	X	7	2	Winston Forest
Lonicera oblongifolia	Swamp Fly-honeysuckle	X	X	8	4	Winston Forest
Nemopanthus mucronatus	Mountain Holly	X	X	8	1	Charles Sauriol Forest
Orthilia secunda	One-side Wintergreen	X	X	5	2	Caledon Creek Forest

Table 10. Ranking of forest species detected in the Credit River Watershed according to CVC's Species of Conservation Concern.

Species of Conservation Concern Tier	# of Species
Species of Conservation Concern	0
Species of Interest	14
Species of Urban Interest	34
Secure	71
Non-native	15

3.1.7 Wetness Index

Monitoring Question: What was the mean wetness index per site across the watershed?

- The mean wetness value for each site ranged from 1.97 to 2.22 across the monitoring period.

The mean wetness score averaged across all sites ranged from a mean of 1.97 to 2.22 across sites, over the monitoring period. Vegetation detected at monitoring sites in the Credit River Watershed ranged in wetness values from -5 (Obligate Wetland) through +5 (Obligate Upland Species). The majority (58%) of vegetation species detected ranged from Facultative Upland Species to Obligate Upland Species (2 to 5) (Fig. 17), indicating that they prefer or require dry habitats. Five species detected in forest plots are considered Obligate Wetland Species, indicating that they are always found in wetlands. These included: Crested-shield Fern (*Dryopteris cristata*), Fowl Manna-grass (*Glyceria striata*), Mountain Holly (*Nemopanthus mucronatus*), Swamp Fly-honeysuckle (*Lonicera oblongifolia*), and Swamp Red Currant. These species are distributed among six sites, including Willoughby Nature Reserve Forest, Fairy Lake Forest, Winston Forest, Charles Sauriol Forest and Forks of the Credit Forest, with some species being found at multiple sites. Some of these sites are fairly moist forests (Winston Forest), and others are swampy habitats (Fairy Lake Forest) and contain vernal pools (Willoughby Nature Reserve Forest). Small discrete habitats within the larger forest complex, such as vernal pools, may be suitable habitat for obligate wetland species.

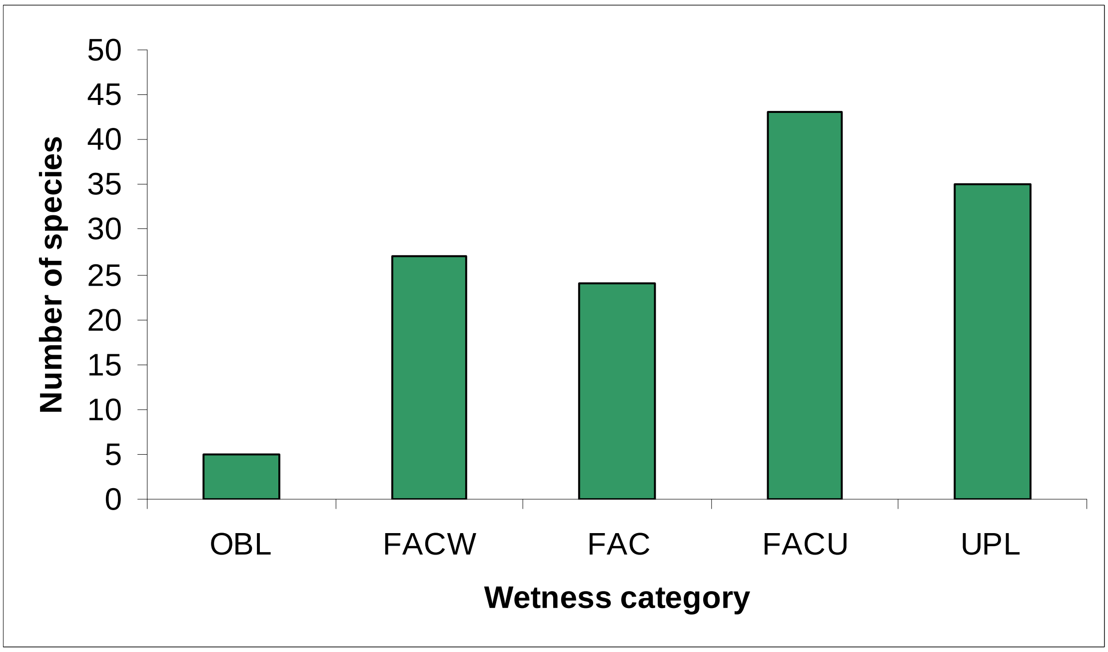


Figure 17. Number of species within each wetness category for plants detected during the monitoring period in the Credit River Watershed. OBL, Obligate Wetland (-5); FACW, Facultative Wetland (-2 to -4); FAC, Facultative (-1 to +1); FACU, Facultative Upland (+2 to +4); UPL, Obligate Upland (+5).

3.1.8 Weediness

Monitoring Question: How many species with a weediness score of -3 were present in the watershed?

- Two potentially problematic weedy species were detected in forest vegetation throughout the watershed.

A total of 14 non-native plants that have been assigned a weediness ranking in Ontario by Oldham et al. (1995) were detected in forests by the monitoring program (Table 7, Appendix D). Four of these species had a weediness score of -1, indicating that they have little or no impact on natural areas (Fig. 18). Eight of the species detected had a weediness score of -2, indicating that they can be locally problematic. The remaining two species (Garlic Mustard and Common Buckthorn) have a score of -3 and are considered problematic, or have the potential to become seriously problematic weeds.

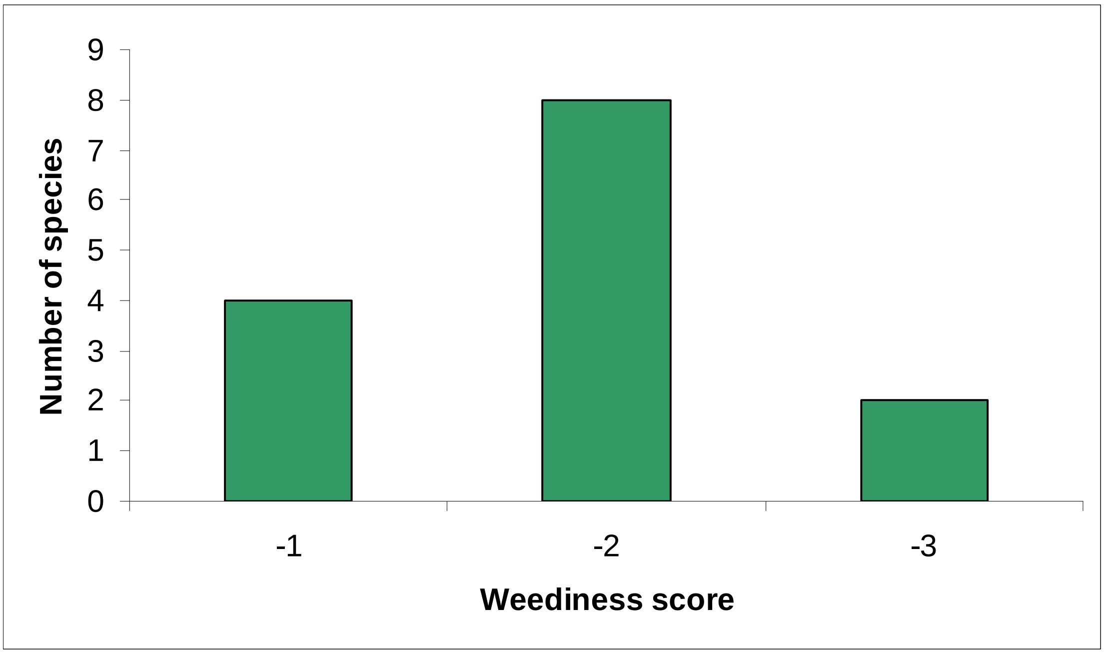


Figure 18. Number of species with each weediness score for non-native plants detected during the monitoring period in the Credit River Watershed.

Detecting problematic non-native species before they are widespread allows for rapid and effective management of invasive species (Canadian Food Inspection Agency 2004). Management efforts may be difficult for species such as Garlic Mustard as it already appears to be widespread, found in at least twelve sites across the watershed. Species with a more limited distribution, such as Yellow Hawkweed (*Hieracium caespitosum*), may be easier to control because it has been demonstrated that control is most successful and economical when species are in small populations (Moody and Mack 1988; Welling and Becker 1993; Blossey et al. 2000).

3.1.9 Community Composition

Monitoring Question: Was species composition different among physiographic zones? Did species composition change over the monitoring period?

- Species composition was highly variable among physiographic zones, ranging from 28% to 49% similarity between zones.
- Species turnover in the monitored sites averaged approximately 20% between years.

The Lower zone was 34% similar in community composition to the Middle zone, and 28% similar in community composition with the Upper zone. Similarity between the Middle and Upper zones was higher at 49%. Therefore, although all three zones tended to have relatively dissimilar community composition, the Middle and Upper are more alike than either is to the Lower zone. This is expected due to higher urban cover in the Lower zone.

Similarity in combined community composition between consecutive years over the monitoring period ranged from 72% to 88% (Table 11). This indicates that community dissimilarity averages around 20% between years, and community turnover was greater during the initial years of the monitoring program. This observed trend may be partially due to changes in staff and increasing familiarity with monitoring sites. Community similarity is lower when 2005 and 2009 are compared, at only 64% similarity. Varying weather patterns (Fig. 19) and natural community turnover rate are likely responsible for some changes in community composition.

Table 11. Percent community similarity and dissimilarity for combined vegetation watershed wide between years.

Comparison	% Community Similarity	% Community Dissimilarity
2005-2006	72.48	27.52
2006-2007	78.26	21.74
2007-2008	78.40	21.60
2008-2009	87.80	12.20
2005-2009	64.00	36.00

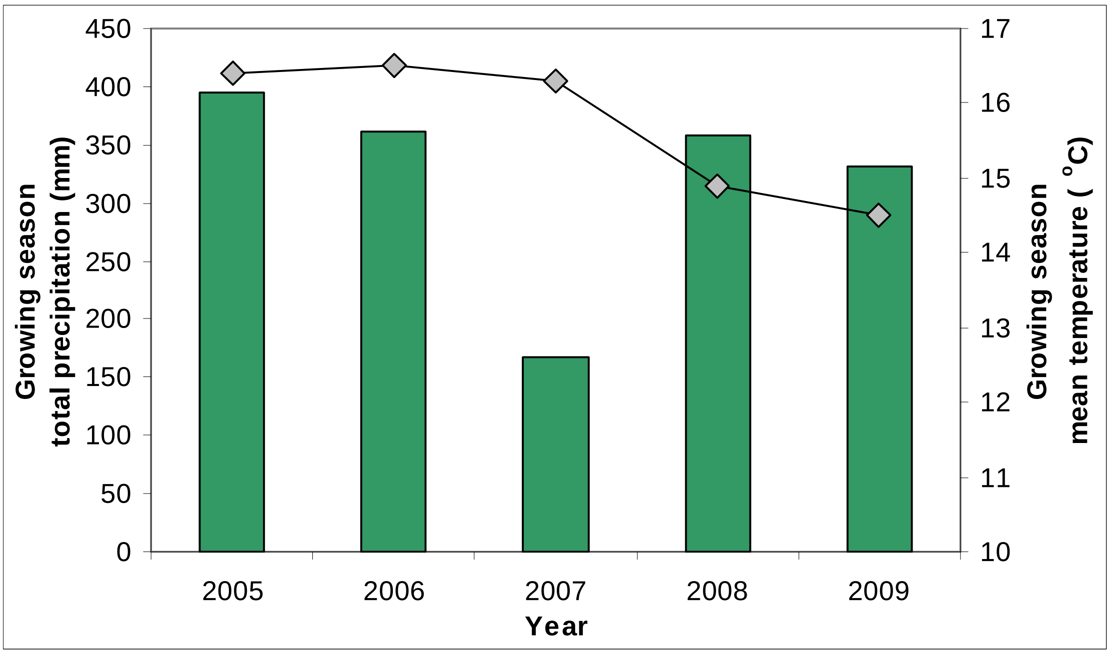


Figure 19. Total monthly precipitation and mean monthly temperature from 2005 to 2009 in Georgetown, ON during the growing season. Mean temperature (points) and precipitation (bars) over the growing season were 16.4°C and 395.3 mm, 16.5°C and 360.7 mm, 16.3°C and 166.5 mm, 14.9°C and 358.0 mm, 14.5 and 331.1 mm in 2005, 2006, 2007 2008 and 2009, respectively.

3.1.10 Site Quality

Monitoring Question: Which sites were the most pristine and most degraded throughout the watershed?

- Silver Creek, Forks of the Credit, Hillsburgh and Terra Cotta Forests are the most pristine sites in the watershed.
- UCC, Roy Ivors, Britannia and Streetsville Forests are the most degraded sites in the watershed.

Forest sites in the Credit River Watershed were ranked based on several forest vegetation parameters, including: the combined proportion of native species, mCC, FQI, the number of -3 weedy species, number of rare species, combined species richness and ground vegetation species diversity (Table 12). Sites were sorted from the highest to lowest values for each parameter, and given a score of between 1 (Highest Quality) and 25 (Lowest Quality). For example, Fairy Lake Forest had the highest species richness, and was given a score of 1 for this parameter. Each site was ranked seven times (once for each vegetation parameter) and these scores were summed to give an overall site score. This allowed a coarse determination of which forest monitoring sites are the most pristine and which sites are most degraded. This is a rough method of ranking the sites, as it assumes that each vegetation parameter contributes equally to the overall quality of the site.

Silver Creek Forest was ranked as the most pristine site across the watershed. This forest is located along the Niagara Escarpment in the Middle watershed. Using this ranking system, it appears that high species richness, diversity and floristic quality are driving factors in ranking Silver Creek as the highest quality forest. Forks of the Credit, Hillsburgh and Terra Cotta Forests were ranked as the second, third and fourth most pristine sites in the watershed, respectively. Forks of the Credit is located in the Upper watershed and is situated in a large habitat patch (534 ha). Hillsburgh Forest is also in the Upper watershed, but unlike Forks of the Credit it is not situated in a large habitat patch (60 ha). Nevertheless, Hillsburgh still supports a relatively high number of species and has high diversity in comparison to other sites. Finally, Terra Cotta Forest was the fourth most pristine forest site across the watershed. This site has a high mCC score, has high diversity, and is found in the largest habitat patch of all monitoring sites across the watershed (753 ha).

The sites which were ranked as the most degraded included UCC, Roy Ivors, Britannia and Streetsville Forests. Britannia, Roy Ivors and Streetsville Forests are each found in small habitat patches in the Lower Watershed (5, 18 and 25, ha respectively). Britannia is a relatively barren forest, where only two vegetation species have been identified to species-level over the monitoring period: Sugar Maple and Yellow-trout Lily (*Erythronium americanum ssp. americanum*). Roy Ivors is a mature coniferous forest with very little understory, supporting a small number of ground vegetation species. UCC is also a mature forest found within the Middle watershed in a medium sized habitat patch (141 ha). The ranking of these sites as degraded may be biased by the age of the forest, which causes some of these sites to support very few ground vegetation and regeneration species in the understory. Future ranking of the sites will also consider abiotic factors, such as soil quality and decomposition rates. Ecological Land Classification of sites will be completed in 2010, allowing for more detailed interpretation of site rankings in the future.

