Credit Valley Conservation

Terrestrial Monitoring Program Report 2013

Landscape Monitoring of Terrestrial Ecosystems in the Credit River Watershed

CREDIT VALLEY CONSERVATION

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ABSTRACT

Landscape Monitoring of Terrestrial Ecosystems in the Credit River Watershed
Overall Landscape: Currently there is 34% natural and semi-natural cover across the Credit River watershed. Woodlands and wetlands tend to be generally well connected, predominantly through the Credit River corridor. However, some areas are isolated, particularly patches within the urban matrix in the lower zone.
Woodland: Currently there is 21% woodland cover in the Credit River watershed. Cover in the lower zone is of greatest concern, falling below 10%. Woodland patches have an average area of 9.8ha, and the watershed contains seven large woodland patches >200ha. Despite the presence of several large patches, the overall amount of woodland interior (100m in from edge) is only 3% within the watershed.
Wetland: There is currently 6% wetland cover within the watershed, with large differences between the physiographic zones (10% upper, 8% middle and 1% lower). Wetland patches have an average area of 5.6ha, and many are part of larger wetland complexes within the middle and upper watersheds.
Successional: Successional areas compose a large proportion of the existing natural and semi-natural cover within the watershed, covering 10% of watershed area. Half of existing successional patches are >10ha, and may provide important habitat for open country, meadow or prairie species.
Riparian: Across the watershed, 74% of stream length is naturally vegetated in riparian areas. In addition, 64% of the 30m stream corridor adjacent to streams is naturally vegetated. The lower zone contains less natural vegetation adjacent to streams than the middle and upper zones.
Recommendations: As natural cover is 34%, opportunities for restoration and protection of natural habitats should be encouraged where possible to ensure that ecosystem integrity is maintained and enhanced within the watershed. To improve ecosystem function across the landscape, efforts should focus on increasing connectivity and increasing habitat patch size in the watershed. Maintaining connectivity through a Natural Heritage System will be essential to maintain and enhance current levels of ecosystem function, and provide resilience in the face of climate change. As urbanization pressures will continue to occur, landscape scale monitoring can be used to track land use change over time. Future analyses should relate monitoring data collected at the community and species levels to landscape level trends in the watershed.

Landscape Monitoring of Terrestrial Ecosystems in the Credit River Watershed

Landscape monitoring is an integral component of Credit Valley Conservation's Terrestrial Monitoring Program. Examining the status and trends in landscape-scale variables (or metrics) in the Credit River watershed provides information to guide adaptive environmental management. In addition, landscape structure has a strong impact on ecosystem function and monitoring at the landscape scale provides context for evaluating ecological integrity at the community and species levels. Landscape scale monitoring is a computer-based analysis using Geographical Information Systems (GIS) software and remote sensing data (i.e. aerial photography). A series of landscape metrics were selected to answer a set of landscape-scale questions related to the integrity of terrestrial ecosystems in the Credit River watershed. The landscape metrics examined include (i) the amount of natural land cover; (ii) number and area of woodlands, wetlands and successional areas; (iii) amount of woodland interior habitat; (iv) distance between natural habitats (e.g. between woodlands); (v) the surrounding land use around natural habitat patches (matrix quality); and (vi) natural vegetation along riparian areas. Landscape metrics were analyzed across the watershed and within physiographic zones. Some metrics were further analyzed within subwatersheds, which may provide additional direction for future management.

The landscape analysis demonstrated that the Credit River watershed is made up of a nearly equal mixture of natural & semi-natural (34%), urban (29%) and agricultural (37%) land uses. Given that natural and semi-natural cover represents one third of the watershed, ensuring connectivity through restoration, stewardship and planning, guided by a watershed Natural Heritage System, will be critical to maintain ecosystem function over the long term. Woodland cover is 21%, indicating that the watershed is likely inhospitable for some area-sensitive species and experiencing decreased ecosystem function. Woodland patches ranged from small to large, with seven patches in the watershed being larger than 200ha. Despite the presence of several large patches, woodland interior in the watershed was only 3%. Further, wetland cover is 6% watershed wide, well below the estimate of 10.4% wetland cover at the time of European settlement. Connectivity measures indicated that several natural areas in the watershed are experiencing barriers for dispersal, and one third of habitat patches are surrounded predominantly by urban land use. Riparian metrics indicate that 74% of stream length in the watershed is naturally vegetated. Additional restoration is needed to meet the 90% target outlined in the Credit River Watershed Fisheries Management Plan.