Table 12. Monitoring site quality within the Credit River Watershed. [abcd]

Site Name	Zone	%Native	mCC	FQI	Weediness Count -3	Rare Count	Species Richness	Species Diversity	Wetness	Site Quality
Silver Creek Forest	Middle	0.88	4.88	24.68	1	0.4	30	1.97	2.89	**Pristine**
Forks of the Credit Forest	Upper	0.84	4.91	21.99	0.2	0	25.2	1.57	2.70	
Hillsburgh Forest	Upper	0.97	4.71	20.18	0	0	19.2	1.20	3.23	
Terra Cotta Forest	Middle	0.89	5.15	17.36	0.8	1.4	14	1.55	2.74	
Charles Sauriol Forest	Upper	0.89	4.34	20.13	0	0.2	25.6	1.62	1.54	
Orpen Lake Forest	Upper	1.00	5.22	16.33	0	0.6	10	1.04	2.75	
Fairy Lake Forest	Middle	0.95	3.71	19.74	0	0	31.4	1.63	0.11	
Willoughby Nature Reserve Forest	Middle	0.89	4.56	19.79	0.2	0	22.2	1.28	1.43	
Winston Forest	Lower	0.88	4.52	20.06	2	1.2	22.8	1.12	1.71	
Monora Park Forest	Upper	1.00	4.53	15.80	0	0	12.4	0.78	2.67	
Meadowvale Forest	Lower	0.89	4.83	14.19	0.8	0	10	1.16	2.15	
Belfountain Forest	Upper	0.93	4.79	15.51	0	0	11.4	0.47	1.97	
Mississauga Gardens Forest	Lower	0.90	4.61	14.55	1.5	0	11.5	1.06	1.51	
Alton Forest	Upper	0.87	4.37	15.79	0	0	15.6	1.00	1.21	
Levi Creek Forest	Lower	1.00	4.39	13.28	0	0	9.2	0.73	0.97	
Limehouse Forest	Middle	0.71	4.16	13.82	1.2	0	16.2	1.33	1.45	
Robert Baker Forest	Middle	0.95	4.04	13.62	0	0	12.2	0.62	2.36	
Warwick Forest	Middle	0.94	4.72	12.47	0.2	0	7.6	0.56	3.36	
Caledon Creek Forest	Upper	1.00	3.89	12.88	0	0.4	11.2	0.58	0.25	
Huttonville Forest	Lower	0.92	4.70	11.94	0.6	0	7.4	0.56	2.35	
Churchill Meadows Forest	Lower	1.00	4.27	12.53	0	0	8.6	0.15	1.96	
Streetsville Forest	Lower	0.90	4.46	12.12	1	0	8.4	0.69	2.88	
Britannia Forest	Lower	1.00	4.40	5.89	0	0	1.8	0.02	3.80	
Roy Ivors Forest	Lower	0.85	4.33	12.03	1.2	0	9.2	0.71	2.06	**Degraded**
UCC Forest	Middle	0.84	4.63	9.25	0.8	0	5.2	0.31	2.15	

[a] It is important to note that while this ranking system provides a general overview of site health, the ranking system is subjective.

[b] Parameters represent means across all years for each site.

[c] Sites were ranked based on their proportion of native species, mCC, number of -3 weedy species and number of rare species, combined species richness and ground vegetation species diversity. Average wetness is also included for visualization purposes, but was not used to determine the overall site quality.

[d] Green, yellow and red shading is used to indicate the quality of sites and parameters across the spectrum of most pristine to most degraded. Green shading indicates the highest quality sites/parameters, yellow indicates median ranking of sites/parameters, and red indicates the lowest rankings of sites/parameters.

3.2 TEMPORAL ANALYSES

Monitoring Question: Did forest vegetation exhibit temporal variation over the monitoring period?

- Ground vegetation richness and diversity were the only parameters which exhibited a significant trend, and were increasing over the monitoring period.
- Several vegetation parameters exhibited significant yearly fluctuations, including: combined vegetation richness, ground vegetation richness, regeneration tree richness, regeneration evenness, ground vegetation evenness, ground vegetation diversity, the combined proportion of native species, tree stems in all height classes, FQI, weediness parameters.

3.2.1 Species Richness

Ground vegetation species richness was the only richness parameter which exhibited a significant trend between 2005 and 2009 in the Credit River Watershed (Table 13; Fig. 20). Combined vegetation and regeneration (total, tree and shrub) richness were stable. Despite the fact that few increasing or decreasing trends were observed, fluctuations in species richness did occur among years. Differences in species richness were observed among years for combined vegetation, ground vegetation and tree regeneration (F=5.818, p<0.001; F=13.399, p<0.001; F=2.739, p=0.034, respectively; Table 13, Fig. 21). For combined vegetation, species richness was lowest in 2005 and highest in 2009. Ground vegetation followed a similar pattern. Regenerating tree richness was greater in 2005 and 2006 than 2007. Differences among years may represent natural variation and species turnover, rather than an increasing trend. Observed increases in species richness may also be due to improved species identification over the monitoring period. Species identification improved due to increased knowledge of the monitoring staff as well as the development of species lists for each site from past years. With only five years of data it is difficult to determine the range of natural variation. As increasing data becomes available the natural variability may become more apparent. No differences were detected among years for overall and shrub regeneration (F=2.428, p=0.054; F=1.068, p=0.378, respectively; Table 14, Fig. 19).

Table 13. Summary of trend analysis results using linear regression for vegetation parameters between 2005 and 2009.

Vegetation Parameter	*F* value	*p* value [a]	R^2	Observed Trend
Richness				
Combined Vegetation Richness	1.656	0.201	0.005	None
Regeneration Overall Richness	0.020	0.888	-0.008	None
Regeneration Tree Richness	0.282	0.605	-0.006	None
Regeneration Shrub Richness	1.290	0.258	0.002	None
Total Ground Vegetation Richness	**4.336**	**0.037**	**0.027**	**Increasing**
Diversity				
Regeneration Diversity	0.039	0.844	-0.008	None
Ground Vegetation Diversity	**4.902**	**0.029**	**0.031**	**Increasing**
Regenerating Tree Stem Counts				
a) Total	0.217	0.623	-0.006	None
b) 16-95cm	0.143	0.706	-0.007	None
c) >95cm	0.879	0.350	-0.001	None
Floristic Quality				
mCC	0.021	0.886	-0.008	None
FQI	1.502	0.223	0.004	None
Wetness	0.834	0.363	-0.001	None

[a] Results were considered significant when $p<0.05$, and are reported in bold.

Table 14. Summary of temporal analysis results using repeated measures ANOVA or the Friedman Test for vegetation parameters between 2005 and 2009.

Parameter	**Test**	***F* value**	***p* value [a]**	**Observed Differences [bc]**
Richness				
Combined Vegetation Richness	Repeated Measures	**5.818**	**<0.001**	2005 < 2008, 2009 2006 < 2009
Regeneration Overall Richness	Repeated Measures	2.428	0.054	None
Regeneration Tree Richness	Repeated Measures	**2.739**	**0.034**	2005, 2006 > 2007[c]
Regeneration Shrub Richness	Repeated Measures	1.068	0.378	None
Total Ground Vegetation Richness	Repeated Measures	**13.399**	**<0.001**	2005 < 2008, 2009 2006 < 2007, 2008, 2009
Evenness				
Regeneration Evenness	Friedman	**13.784**	**0.008**	2005, 2008, 2009 < 2006, 2007
Ground Vegetation Evenness	Friedman	**24.601**	**<0.001**	2005, 2006, 2009 < 2007, 2008
Diversity				
Regeneration Diversity	Repeated Measures	1.933	0.112	None
Ground Vegetation Diversity	Repeated Measures	**8.982**	**<0.001**	2005, 2006 < 2007, 2008, 2009
Proportion of Native Species				
Ground Vegetation	Friedman	8.722	0.068	None
Combined Vegetation	Friedman	**9.895**	**0.042**	2005 > 2006, 2007, 2008, 2009
Regeneration Stem Counts				
Shrub Stem Counts				
a) Total	Friedman	**13.058**	**0.011**	2005, 2006 > 2007, 2008, 2009
b) 16-95cm	Friedman	12.335	0.091	None
c) >95cm	Friedman	7.035	0.134	None
Tree Stem Counts				
a) Total	Repeated Measures	**9.110**	**<0.001**	2005 > 2007, 2008 2006 > 2007 < 2009
b) 16-95cm	Repeated Measures	**6.744**	**<0.001**	2005 > 2007, 2008 2007 < 2009
c) >95cm	Repeated Measures	**4.213**	**0.004**	2005, 2006 > 2007
Floristic Quality				
mCC	Repeated Measures	1.097	0.363	None
FQI	Repeated Measures	**4.301**	**0.003**	2005, 2006, 2007 < 2009
Wetness	Repeated Measures	1.974	0.106	None
Weedy Species Richness	Friedman	**18.506**	**0.001**	2005, 2006 < 2008, 2009
Weediness Count -3	Friedman	1.647	0.800	None

[a] Results were considered significant when $p<0.05$, and are reported in bold.

[b] Differences between years determined using Tukey's post-hoc test for repeated-measures ANOVA analyses, and by visual observation for the Friedman Test.

[c] Post-hoc test p values <0.08.

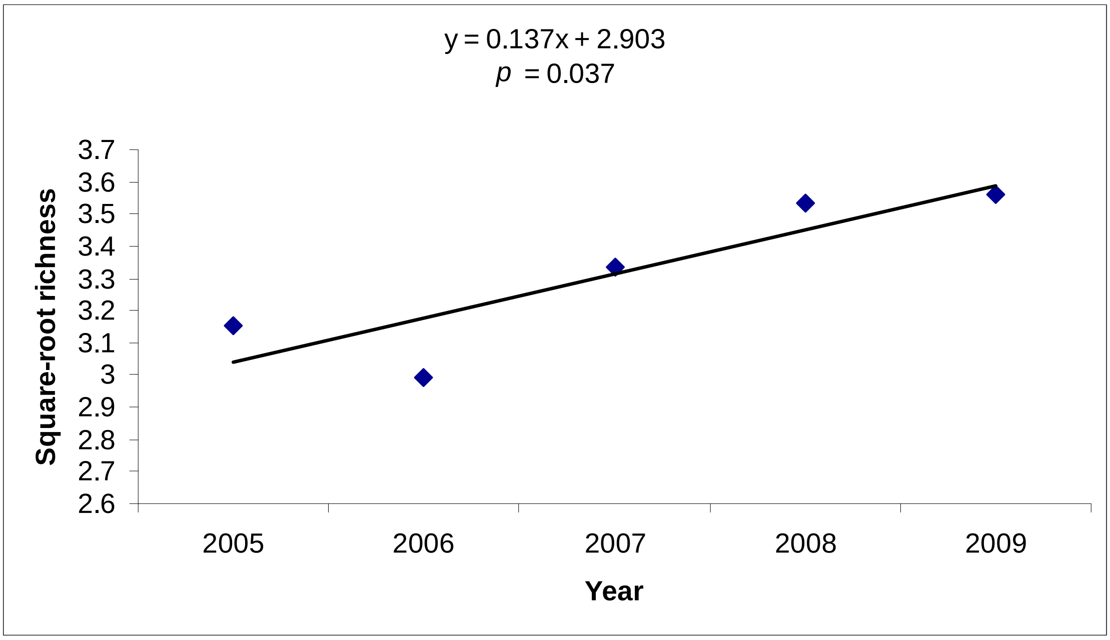


Figure 20. Species richness for ground vegetation observed at 25 forest sites in the Credit River Watershed between 2005 and 2009. Equation of the regression line and *p*-value provided.

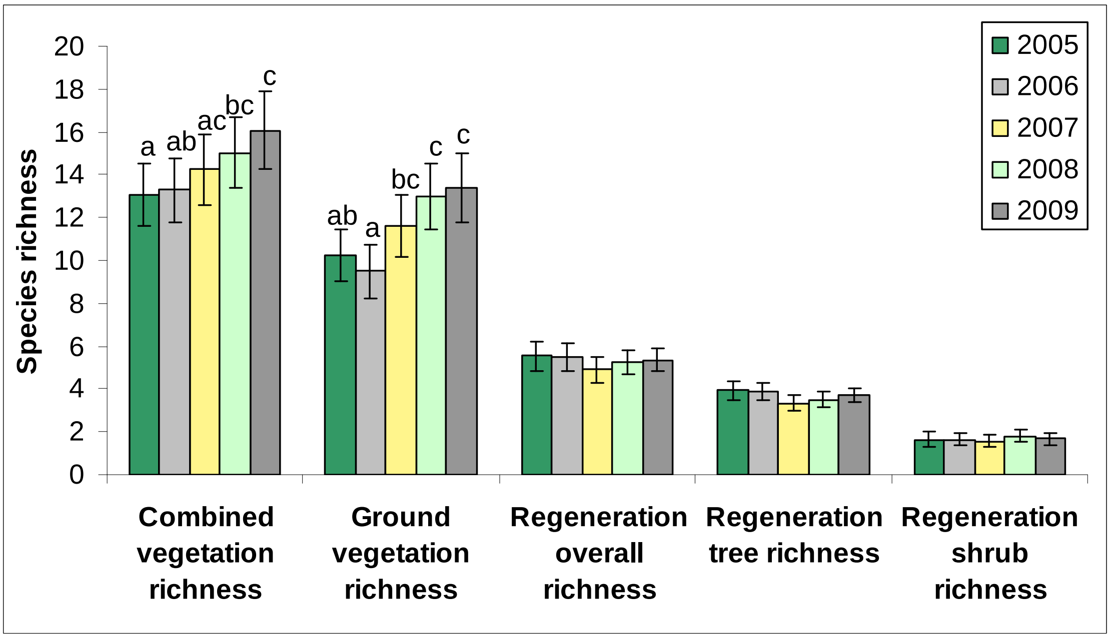


Figure 21. Mean species richness across sites, as affected by year, for combined vegetation, ground vegetation and total, tree and shrub regeneration. Within vegetation parameters, bars with different letters indicate a significant difference according to Tukey's HSD test for unequal sample sizes ($p<0.05$). Error bars indicate +/- SE.

3.2.2 Proportion of Native Species

Linear regression analysis was not completed on the proportion of native species parameters due to the nominal natural of the data. The proportion of native species differed among years for combined vegetation, and was nearly significant for ground vegetation (F=9.895, p=0.042; F=8.722, p=0.068, respectively; Table 14, Fig. 22). Although the Friedman test indicated differences among years for combined vegetation, no associated post-hoc tests are available to determine where these differences exist. By examining the means for each year it appears that the proportion of native species was highest in 2005 and decreased in subsequent years (Fig. 22). This may indicate an increase in non-native species within the watershed over the monitoring period; however, conclusive results cannot yet be drawn.

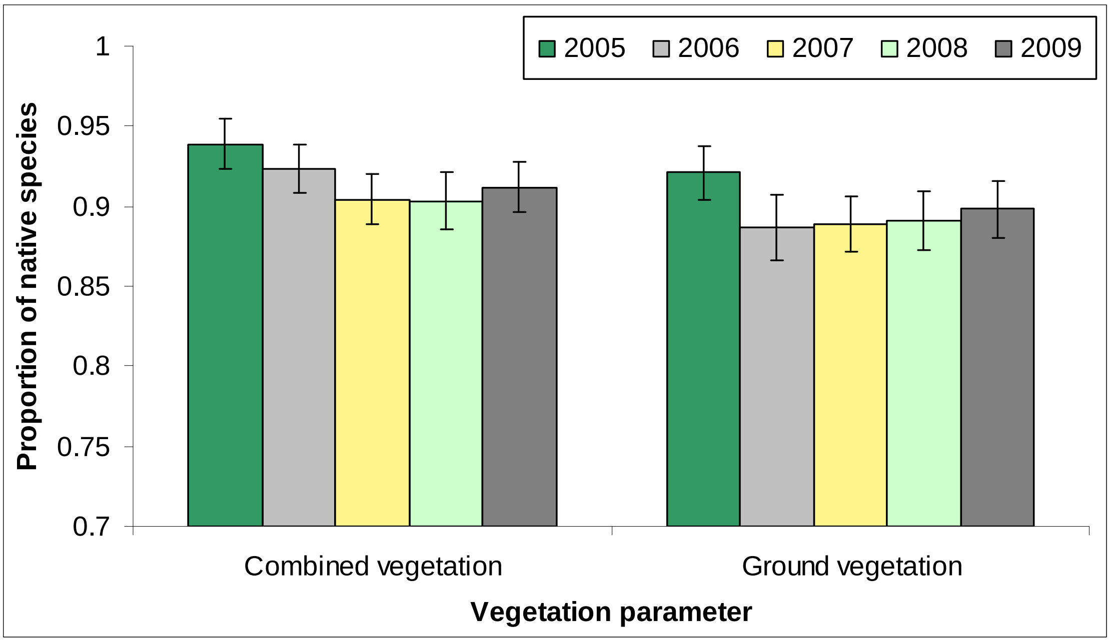


Figure 22. Mean proportion of native species across sites, as affected by year, for combined vegetation and ground vegetation. Error bars indicate +/- SE.