When metrics are examined across physiographic zones, the middle and upper zones have a greater amount of natural cover, and larger, more connected habitats than the lower zone. The lower zone further contains less woodland interior, more urban land use surrounding remaining habitat patches, and less natural vegetation in the 30m stream corridor. Degradation in the lower zone is most likely a result of increased urbanization and past land use changes within this region.

Landscape level monitoring provides information which can be used to help interpret observed trends at the species and community level across the watershed. In addition, landscape monitoring can guide adaptive environmental management, directing protection and restoration efforts. The frequency of landscape monitoring depends on the availability of watershed-level remote sensing data, and typically occurs ever 5-7 years. As land use changes continue to occur, monitoring landscape status and trends over time will continue to be an important component of the Terrestrial Monitoring Program in the future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 BACKGROUND

The structure and composition of a landscape has important impacts on ecological populations and processes. Species distributions, population sizes, ecosystem functioning and biodiversity are all affected when land use patterns are altered (Forman and Godron 1986; Forman 1995; Gutzwiller 2002). Habitat loss is currently considered one of the largest threats to biodiversity (Andrén 1994; Fahrig 2003). The impacts of habitat loss have a range of cascading effects, including disruption to trophic interactions such as predator-prey relationships, disruption to species breeding patterns, and alterations to species dispersal (Long et al 2005; Cushman 2006; Gonzalez et al 2011).

Recognition of the hierarchical organization of ecosystems (genes, individuals, populations, species, communities, ecosystems, landscapes) provides an important context for monitoring ecological integrity. Indicators at lower levels of organization (e.g. species) are expected to respond to stress before the entire ecosystem, and thus have the capability to act as an early warning system (Woodley 1993). Higher levels of organization (e.g. community or landscape) are expected to be more resilient to stress, and thus measures at these levels will allow for tracking of the long-term impacts of disturbance (Woodley 1993). In addition, changes at the landscape scale are anticipated to be one of the largest drivers of structure, composition and function at the species and community scales within the Credit River watershed.

In 2002, the Terrestrial Monitoring Program was initiated at CVC to examine the integrity of landscapes, communities and species in the Credit River watershed. The program examines biotic and abiotic indicators in forest, wetland and riparian ecosystems. The main goals of the Terrestrial Monitoring Program are to: (1) measure indicators of the structure, composition and function of terrestrial ecosystems in order 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 (Credit Valley Conservation 2010a).

Monitoring at a landscape scale will help inform watershed-level management at Credit Valley Conservation. 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 addition, in order to maintain existing natural habitat in the watershed, the impacts of the surrounding landscape must be managed as a whole. Landscape monitoring results can also assist with evaluating targets set out in Conservation Authority strategies and plans, such as the Wetland Restoration Strategy, Credit River Watershed Management Strategy and Fisheries Management Plan. In addition, the results of this study may be used to focus future land use planning and restoration goals, which include developing and implementing a Natural Heritage System (Credit Valley Conservation 2011a), as well as a Restoration Strategy for the Credit River watershed. Overall, a landscape context is an important component in the assessment of ecosystem integrity within the Credit River watershed.