3.2.3 Species Evenness

Due to the proportional nature of the data, species evenness was analyzed using non-parametric methods. Significant differences were detected among years for both ground vegetation and regeneration species evenness (F=24.601, p<0.001; F=13.784, p=0.008, respectively) (Table 14; Fig. 23). It does not appear that species evenness is steadily increasing or decreasing over time, and the observed differences may be due to natural species turnover which is known to occur between years.

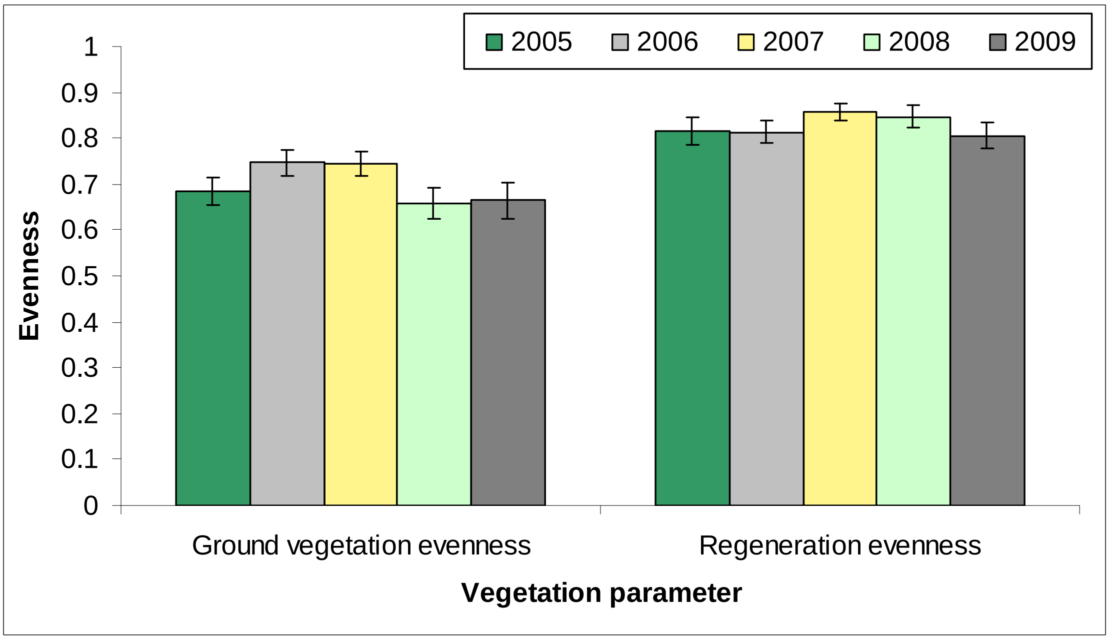


Figure 23. Mean species evenness across sites, as affected by year, for ground vegetation and regeneration. The Friedman test was used for both parameters. Error bars indicate +/- SE.

3.2.4 Species Diversity

Linear regression analysis indicated that ground vegetation diversity increased significantly over the monitoring period, whereas regeneration diversity did not (*F*=4.902, *p*=0.209; *F*=0.039, *p*=0.844, respectively; Table 13, Fig. 24). Although ground vegetation exhibited a significant trend over time, the fitted linear model exhibited a low R^2 value indicating that the model explained little of the variation in the data (Table 13). Significant differences among years were observed for ground vegetation; however, no differences were apparent for regeneration (*F*=8.982, *p*<0.001; *F*=1.933, *p*=0.112, respectively; Table 14, Fig. 25). Ground vegetation diversity was higher in 2007 and 2008 than the previous two years. This is consistent with the increasing trend observed in the linear regression. Similar to species richness, these increasing trends may be attributed to improved sampling over the monitoring period.

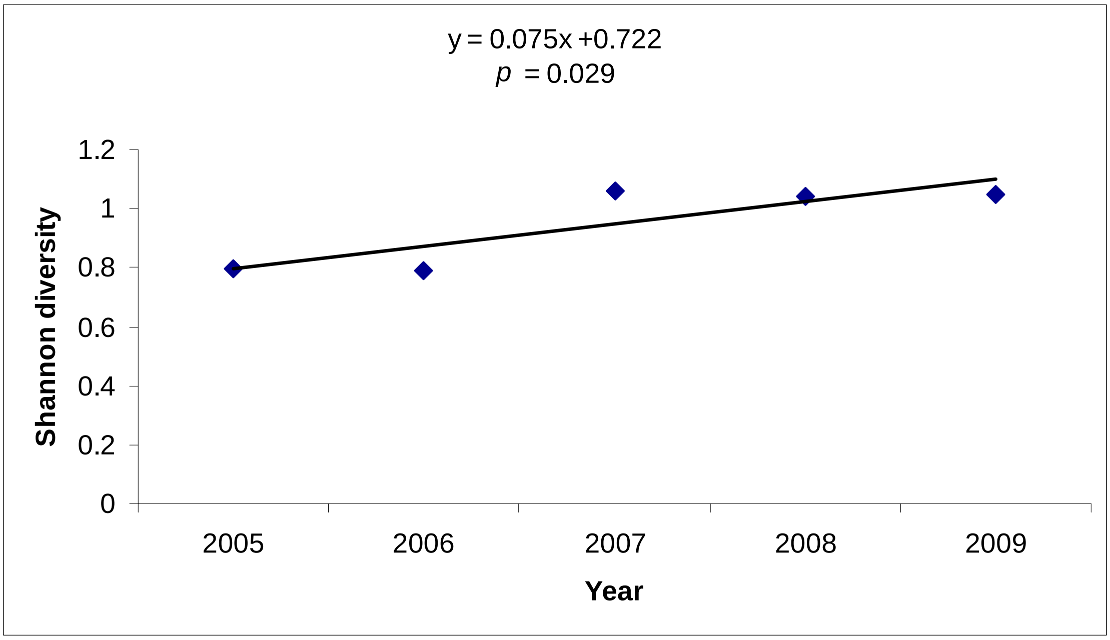


Figure 24. Diversity for ground vegetation observed at 25 forest sites in the Credit River Watershed between 2005 and 2009. Equation of the regression line and *p*-value provided.

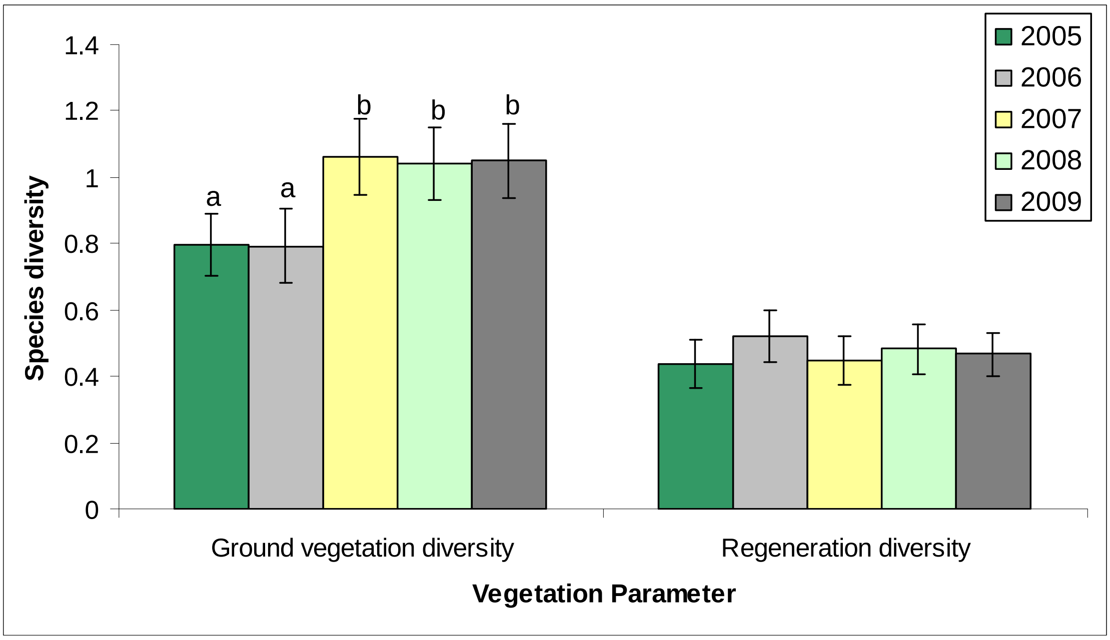


Figure 25. Mean diversity across sites, as affected by year, for ground vegetation and regeneration. Within vegetation parameters, bars with different letters indicate a significant difference according to Tukey's HSD test for unequal sample sizes ($p<0.05$). Error bars indicate +/- SE.

3.2.5 Regeneration Stem Counts

No tree stem count parameters displayed a significant trend over time (Table 13). However, significant fluctuations among years were observed in all tree height classes (Table 14). In general, more stems were detected in early years of monitoring (2005 & 2006), than later years (2007, 2008 and 2009) (Fig. 26; Table 14).

Shrub stem count parameters were analyzed with non-parametric methods, due to the large number of zeros in the dataset (Table 14; Fig. 27). No differences were observed among years when the 16-95 cm and >95 cm height classes were analyzed separately. However, when all stems were combined a significant difference was observed among years. From visual examination of the data it also appears that more shrub stems were detected in 2005 and 2006 than in later years of the monitoring program (Fig. 27).

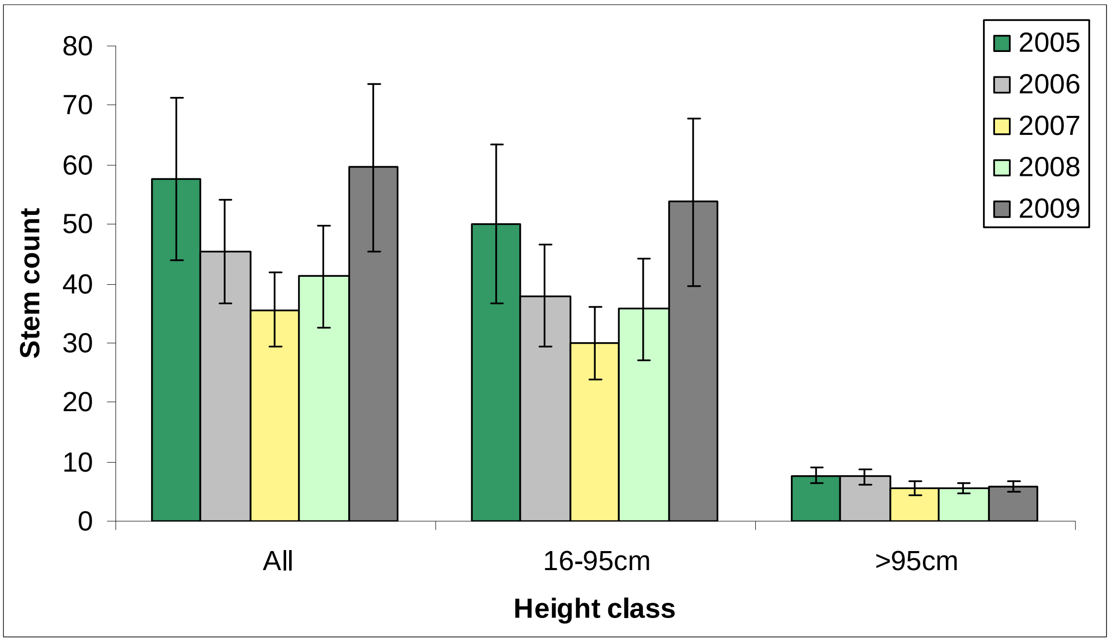


Figure 26. Mean tree stem count across sites, as affected by year, for the three height classes. Error bars indicate +/- SE.

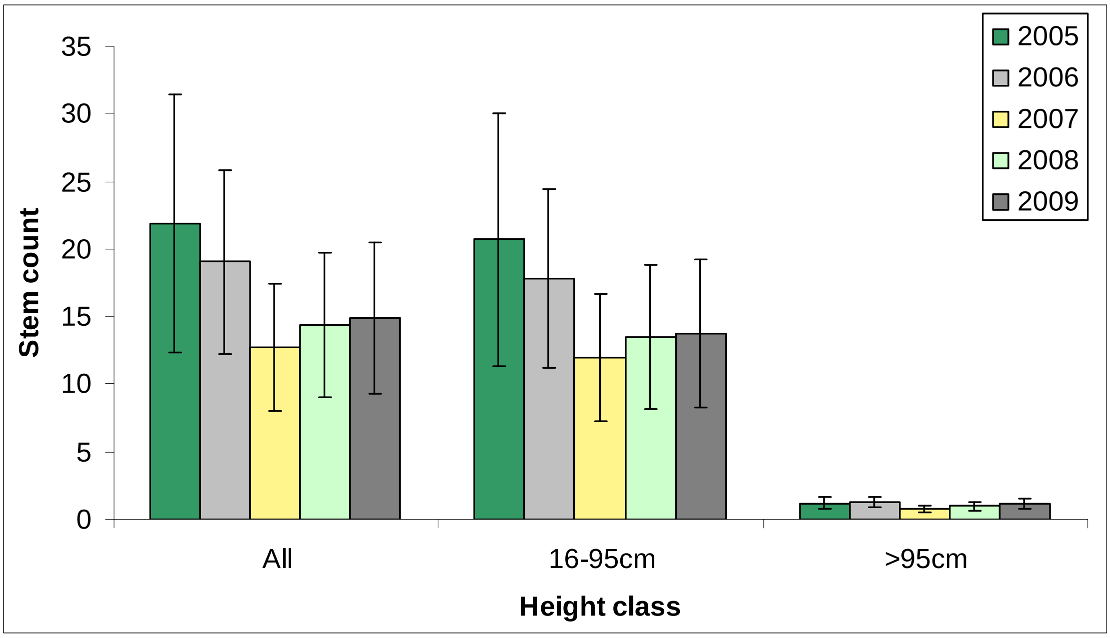


Figure 27. Mean shrub stem count across sites, as affected by year, for the three height classes. Error bars indicate +/- SE.

3.2.6 Floristic Quality Parameters

Linear regression analysis was completed for mCC, FQI and wetness index. However, weediness parameters were analyzed non-parametrically due to the low number of species observed at each site. The mCC, FQI and wetness index parameters did not display a significant trend over time (Table 13). In addition, mCC, wetness and the number of -3 weedy species did not vary between years (Table 14; Fig. 28, Fig. 29, Fig. 30). However, FQI and the weedy species richness did display significant differences among years (Table 14, Fig. 28, Fig. 30). FQI was significantly higher in 2009 than in earlier years (p=0.016, p=0.047 and p=0.030 in 2005, 2006 and 2007, respectively). As no post-hoc test is available for the Friedman analysis, it is not possible to determine which years are significantly different from one another for weedy species richness. However, by examining the graph it appears that weedy species richness has generally increased since the inception of the monitoring program (Fig. 30). It will be important to continue to monitor these patterns to determine if the presence of problematic weedy species is increasing in the Credit River Watershed.

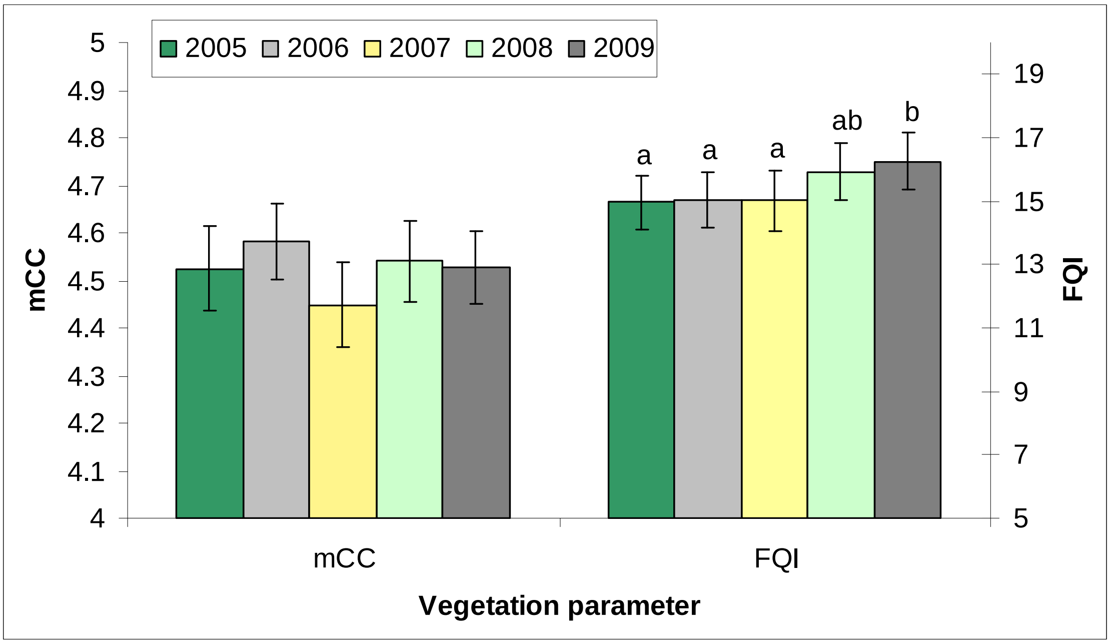


Figure 28. Mean mCC and FQI across sites, as affected by year. Within vegetation parameters, bars with different letters indicate a significant difference according to Tukey's HSD test for unequal sample sizes ($p<0.05$). Error bars indicate +/- SE.

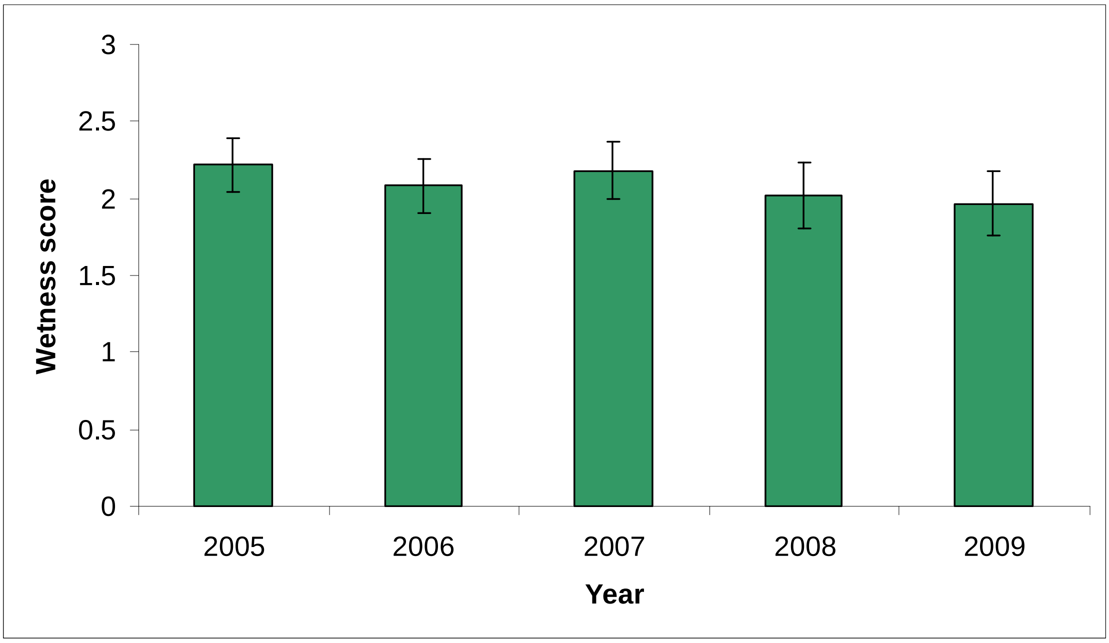


Figure 29. Mean wetness score across sites, as affected by year. Error bars indicate +/- SE.

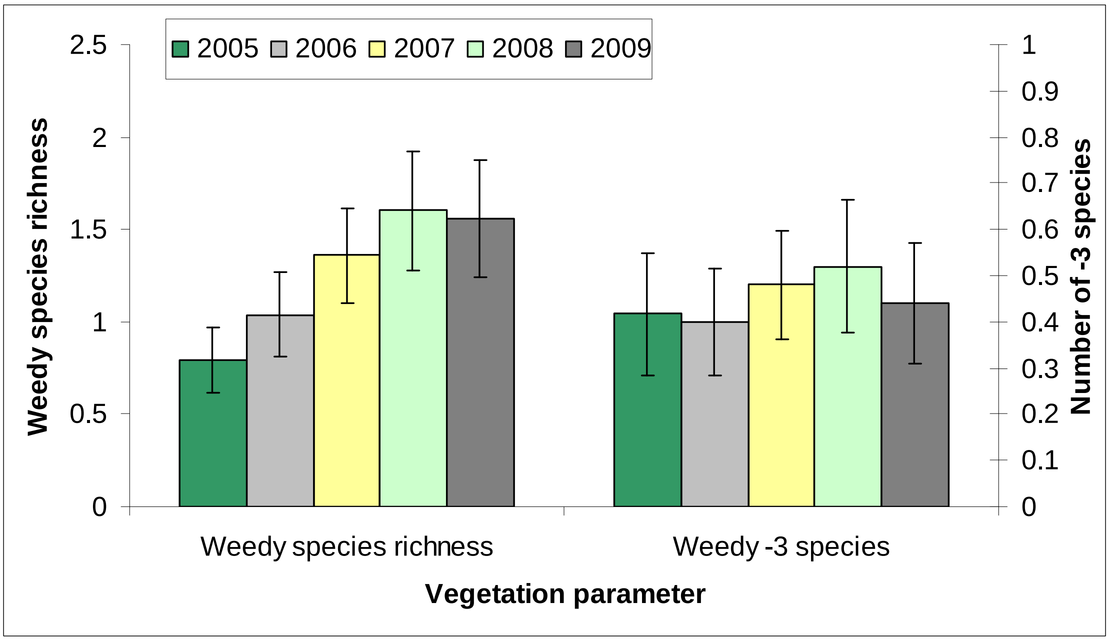


Figure 30. Mean weedy species richness and the average number of -3 weedy species across sites, as affected by year. Error bars indicate +/- SE.

Table 15 lists the critical and warning limits calculated for each forest vegetation parameter using the five available years of data. These upper and lower limits will be adopted as monitoring thresholds for comparison with future vegetation monitoring data. Future values that exceed the upper or lower warning limits (2 SD) will provide a forewarning of potentially increasing or declining trends, and values that exceed the upper and lower critical limits (3 SD) will signify a significant deviation from natural variability. Such deviations may warrant immediate management action before trends became irreversible. No monitoring thresholds can be applied to ground vegetation diversity, as this parameter was not in control.

Table 15. Monitoring thresholds for forest vegetation parameters extracted from Statistical Process Control Individual Moving Average (IMA) charts for data collected from 2005 through 2009.

Parameter	**Thresholds** [a]			
	Lower Critical Threshold	**Lower Warning Threshold**	**Upper Warning Threshold**	**Upper Critical Threshold**
Richness				
Combined Vegetation Richness	12.35	13.01	15.67	16.34
Regeneration Overall Richness	4.54	4.79	5.81	6.06
Regeneration Tree Richness	3.01	3.22	4.08	4.28
Regeneration Shrub Richness	1.36	1.46	1.86	1.96
Total Ground Vegetation Richness	8.42	9.46	13.62	14.66
Herbaceous Richness	6.06	6.62	8.4	9.4
Woody Richness	1.51	2.28	5.36	6.14
Evenness				
Regeneration Evenness	0.76	0.78	0.87	0.90
Ground Vegetation Evenness	0.59	0.63	0.77	0.80
Diversity				
Regeneration Diversity	0.33	0.38	0.56	0.61
Ground Vegetation Diversity	*Not in control*			
Proportion of Native Species				
Ground Vegetation	0.87	0.88	0.91	0.93
Combined Vegetation	0.89	0.90	0.94	0.95
Regeneration Stem Counts				
Shrub Stem Counts				
a) Total	9.04	11.56	21.62	24.14
b) 16-95cm	8.53	10.87	20.21	22.56
c) >95cm	0.42	0.63	1.49	1.69
Tree Stem Counts				
a) Total	17.24	27.44	68.26	78.45
b) 16-95cm	12.36	22.05	60.81	70.50
c) >95cm	4.77	5.32	7.50	8.05
Floristic Quality				
mCC	4.33	4.39	4.65	4.72
FQI	14.56	14.85	16.03	16.32
Wetness	1.80	1.90	2.29	2.39
Weedy Species Richness	0.706	0.894	1.646	1.835
Weediness Count -3	0.31	0.37	0.54	0.60

[a] Limits are presented in the specific units used to measure each given parameter.

Power analysis was completed for all vegetation parameters which were in control (Table 16). According to power analysis 38.1, 7.2 and 2.6 sites would be needed in order to detect 1, 2 and 3 SD of change, respectively, over five monitoring years for all vegetation parameters analyzed using linear regression analysis. Therefore, a sufficient number of sites were monitored to detect significant changes in the vegetation parameters with 90% power at an 80% confidence level for effect sizes greater than or equal to 2 SD. This is important because changes in the magnitude of 2 SD will be used as a warning threshold in statistical process control and changes in the magnitude of 3 SD will be used as the critical threshold. Detectable effect size for the vegetation parameters were ranked as "Green" for most parameters with the exception of woody ground vegetation richness and regeneration stem count parameters. This means that the data quality is good according to the standards applied by Dobbie et al. (2006).

Table 16. Power analysis results for detecting effect sizes for Trend Analyses.

Parameter	Minimum Detectable Percent Change (%)[a]	Data Quality
Ground Vegetation		
Total Ground Vegetation Richness	19.1	Green
Woody Ground Vegetation Richness	28.8	Yellow
Herbaceous Ground Vegetation Richness	18.1	Green
Regeneration		
Total Regeneration Richness	6.6	Green
Tree Regeneration Richness	8.2	Green
Shrub Regeneration Richness	6	Green
Regeneration Diversity	10.6	Green
Tree Regeneration Stem Count - All Stems	28.5	Yellow
Tree Regeneration Stem Count - 16-95cm	31.6	Yellow
Tree Regeneration Stem Count - >95cm	21.8	Yellow
Shrub Regeneration Stem Count - All Stems	29.5	Yellow
Shrub Regeneration Stem Count - 16-95cm	30.2	Yellow
Shrub Regeneration Stem Count - >95cm	23.7	Yellow
Combined Vegetation		
Combined Species Richness	11.5	Green
Wetness	6.6	Green
mCC	1.4	Green
FQI	5.1	Green

[a] Values represent the minimum effect size detectable under current monitoring conditions.

3.2.7 Species Level Analyses

Monitoring Question: Were trends in site occupancy observed for individual forest vegetation species over the monitoring period?

- Brown-seed Dandelion increased in occurrence between 2005 and 2009.
- White Ash decreased in occurrence between 2005 and 2009.

Trends were examined for forest vegetation selected species using the Cochrane-Armitage Test. Trends in species occurrence were examined separately for the ground vegetation and regeneration layers. Ground vegetation species examined included Garlic Mustard, Canada Mayflower, Brown-seed Dandelion, and Trillium species. In addition, two regeneration species were examined, including White Ash and Common Buckthorn (Table 17). Two species exhibited significant trends over time: Brown-seed Dandelion increased and White Ash decreased between 2005 and 2009. Brown-seed Dandelion was not recorded at any sites in 2005, but occurred at nine sites by 2009. This may be an artifact of poor sampling in the early years of the monitoring program, however continued monitoring will reveal if this is a concerning trend.

White Ash was detected in the regeneration layer at 17 sites in 2005, but decreased steadily to 10 sites by 2009. This trend is concerning, as White Ash is currently under threat from the Emerald Ash Borer (*Agrilus planipennis*) in Southern Ontario, and has been detected within the Region of Peel (Canadian Food Inspection Agency 2009). However, White Ash populations sometimes undergo declines triggered by climate-induced stress (Farrar 1995). Further monitoring will reveal whether observed decreases in Ash are due to natural cyclic patterns and if management action is required.

Power analysis and Statistical Process Control were completed for species evaluated with the Cochrane-Armitage test (Table 17, Table 18). Power analysis revealed that under the current monitoring program, data quality is generally poor using the Cochrane-Armitage test to examine trends in species occurrence (Table 18). It appears that examining trends in individual species site occupancy may have limited utility within the current monitoring program, as a larger sample size is needed to detect changes of 2 SD (warning threshold). Therefore, it may be necessary for the current monitoring program to re-evaluate its current methodology for examining individual species trends, to yield results which are meaningful for ecological management.

Table 17. Cochrane-Armitage results and power analysis for selected species trends between 2005 and 2009.

Vegetation Parameter	**Critical Z**	**Observed Z**	**p-value**[a]	**Thresholds**			**Minimum Detectable Effect Size (SD)**	**Data Quality**
				1SD	**2SD**	**3SD**		
Ground Vegetation								
Brown-seed Dandelion	**3.013**	**1.960**	**0.003**	62	28	16	2.5	Yellow
Canada Mayflower	0.127	1.960	0.899	124	59	34	4.7	Red
Garlic Mustard	0.518	1.960	0.604	144	67	43	5.3	Red
Trillium species	1.257	1.960	0.209	511	252	166	18.5	Red
Regeneration								
Common Buckthorn	0.275	1.960	0.783	443	218	143	16.1	Red
White Ash	**2.332**	**1.960**	**0.020**	72	33	20	2.8	Yellow

[a] Results were considered significant when p<0.05, and are reported in bold.

Table 18. Monitoring thresholds for individual forest vegetation species extracted from Statistical Process Control individual (moving average) IMR charts for data collected from 2005 through 2009.

Parameter	**Thresholds**[a]			
	Lower Critical Threshold	**Lower Warning Threshold**	**Upper Warning Threshold**	**Upper Critical Threshold**
Ground Vegetation				
Brown-seed Dandelion	*Can not detect*	0.059	0.453	0.549
Canada Mayflower	*Can not detect*	0.019	0.417	0.517
Garlic Mustard	0.006	0.079	0.373	0.447
Trillium	0.087	0.104	0.170	0.187
Regeneration				
Common Buckthorn	*Can not detect*	0.002	0.112	0.139
White Ash	0.385	0.459	0.753	0.826

[a] Limits are presented in the specific units used to measure each given parameter.

3.3 SPATIAL ANALYSES

3.3.1 Forest Vegetation Spatial Analyses

Monitoring Question: Did forest vegetation differ among physiographic zones within the Credit River Watershed?

- Herbaceous ground vegetation richness was greater in the Upper watershed than the Lower watershed
- The number of -3 weedy species was generally greater in the Lower watershed than the Upper watershed

Only two forest vegetation parameters exhibited differences among physiographic zones within the Credit River Watershed. Species richness was consistently similar among zones (Table 19), with the exception of herbaceous ground vegetation richness (F=4.327, p=0.027; Fig. 31). This parameter exhibited significantly fewer species in the Lower watershed than Upper watershed (post-hoc p=0.037). Species evenness, diversity the proportion of native species, and the remainder of species richness parameters were all consistently similar among zones (Table 19; Fig. 31, Fig. 32, Fig. 33, Fig. 34). In addition, no differences were observed in the number of regenerating trees and shrubs in each zone (Table 19; Fig. 35, Fig. 36). From visual examination of the data it appears that the Lower zone contains fewer regenerating shrubs than the other two zones (Fig. 36). However, there was a large amount of variation between sites, and thus no significant differences were detected.