1.2 GEOGRAPHY OF THE CREDIT RIVER WATERSHED

1.2.1 Land use: Past and present

Ontario has undergone dramatic change since the arrival of European settlers. Previous to settlement (ca. 1800) the landscape was dominated by upland forests and wooded wetlands, and agricultural practices of aboriginal peoples were responsible for deforestation in southern Ontario (Larson et al 1999). However, it is estimated that land conversion was moderate and relatively localized, and that only 5% of forested lands were cultivated at some point (Larson et al 1999). In contrast, the arrival of European settlers resulted in intense logging and conversion of land for agriculture. Woodland cover in Ontario reached an all-time low of approximately 10% by 1920 (Larson et al 1999). Since 1920, reforestation and natural succession on marginal lands has expanded and recovered a portion of the original woodlands lost (Larson et al 1999; Credit Valley Conservation 1956). In the Credit River watershed it is estimated that woodland cover in 1921 was approximately 10%, rising to 16.3% in 1954.

A wetland conversion analysis conducted by Ducks Unlimited further indicates that approximately 72% of southern Ontario wetlands were lost following European settlement, primarily through early conversion of land for agriculture (Ducks Unlimited Canada 2010). This wetland loss is consistent in municipalities which fall into the Credit River watershed, with wetland coverage in the Region of Peel declining from 7.6% (c. 1800) to 1.6% by 2002, and coverage in Halton Region declining from 12.6% (c. 1800) to 3.9% in 2002 (Ducks Unlimited Canada 2010). Built up lands in the Greater Golden Horseshoe have contributed significantly to wetland loss (Ducks Unlimited Canada 2010).

Based on detailed surveyor records dating from 1806, around the time of European settlement, the region was composed primarily of deciduous forest (Credit Valley Conservation and University of Guelph 2003). Other communities included marsh, swamp, and a few pockets of savannah. The pre-settlement vegetation of the Credit River watershed consisted of approximately 65% upland forest, 22% lowland forest and swamp, 7% non-forest wetland and aquatic (watercourse and water bodies) and 1% early successional habitats (Credit Valley Conservation 2006).

Population growth and development are still among the largest pressures on terrestrial ecosystems within the watershed. The watershed is located within the Greater Golden Horseshoe, the most rapidly urbanizing region of Ontario. According to the 2001 census, the watershed was estimated to have a population of approximately 600,000 people (Statistics Canada 2003), and by 2020 roughly 40% of the watershed is expected to be developed (Credit Valley Conservation 2007a, Credit Valley Conservation 2007b). The *Places to Grow Act* (2005) and associated *Places to Grow- Growth Plan for the Greater Golden Horseshoe* (Ministry for Public Infrastructure and Renewal 2006) has directed that growth and intensification be focused on major urban centers, including Mississauga and Brampton. With increasing population and development, the watershed's resources will be increasingly strained. These growing pressures place a large importance on tracking and understanding the state of ecosystems across the landscape, as a growing population will be dependant on the ecological goods and services provided by the Credit River watershed (The Pembina Institute and Credit Valley Conservation 2009).

1.2.2 Physiographic setting

The physiographic setting of the Credit River watershed significantly shapes the watershed's terrestrial ecosystems. Physical characteristics including climate, glacial history, soils, hydrology, and surficial geology strongly influence the composition and distribution of vegetation communities and wildlife that can be found within the watershed. Currently the watershed encompasses 950 square kilometres of land in southern Ontario (Credit Valley Conservation 2003). The watershed is made up of eight major and two minor physiographic regions that have characteristic differences in glacial deposits and unique combinations of soils, elevation, and drainage (Chapman and Putnam 2007; Fig. A1, Appendix A). The Credit River flows southeast for nearly 100 km from its headwaters in Orangeville to its drainage point in Lake Ontario. Twenty-one subwatersheds have been identified within the watershed, as well as approximately 14 creeks located within the City of Mississauga that drain directly into Lake Ontario (Fig. A2, Appendix A).

The physiographic regions have been grouped into three broad physiographic zones (referred to as 'upper', 'middle' and 'lower' herein) of approximately equal area. Zone designations are based on a combination of subwatershed boundaries and physiographic regions (Fig. A1, Appendix A). The three zones of the Credit River watershed currently provide the basis for broad comparisons of terrestrial community integrity across the watershed's landscape (Credit Valley Conservation 2010b, Credit Valley Conservation 2010c).