When floristic quality parameters were examined there was no difference in the mCC, FQI (Fig. 37) or the mean wetness index per site (Fig. 38) among zones. Furthermore, it was expected that the impact of weedy species would be greatest in the Lower watershed, as non-native species are known to persist in disturbed environments caused by urbanization (McKinney 2006). No spatial differences were observed for the average weedy species richness (Fig. 39), however the Kruskal-Wallis test detected significant differences in the number of -3 weedy species between physiographic zones in three of the five survey years (2006 H=8.044, p=0.018; 2007 H=8.754, p=0.013; 2009 H=6.431, p=0.040; Table 19). The associated post-hoc test was only able to differentiate among zones in 2007, where the Lower watershed contained a greater number of -3 weedy species than the Upper watershed (p=0.048; Fig. 39).

Overall, it was surprising that so few differences were detected among physiographic zones in the watershed, as vegetation is known to be impacted by urbanization and habitat fragmentation (Fahrig 2003; McKinney 2006). Urban land cover accounts for 57% of area in the Lower watershed, but only 15% of land use in the Middle and Upper zones (Fig. 40). The lack of differences among physiographic zones may result from the differences among sites within a given zone being much greater than the differences among the zones themselves. The sites included in the forest monitoring program represent a wide variety of forest communities, successional stages, and habitat qualities. For example, the Middle watershed contains Fairy Lake, an early successional forest, as well as mature forests such as Warwick. Sites included in the monitoring program also represent coniferous, deciduous and mixed forest types. Future spatial analyses should aim to separate habitats based on community type and successional stage, which will be possible after detailed Ecological Land Classification of each site is completed in 2010.

Power analysis was completed for all vegetation parameters which were in control. According to this analysis 33, 12 and 9 sites would be needed across the watershed to detect 1, 2 and 3 SD of change, respectively, for all vegetation parameters analyzed using repeated-measures ANOVA analysis. Therefore, a sufficient number of sites were monitored to detect significant changes in the vegetation parameters with 90% power at an 80% confidence level for effect sizes greater than or equal to 2 SD.

Table 19. Summary of spatial analysis results using repeated measures ANOVA or the Kruskal-Wallis test for vegetation parameters between 2005 and 2009.

Parameter	Physiographic Effect		Physiographic Differences
	F-value	P-value[a]	
Richness			
Combined Vegetation Richness	3.019	0.070	None
Total Regeneration Richness	1.229	0.313	None
Regeneration Tree Richness	0.718	0.499	None
Regeneration Shrub Richness	1.105	0.350	None
Total Ground Vegetation Richness	1.158	0.070	None
Herbaceous Ground Vegetation Richness	**4.327**	**0.027**	Upper > Lower
Woody Ground Vegetation Richness	1.167	0.331	None
Evenness			
Regeneration Evenness[b]	1.299	0.522	None
Ground Vegetation Evenness[b]	1.377	0.502	None
Diversity			
Regeneration Diversity	1.262	0.304	None
Ground Vegetation Diversity	2.470	0.109	None
Proportion of Native Species			
Ground Vegetation[b]	1.664	0.435	None
Combined Vegetation[b]	0.178	0.411	None
Regeneration Stem Counts			
Shrub Stem Counts			
a) Total[b]	2.252	0.324	None
b) 16-95cm[b]	3.284	0.194	None
c) >95cm[b]	0.033	0.984	None
Tree Stem Counts			
a) Total	0.309	0.737	None
b) 16-95cm	0.052	0.949	None
c) >95cm	2.285	0.127	None
Floristic Quality			
mCC	0.167	0.233	None
FQI	2.827	0.082	None
Wetness	0.101	0.904	None
Weedy Species Richness[b]	2.200	0.333	None
Weediness Count -3[b]	**6.431**	**0.040**	Lower > Upper[c]

[a] Results were considered significant when $p<0.05$, and are reported in bold.

[b] Kruskal Wallis test conducted for each year separately to test for effect of physiographic zone on relative abundance of those same species, with H and p values shown for 2009 tests only.

[c] Tukeys post-hoc $p=0.12$ in 2009.

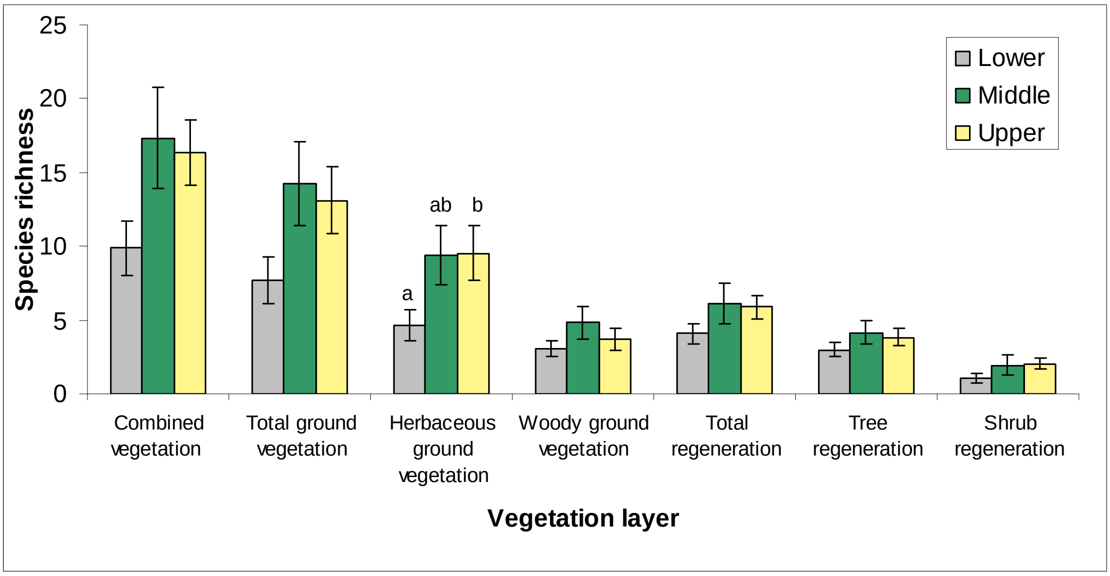


Figure 31. Mean vegetation species richness across sites, within each physiographic zone within the Credit River Watershed. Within vegetation parameters, bars with different letters indicate a significant difference according to Tukey's HSD test for unequal sample sizes (p<0.05). Error bars indicate +/- SE.

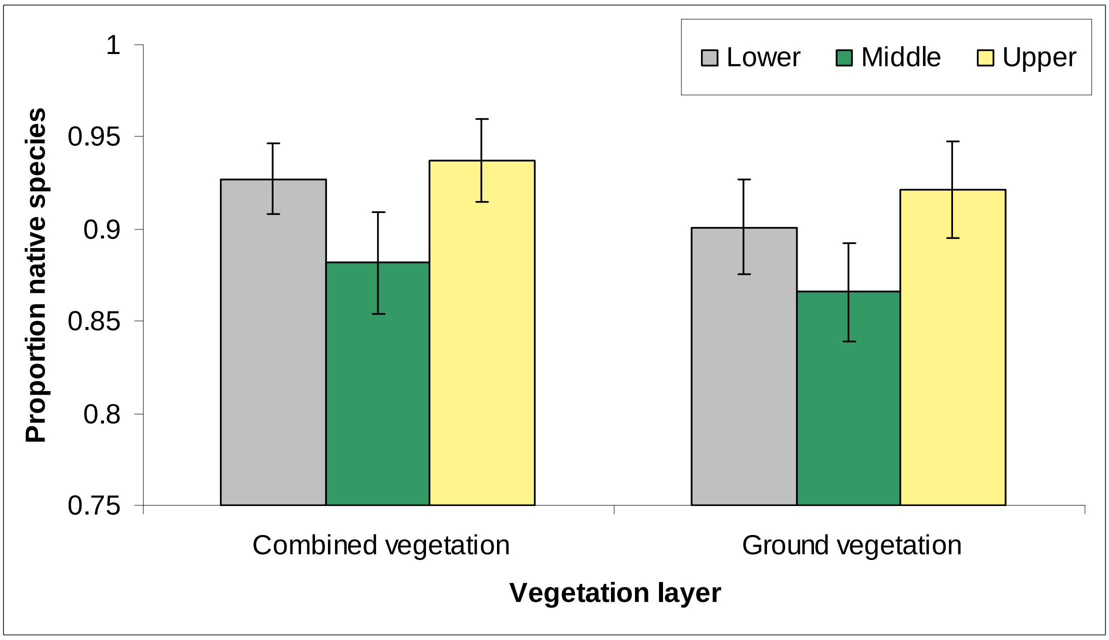


Figure 32. Mean proportion of native species across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

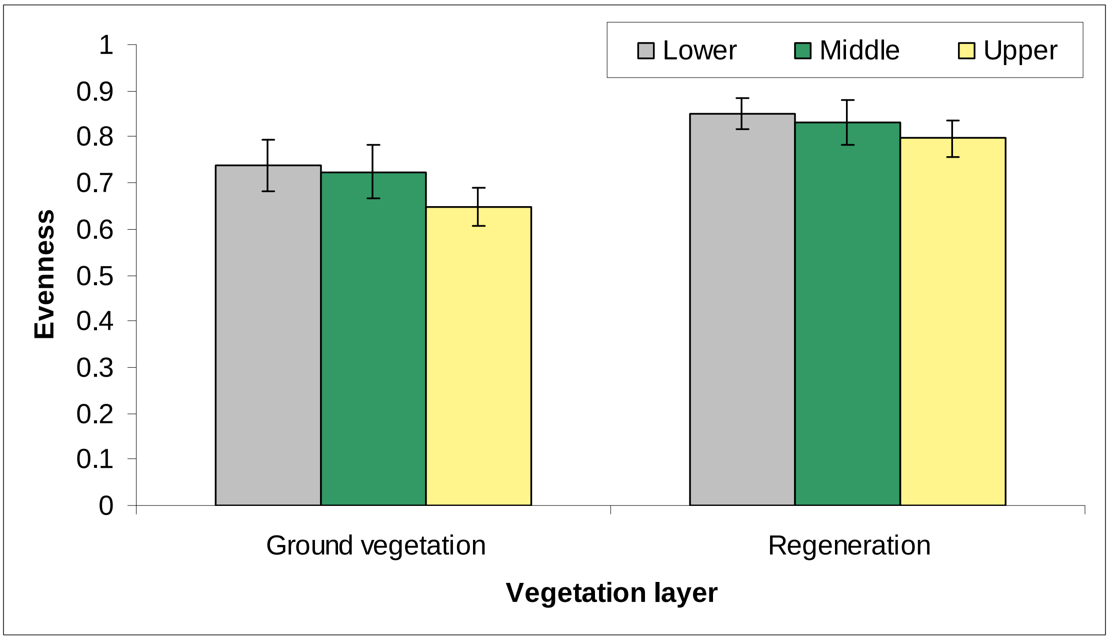


Figure 33. Mean vegetation evenness across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

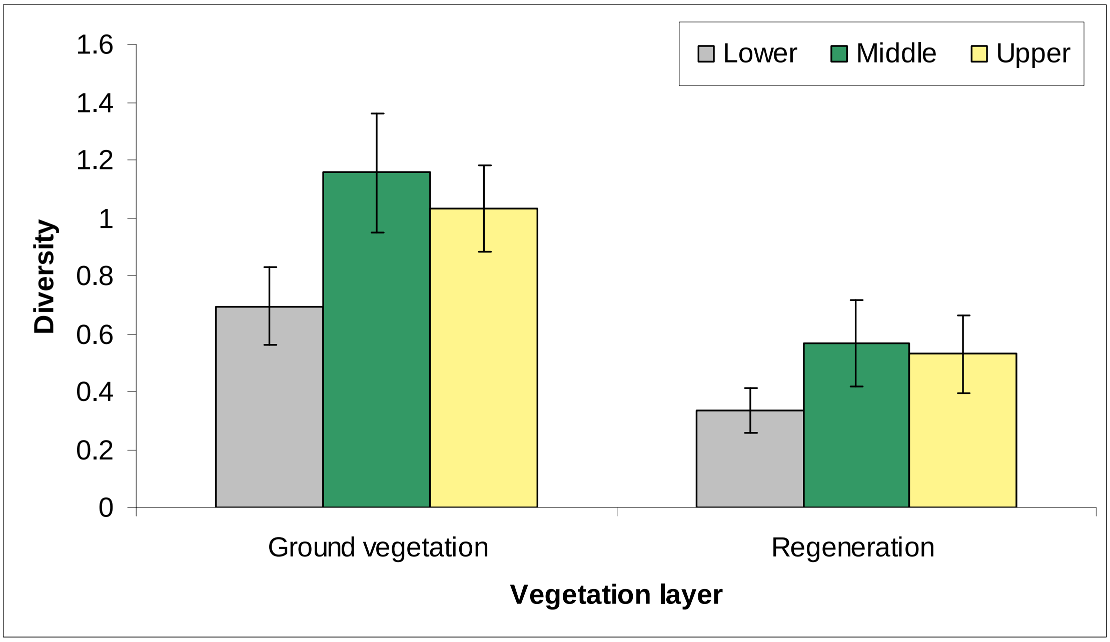


Figure 34. Mean vegetation diversity across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

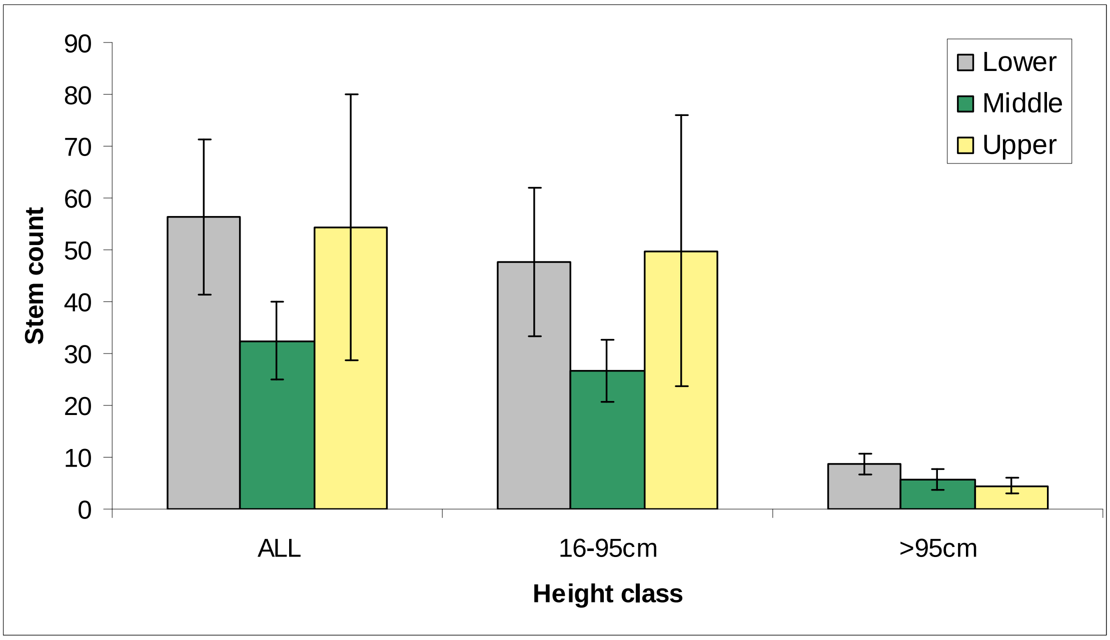


Figure 35. Mean number of regenerating tree stems across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

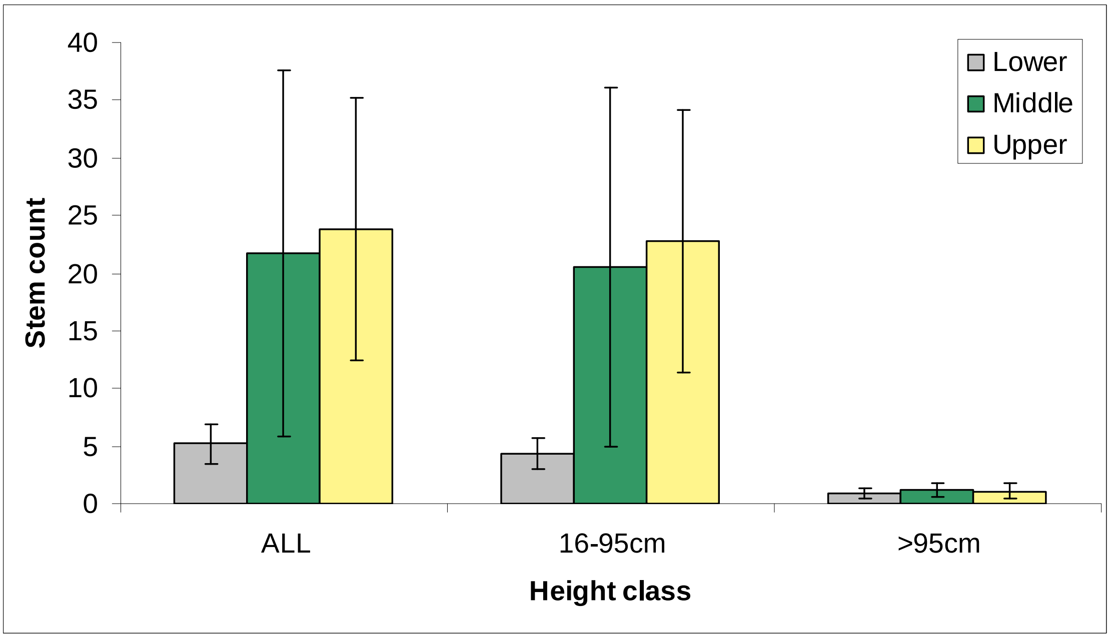


Figure 36. Mean number of regenerating shrub stems across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

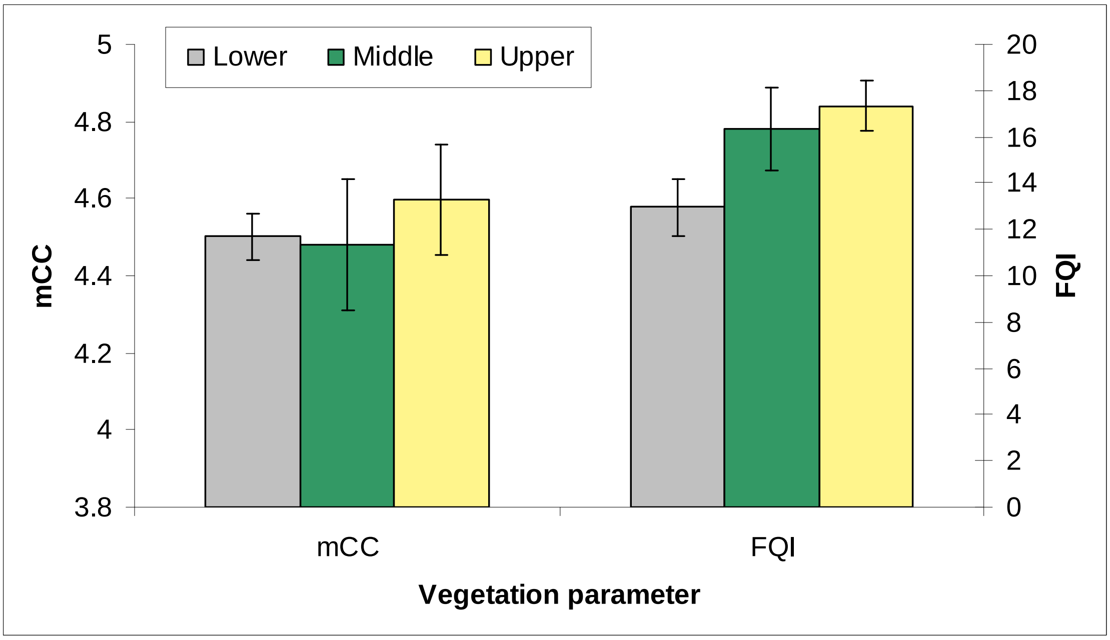


Figure 37. Mean mCC and FQI across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

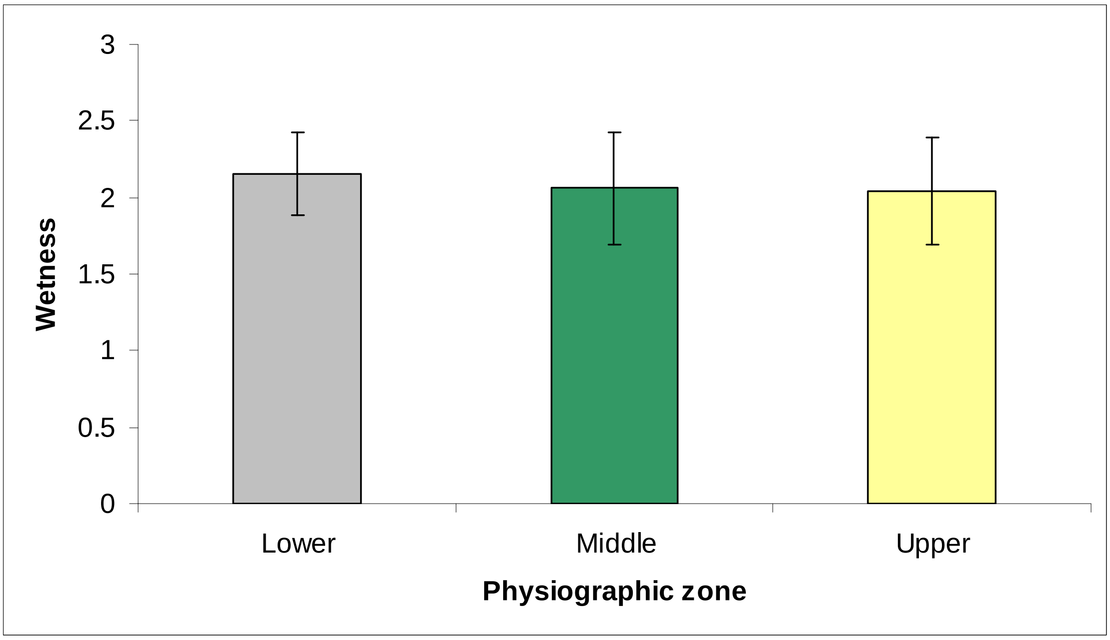


Figure 38. Mean wetness index across sites within each physiographic zone within the Credit River Watershed. Error bars indicate +/- SE.

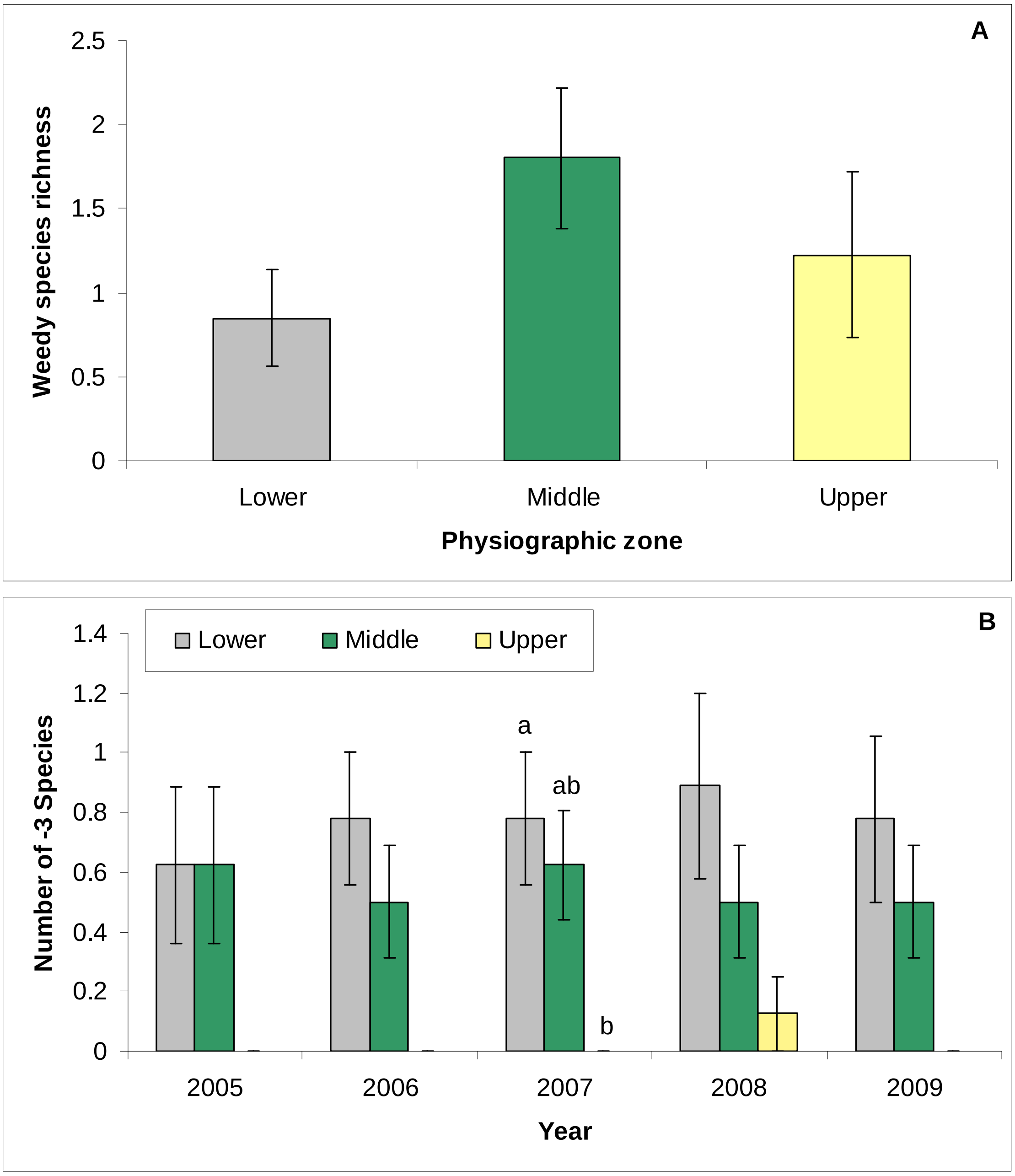


Figure 39. Mean weedy species richness (a) and number of -3 weedy species (b) across sites within each physiographic zone within the Credit River Watershed. Within vegetation parameters, bars with different letters indicate a significant difference according post-hoc analysis (*p*<0.05). Error bars indicate +/- SE.

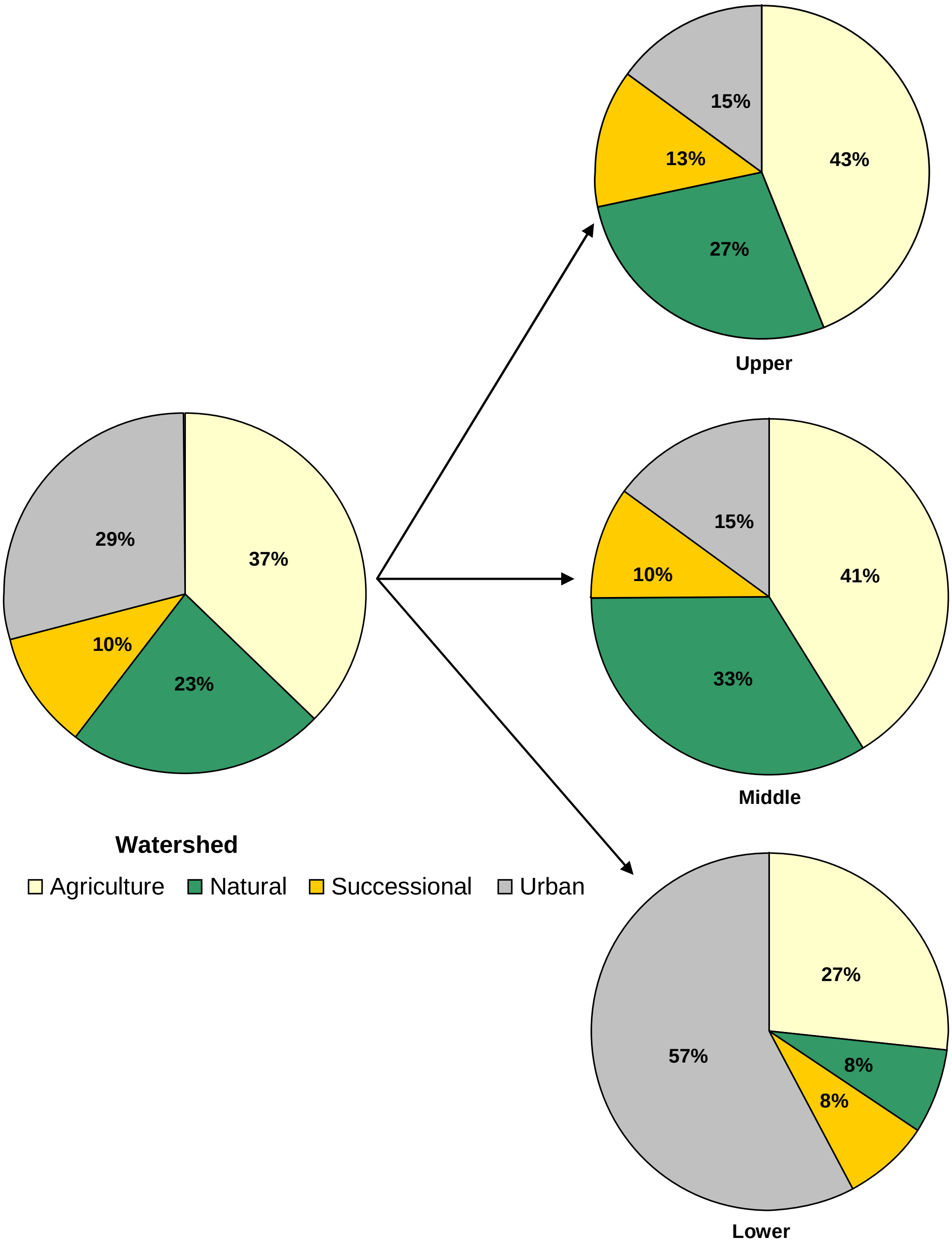


Figure 40. Land cover in the Credit River Watershed (Credit Valley Conservation 2007a).

3.4 LANDSCAPE ANALYSIS

3.4.1 Vegetation Parameters

Monitoring Question: Was there a correlation between forest vegetation parameters and landscape metrics in the Credit River Watershed?

- Combined vegetation richness, total ground vegetation richness, ground vegetation evenness, ground vegetation diversity, tree stems >95 cm, FQI, weedy species richness and the number of -3 weedy species were all significantly correlated with landscape metrics.

Spearman rank correlation was used to examine relationships between forest vegetation and landscape metrics in the Credit River Watershed. Significant correlations must be considered cautiously, as they do not imply a cause-and-effect relationship between two parameters, but simply that the parameters are associated with one another (Zar 1999).

Comparisons were made between twenty-two vegetation parameters and five landscape metrics. Only eight of the vegetation parameters were significantly correlated with landscape metrics: combined vegetation richness, total ground vegetation richness, ground vegetation evenness, ground vegetation diversity, tree stems >95 cm, FQI, weedy species richness and the number of -3 weedy species (Table 20). Two richness parameters, combined vegetation richness and ground vegetation richness, were significantly correlated with habitat patch size, percent natural area and matrix quality. The correlation between richness and the landscape metrics is intuitive as increasing patch size will increase the amount of natural area near the monitoring site and conversely, urbanization is known to have negative effects on vegetation species richness (McKinney 2008). In compliment with these results, ground vegetation diversity was significantly correlated with habitat patch size and percent natural cover. Ground vegetation evenness was also correlated with habitat patch size.

Weedy species richness was positively correlated with habitat patch size. This is because very few species were detected in forest plots located in small habitat patches. As habitat patch size increased, the total number of species was observed to increase, corresponding with an increase in weedy species. On the other hand, the number of potentially problematic (-3) weedy species was negatively correlated with percent agricultural area and positively correlated with percent urban area. This is consistent with work that has found that urbanization leads to an increase in non-natives species in forest vegetation (Duguay et al. 2007).

Finally, distance to the nearest road was not correlated with any vegetation parameters. Local biodiversity may be negatively affected by roads through obstructing migration between local populations, increasing edge effects in habitat patches, increasing the transportation of chemicals, and facilitating the invasion of exotic species (Forman and Alexander 1998). None of the studied vegetation parameters were correlated with the distance to the nearest road (Table 20). Relationships may not have been noted in this study as the density of surrounding roads was not taken into account. The density of roads surrounding the forested areas may be more indicative of the effects of roads on vegetation species than the distance to a nearby road. For example, Belfountain Forest is situated only 91 m from the nearest road; however, it is located in the Upper watershed where natural land cover is more dominant than urban cover and it is located in a natural habitat patch of over 400 ha. In contrast, Huttonville Forest is located 223 m from the nearest road and is located in the Lower watershed in a natural habitat patch of only 18 ha. Although Belfountain is more than twice as close to a road than Huttonville, many parameters indicative of healthy forest vegetation were consistently higher at the Belfountain site. Therefore, distance to the nearest road may not be an effective indicator of the effects of roads on forest vegetation because it does not account for the type of road and the amount of habitat fragmentation surrounding the monitoring site.

Table 20. Spearman rank correlations between forest vegetation parameters and habitat patch size and distance to the nearest road.

Vegetation Variable	**Habitat Patch Size**		**Distance to Nearest Road**	
	Spearman R	***P* value** [a]	**Spearman R**	***P* value** [a]
Richness				
Combined Vegetation Richness	**0.518**	**0.008**	0.183	0.382
Total Regeneration Richness	0.110	0.600	0.127	0.545
Regeneration Tree Richness	0.151	0.472	0.217	0.297
Regeneration Shrub Richness	0.108	0.609	0.003	0.987
Total Ground Vegetation Richness	**0.546**	**0.005**	0.241	0.247
Evenness				
Regeneration Evenness	-0.058	0.784	-0.155	0.458
Ground Vegetation Evenness	**-0.407**	**0.044**	0.048	0.821
Diversity				
Regeneration Diversity	0.132	0.528	0.232	0.265
Ground Vegetation Diversity	**0.455**	**0.022**	0.335	0.101
Proportion of Native Species				
Ground Vegetation	-0.152	0.469	-0.089	0.671
Combined Vegetation	-0.280	0.175	-0.179	0.393
Regeneration Stem Counts				
Shrub Stem Counts				
a) Total	0.002	0.993	0.134	0.523
b) 16-95cm	0.014	0.946	0.124	0.556
c) >95cm	-0.032	0.880	0.134	0.522
Tree Stem Counts				
a) Total	-0.144	0.491	0.105	0.617
b) 16-95cm	-0.005	0.980	0.189	0.365
c) >95cm	**-0.605**	**0.001**	-0.195	0.351
Floristic Quality				
mCC	0.371	0.068	0.103	0.950
FQI	**0.562**	**0.003**	0.139	0.507
Wetness	0.086	0.682	0.073	0.728
Weedy Species Richness	**0.402**	**0.046**	0.186	0.373
Weediness Count -3	-0.113	0.591	-0.009	0.964

[a] Results were considered significant when $p<0.05$ and are reported in bold.

Table 21. Spearman rank correlations between forest vegetation parameters and % Agriculture, % Natural, % Urban and Matrix Quality.

Vegetation Variable	**% Agriculture**		**% Natural**		**% Urban**		**Matrix Quality**	
	Spearman R	***P* value** [a]	**Spearman R**	***P* value** [a]	**Spearman R**	***P* value** [a]	**Spearman R**	***P* value** [a]
Richness								
Combined Vegetation Richness	0.111	0.598	**0.501**	**0.011**	-0.351	0.085	**0.433**	**0.031**
Total Regeneration Richness	0.324	0.115	0.180	0.389	-0.328	0.110	0.195	0.345
Regeneration Tree Richness	0.315	0.124	0.186	0.372	**-0.420**	**0.037**	0.284	0.168
Regeneration Shrub Richness	0.220	0.291	0.160	0.444	-0.170	0.417	0.094	0.655
Total Ground Vegetation Richness	0.022	0.918	**0.512**	**0.009**	-0.296	0.151	**0.423**	**0.035**
Evenness								
Regeneration Evenness	0.112	0.956	-0.127	0.545	-0.040	0.849	0.001	0.997
Ground Vegetation Evenness	0.242	0.245	-0.298	0.147	-0.042	0.844	-0.142	0.497
Diversity								
Regeneration Diversity	0.206	0.323	0.183	0.381	-0.284	0.169	0.132	0.528
Ground Vegetation Diversity	-0.017	0.936	**0.425**	**0.034**	-0.205	0.327	0.326	0.112
Proportion of Native Species								
Ground Vegetation	0.142	0.498	0.089	0.670	-0.228	0.273	0.165	0.432
Combined Vegetation	0.094	0.655	-0.049	0.815	-0.141	0.503	0.027	0.896
Regeneration Stem Counts								
Shrub Total	0.269	0.193	0.099	0.638	-0.183	0.382	0.042	0.844
Shrub 16-95cm	0.244	0.240	0.117	0.576	-0.191	0.361	0.044	0.835
Shrub >95cm	0.164	0.433	-0.105	0.618	-0.011	0.958	-0.082	0.696
Tree Total	-0.134	0.522	-0.047	0.824	0.185	0.375	-0.122	0.560
Tree 16-95cm	-0.130	0.536	0.075	0.720	0.115	0.585	-0.012	0.953
Tree >95cm	0.214	0.305	**-0.452**	**0.023**	0.181	0.387	0.387	0.056

Vegetation Variable	**% Agriculture**		**% Natural**		**% Urban**		**Matrix Quality**	
	Spearman R	***P* value [a]**	**Spearman R**	***P* value [a]**	**Spearman R**	***P* value [a]**	**Spearman R**	***P* value [a]**
Floristic Quality								
mCC	-0.255	-1.267	0.367	0.071	0.000	1.000	0.348	0.089
FQI	0.021	0.922	**0.572**	**0.003**	-0.329	0.108	**0.515**	**0.008**
Wetness	-0.202	0.334	0.076	0.718	-0.098	0.642	0.074	0.726
Weedy Species Richness	-0.066	0.752	0.212	0.310	0.002	0.993	0.138	0.511
Weediness Count -3	**-0.456**	**0.022**	-0.206	0.322	**0.437**	**0.029**	-0.319	0.120

[a] Results were considered significant when $p<0.05$ and are reported in bold.

3.4.2 Species Level Analyses

Monitoring Question: Was there a relationship between selected species and landscape metrics in the Credit River Watershed?

- Brown-seed Dandelion and Garlic Mustard increased as the proportion of urban cover increased.

Logistic regression was used to test the relationship between selected vegetation species in the watershed and landscape metrics, including habitat patch size, distance to the nearest road, percent natural cover and percent urban cover. Species examined included: Brown-seed Dandelion, Canada Mayflower, Garlic Mustard and Trillium species.

No taxa displayed relationships with distance to nearest road, habitat patch size or percent natural cover. Although roads may facilitate the dispersal of invasive non-native species (Forman and Alexander 1998), the lack of relationship between the selected species and distance to the nearest road was consistent with the non-significant correlations with vegetation parameters (Table 20; Table 21). Examining the density of roads surrounding forest sites may provide more meaningful results.

The lack of relationship between either habitat patch size or percent natural cover and vegetation species was surprising. Larger patches and areas with greater natural cover are expected to contain more native species that are less tolerant of habitat disturbance, such as Canada Mayflower and Trillium species (Coefficients of Conservatism = 5-6). Large habitat patches were also expected to be less likely to contain non-native species, which thrive in disturbed environments. Indeed, this pattern was observed in wetland monitoring plots, where Garlic Mustard was had a higher probability of being observed in smaller habitat patches (CVC 2010c).

Finally, Brown-seed Dandelion and Garlic Mustard were more likely to be found in forest plots surrounded by high urban cover (Table 22; Fig. 41, Fig. 42). This was expected as non-native species are known to increase with urbanization (McKinney 2006).

Table 22. Logistic relationships between selected species and landscape metrics.

Species	**Landscape Metric**	**Test Statistic (X^2)**	***p* value [a]**
Brown-seed Dandelion	Habitat Patch Size	1.112	0.292
	Distance to Nearest Road	1.368	0.242
	% Natural Cover	2.129	0.145
	% Urban Cover	**13.454**	**<0.001**
Canada Mayflower	Habitat Patch Size	0.098	0.754
	Distance to Nearest Road	0.074	0.785
	% Natural Cover	0.814	0.367
	% Urban Cover	2.956	0.086
Garlic Mustard	Habitat Patch Size	0.108	0.743
	Distance to Nearest Road	0.090	0.764
	% Natural Cover	1.339	0.247
	% Urban Cover	**4.221**	**0.040**
Trillium species	Habitat Patch Size	0.196	0.658
	Distance to Nearest Road	0.706	0.401
	% Natural Cover	0.529	0.467
	% Urban Cover	0.334	0.563

[a] Results were considered significant when $p<0.05$, and are reported in bold.

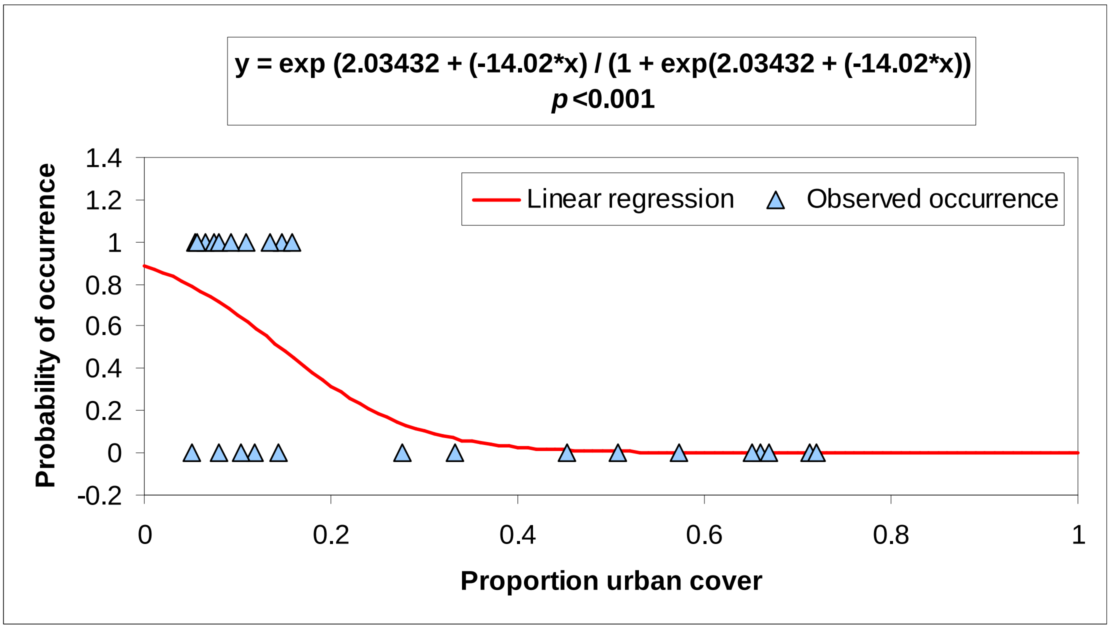


Figure 41. Logistic regression between Brown-seed Dandelion and proportion of urban cover. Equation of the regression line and p-value provided. Logistic regression significant when $p<0.05$.

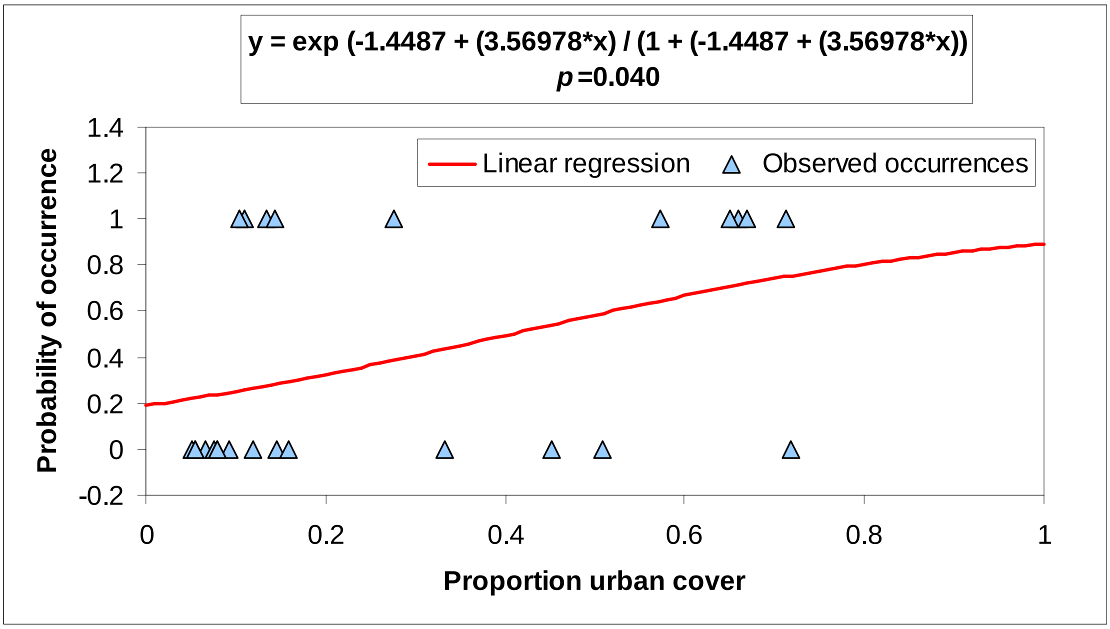


Figure 42. Logistic regression between Garlic Mustard (*Alliaria petiolata*) and proportion of urban cover. Equation of the regression line and p-value provided. Logistic regression significant when $p<0.05$.

Table 23 lists the number of monitoring sites required to determine a significant logistic relationship between the presence of the selected species and the landscape metrics. Analysis could not be performed for percent urban cover, as it had a bimodal distribution that could not be normalized. Several of the calculated N values were alarmingly high. For example, 1013 sites were required to legitimately detect a relationship between Garlic Mustard and distance to the nearest road. The significant relationship between Canada Mayflower and habitat patch size required 128 monitoring sites for legitimate reporting. Such a large number of monitoring sites are not reasonable within the monitoring program.

Table 23. The calculated number of monitoring sites (N) required to determine a significant logistic relationship between selected species and landscape metrics.

Species	**Landscape Metric** [a]	**Number of Sites Required (N)** [b]	**Data Quality**
Brown-seed Dandelion	Habitat Patch Size	41	Red
	Distance to Nearest Road	69	Red
	% Natural Cover	39	Red
Canada Mayflower	Habitat Patch Size	128	Red
	Distance to Nearest Road	644	Red
	% Natural Cover	186	Red
Garlic Mustard	Habitat Patch Size	298	Red
	Distance to Nearest Road	1013	Red
	% Natural Cover	97	Red
Trillium spp.	Habitat Patch Size	4803	Red
	Distance to Nearest Road	750	Red
	% Natural Cover	246	Red

[a] Habitat patch size was square root transformed and distance to nearest road was log transformed for power analysis.
[b] Number of sites required to detect a significant logistic relationship.

4.0 CONCLUSIONS

Several forest vegetation parameters were stable in the Credit River Watershed between 2005 and 2009. The only vegetation parameters exhibiting significant trends were total ground vegetation richness and ground vegetation diversity, which increased over the monitoring period. All other vegetation parameters, including regeneration species richness, species evenness, regeneration diversity, regeneration stem counts, the proportion of native species, and measures of floristic quality, did not exhibit significant trends over time. In addition, differences between years were observed for the majority of vegetation parameters. Yearly fluctuations in vegetation are a normal part of ecosystem functioning, as weather and disturbance fluctuate over time (Woodward and Cramer 1996; Lavorel and Garnier 2002). That being said, ecosystem change in response to environmental degradation is expected to occur slowly (Niemi 2004; Lovett et al. 2007). Therefore, it is encouraging that no forest vegetation trends of concern were detected at this early stage in the monitoring program. In addition, given that forest vegetation was stable, it was possible to set monitoring thresholds for most parameters. These thresholds will be used as a baseline for detecting future concerning trends.

Very few differences in forest vegetation were observed between the three physiographic zones of the Credit River Watershed. It was predicted that the Lower zone would contain the most degraded forest habitats as a result of urbanization, and the Middle watershed would contain the most pristine forests, as it is comprised of the most undeveloped land and protected areas. However, only two of the twenty-four vegetation parameters exhibited spatial differences. The Upper watershed contained greater herbaceous ground vegetation richness than the Lower watershed. In addition, the Lower watershed contained more -3 weedy species than the Upper watershed in 3/5 survey years. The increased number of potentially problematic weedy species in the urbanized Lower watershed supports the need for an invasive species management program at CVC. Overall, these results were surprising, as urbanization is much greater in the Lower watershed than the Middle and Upper watersheds (Fig. 30). Furthermore, several differences have been observed among physiographic zones for other ecological measures monitored in the Terrestrial Monitoring program at CVC, including wetland vegetation, forest birds, forest tree health and wetland anurans (CVC 2010b-e).

Currently, forest community types are not evenly distributed among physiographic zones, and reflect a wide range of potential communities in the Credit River Watershed. Monitored forest communities include deciduous forests dominated by Sugar Maple, coniferous Pine forests and mixed Sugar Maple - Hemlock forests. Ecological Land Classification of the forest community types is currently underway and will lead to greater understanding of the effect of community type on forest vegetation in the Credit River Watershed.

Of the over 100 comparisons made between landscape metrics and vegetation parameters, eighteen significant correlations were detected. Combined species richness, total ground vegetation richness, ground vegetation evenness, ground vegetation diversity, tree stems >95cm, FQI, weedy species richness and the number of -3 weedy species were all significantly correlated with at least one landscape metric. Parameters which are correlated with landscape metrics may be considered good monitoring variables, as they may be sensitive to anthropogenic disturbance (Noss 1999). Special attention should be paid to these vegetation parameters in the future, as increasing or decreasing trends may be an early warning sign for ecosystem degradation.

Overall, very few changes were observed for forest vegetation over the monitoring period. It is encouraging that vegetation appears to be stable over the short term. This monitoring data provides a baseline for detecting future ecosystem change in the Credit River Watershed.

5.0 FUTURE DIRECTIONS

Several improvements and changes to the Terrestrial Monitoring Program are currently being evaluated, which will assist in future data collection and interpretation of results. Ecological Land Classification of all sites will be completed during the summer of 2010. These designations will provide insight to the effect of ecological classification on vegetation in the Credit River Watershed and assist the interpretation of temporal and spatial results. In addition, the Terrestrial Monitoring Program is examining the application of panel design to minimize the impact of monitoring on vegetation plots.

At the data analysis stage, several additional analyses will be explored that were beyond the scope of the five year review. Additional methods recommended by external reviewers (Bohdan Kowalyk, pers. comm.; Emily Gonzales, pers. comm.) will be evaluated, including generalized linear models and Bayesian analyses (Wade 2000) to examine vegetation trends over time. Several other metrics may be incorporated into the analyses as covariates, including: surveyor variation, soil moisture, soil pH, and canopy cover. In addition, vegetation parameters will be compared to other biotic and abiotic parameters such as soil chemistry and pH, birds and salamanders within forest communities.

In addition, thresholds will be established for each monitoring parameter when at least five years of stable baseline data exists. It should be noted that the baselines and thresholds presented in this report are preliminary in nature. The five year baseline period used to calculate indicator thresholds is based on the maximum number of years of reliable data currently available to the monitoring program. These current data represents the best available steady state information. Though indicators may naturally vary above and below these baselines over longer timeframes, we do not currently possess this information. Long term data may reveal additional patterns, such as wider than expected variability or cyclic behaviour oscillating over multiple years. As a result, established baselines and thresholds must be reviewed as additional monitoring data becomes available. To this end, a complete review of all indicator baselines and thresholds will be conducted at the 10 year point of the program.

The limitations of current baselines and thresholds should also be considered in the context of overall monitoring program design. This is because power analysis, a statistical assessment tool that can help inform decisions concerning program design, incorporates values associated with the identified baselines. This reliance on preliminary baselines, combined with the idiosyncrasies associated with individual power analysis techniques and the highly assimilative nature of most ecological indicators, preclude us from making program design decisions based solely on assessment of power. For instance, indicators with low abundance or high natural variability are more likely to provide data of lower power. Even if tests reveal a lack of power in the current program configuration, the data may still be providing valuable information. This is particularly the case when results from all monitoring questions are assessed in an integrated fashion. Hence, program design should be steered by a combination of power analysis, logistic considerations, and integrated ecological knowledge.

Finally, the Terrestrial Monitoring Program is developing a strategy for management actions to be undertaken when an indicator (or a suite of indicators) surpasses their established threshold, indicating a decline in the overall integrity of the Credit River Watershed. Developing a management actions strategy will ensure that detrimental ecosystems changes observed by the Terrestrial Monitoring Program can be mitigated. Through this mitigation the Terrestrial Monitoring Program will assist CVC in achieving its corporate vision of “an environmentally healthy Credit River Watershed for present and future generations.”

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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	County	Physiographic Zone	Habitat Patch Size (Ha)
F-01	Monora Park Forest	Mono	Dufferin	Upper	112.06
F-02	Hillsburgh Forest	Erin	Wellington	Upper	60.43
F-03	Charles Sauriol Forest	Caledon	Peel	Upper	233.83
F-04	Caledon Creek Forest	Caledon	Peel	Upper	134.21
F-05	Robert Baker Forest	Caledon	Peel	Middle	232.56
F-06	Warwick Forest	Caledon	Peel	Middle	191.18
F-07	Silver Creek Forest	Halton Hills	Halton Hills	Middle	370.14
F-08	Limehouse Forest	Halton Hills	Halton Hills	Middle	135.32
F-09	UCC Forest	Halton Hills	Halton Hills	Middle	141.32
F-10	Huttonville Forest	Brampton	Peel	Lower	18.36
F-11	Levi Creek Forest	Mississauga	Peel	Lower	24.2
F-12	Streetsville Forest	Mississauga	Peel	Lower	18.76
F-13	Churchill Meadows Forest	Mississauga	Peel	Lower	5.89
F-14	Roy Ivors Forest	Mississauga	Peel	Lower	24.73
F-15	Winston Forest	Oakville	Halton	Lower	27.24
F-16	Britannia Forest	Mississauga	Peel	Lower	5.19
F-18	Fairy Lake Forest	Halton Hills	Halton Hills	Middle	169.10
F-19	Belfountain Forest	Caledon	Peel	Upper	439.15
F-20	Willoughby Nature Reserve Forest	Caledon	Peel	Middle	93.25
I-01	Mississauga Gardens Forest	Mississauga	Peel	Lower	52.36
I-02	Orpen Lake Forest	Caledon	Peel	Upper	323.18
I-03	Alton Forest	Caledon	Peel	Upper	185.75
I-04	Forks of the Credit Forest	Caledon	Peel	Upper	534.18
I-05	Meadowvale Station Forest	Mississauga	Peel	Lower	45.70
I-06	Terra Cotta Forest	Caledon	Peel	Middle	753.26

APPENDIX B: FOREST VEGETATION PARAMETERS INCLUDED IN ANALYSIS

Table 1: Vegetation parameters analyzed in the Credit River Watershed.

Vegetation Parameter	Normal Distribution	Data Transformation	Analysis Type [a]
Richness			
Combined Vegetation	No	Log (Data +1)	Parametric
Total Ground Vegetation	No	Square-root (Data + 0.5)	Parametric
Herbaceous Ground Vegetation	No	Log (Data +1)	Parametric
Woody Ground Vegetation	No	Log (Data +1)	Parametric
Overall Regeneration	No	Log (Data + 1)	Parametric
Tree Regeneration	No	Square-root (Data + 0.5)	Parametric
Shrub Regeneration[b]	No	Log (Data + 1)	Parametric
Evenness			
Regeneration	NA	None	Non-parametric
Ground Vegetation	NA	None	Non-parametric
Diversity			
Regeneration	No	Log (Data + 1)	Parametric
Ground Vegetation	Yes	None	Parametric
Proportion of Native Species			
Ground Vegetation	NA	None	Non-parametric
Combined Vegetation	NA	None	Non-parametric
Regeneration Stem Counts			
Shrub Stem Counts			
a) Total[b]	NA	None	Non-parametric
b) 16-95cm[b]	NA	None	Non-parametric
c) >95cm	NA	None	Non-parametric
Tree Stem Counts			
a) Total	No	Log (Data + 1)	Parametric
b) 16-95cm	No	Log (Data + 1)	Parametric
c) >95cm	No	Log (Data + 1)	Parametric
Floristic Quality			
mCC	Yes	None	Parametric
FQI	Yes	None	Parametric
Wetness	Yes	None	Parametric
Weedy Species Richness	NA	None	Non-parametric
Weediness Count -3	NA	None	Non-parametric

[a] Parametric analyses were Linear Regression to examine trends over time, and Repeated-Measures ANOVA to examine spatial differences between groups. Non-parametric tests were conducted for data which did not meet parametric test assumptions, and included the Friedman Test to examine temporal differences between years, and Kruskal-Wallis to examine differences over time. Analyses were not completed for the number of locally rare, number of regionally rare and species with high conservatism scores (CC = 8-10).

[b] Data was near normality

APPENDIX C: SEEDLING RATIO INDICES

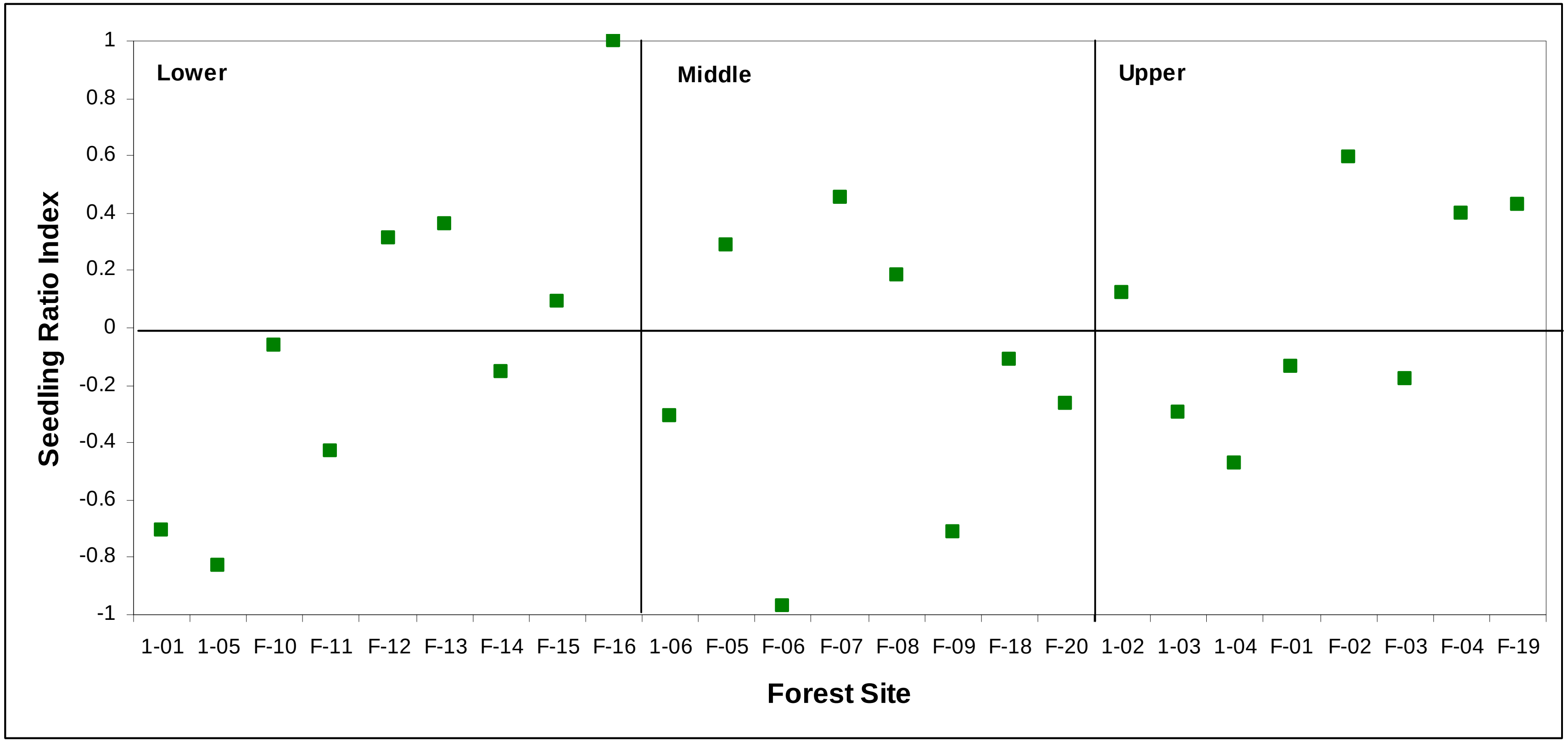

Figure 1. Seedling Ratio Indices (SRI's) for forest sites within the Credit River Watershed. SRI = (Tall Seedlings – Short Seedlings) / (Tall Seedlings + Short Seedlings). The tall seedling category is composed of stems between 36 and 200 cm and short seedlings are less than 36 cm (adapted from Sweetapple and Nugent, 2004). Seedling ratios significantly < 0 can be used to identify forests which are having difficulty regenerating. One possible explanation is extensive deer herbivory, as deer are known to prefer to browse seedlings in the tall category.

APPENDIX D: YEAR OF FIRST DETECTION OF NON-NATIVE WETLAND SPECIES BY THE TERRESTRIAL MONITORING PROGRAM

Table 1. Year of first detection of non-native forest species in the Credit River Watershed by the Terrestrial Monitoring Program

Common Name	Latin Name	Weediness Score	Year of First Detection by Monitoring Program [a]				
			2005	2006	2007	2008	2009
Brown-seed Dandelion	*Taraxacum officinale*	-2		X			
Climbing Nightshade	*Solanum dulcamara*	-2	X				
Common Buckthorn	*Rhamnus cathartica*	-3	X				
Common Burdock	*Arctium minus ssp. minus*	-2				X	
Eastern Helleborine	*Epipactis helleborine*	-2		X			
European Columbine	*Aquilegia vulgaris*	-1			X		
Garlic Mustard	*Alliaria petiolata*	-3	X				
Gypsy-weed	*Veronica officinalis*	-2			X		
Herb-robert	*Geranium robertianum*	-2	X				
Manitoba Maple	*Acer negundo*	NA	X				
Stinging Nettle	*Urtica dioica ssp. dioica*	-1	X				
Tall Buttercup	*Ranunculus acris*	-2				X	
Woods Bluegrass	*Poa nemoralis*	-1	X				
Yellow Hawkweed	*Hieracium caespitosum*	-2	X				

[a] Indicates the year that non-native species were first observed in monitoring plots, not the year that non-natives were first detected within the watershed. 2005 was the year of first detection for many species as it was the first year of the monitoring program.