The upper watershed lies above the Niagara Escarpment, and is contained entirely within the Greenbelt Plan area (Niagara Escarpment and Protected Countryside). This zone contains the headwaters of the Credit River. It is composed of till plains, moraines, and glacial spillways (Credit Valley Conservation 2007b). Much of the upper watershed is characterized as having sandy loam soils, associated with the Guelph Drumlin Field and Hillsburgh Sandhills. The surface topography is undulating and the region is generally well drained. Agriculture is a dominant land use in the area, and urban centres include Orangeville, Erin, Alton, Caledon Village, and Hillsburgh (Fig. A3, Appendix A). In addition, the upper watershed contains several large wetland complexes and numerous headwater streams.

The middle watershed contains the Niagara Escarpment and the western edge of the Oak Ridges Moraine (Fig. A4, Appendix A). This zone is composed of steep slopes, significant rock outcrops, and thin overburden. The topography of this area causes relatively high runoff volumes and velocities. However, the high forest cover in this zone helps to slow runoff and increase infiltration. Soils in the middle watershed are variable as a result of the changing physiography between the upper and lower zones. Towns in the middle watershed include Inglewood, Cheltenham, Terra Cotta, Ballinafad, Acton, and Georgetown (Fig. A3, Appendix A). These areas lie within or near the GTA and are therefore experiencing growth pressures (Credit Valley Conservation 2007b).

The lower watershed is highly urbanized and contains 87% of the watershed's population. The lower watershed is dominated by major urban centers, including most of the City of Mississauga and the western portion of the City of Brampton (Fig. A3, Appendix A). The topography of this zone is relatively flat with a gentle slope south towards Lake Ontario. Much of the lower watershed is comprised of lower permeability clay loam soils associated with the Peel Plain and South Slope. However, localized pockets of sand and gravel do exist. In general, runoff is greater in this zone and infiltration significantly lower than in other parts of the watershed.

For more detail on the physiography of the Credit River watershed, including climate, soils and hydrology, refer to Credit Valley Conservation 2007a, Credit Valley Conservation 2007b, Credit Valley Conservation 2011a.

1.3 LANDSCAPE METRICS AFFECTING ECOSYSTEM FUNCTION

Landscape level monitoring involves examining ecosystem integrity across a variety of land forms, vegetation types and land uses (Noss 1990). Landscape monitoring characterizes various landscape criteria (or metrics) within a defined area, allowing for a broad-scale assessment of the ecological integrity of the landscape. Within the Terrestrial Monitoring Program, landscape monitoring is conducted as a computer-based GIS analysis of the Credit River watershed. The purpose of landscape level monitoring is to characterize and track changes in the composition (e.g. number of community types), structure (e.g. area and distribution) and function (e.g. land use trends) of communities within the Credit River watershed over time (Credit Valley Conservation 2010a).

1.3.1 Natural and Semi-Natural Cover

There is a considerable amount of research indicating the total amount of natural cover significantly affects species distribution and abundance across a landscape (e.g. Askins and Philbrick 1987; Andrén 1994; Allan et al 1997; Fahrig 1997; Eigenbrod et al 2008; Ritchie et al 2009; Zuckerberg and Porter 2010). Additional studies have shown that when the amount of habitat on the landscape falls below 20-30%, habitat fragmentation impacts become apparent and the spatial arrangement of habitat patches becomes important (Andrén 1994; Fahrig 2002). Increased cover is linked to increased biodiversity (Findlay and Houlahan 1997; Houlahan and Findlay 2003; Porej et al 2004), increased reproductive success (Vance et al 2003; Taki et al 2008; Cox et al 2012), and increased species dispersal across the landscape (Bélisle and Desrochers 2002; Long et al 2005). Greater natural cover is also linked to increased aquatic health and water protection services at the landscape scale (Goetz et al 2003; Helms et al 2009; Stephenson and Morin 2009).

The amount of forest cover on the landscapes has been shown to influence the distribution of bird species (Trzcinski et al 1999; Vance et al 2003; Brown 2007; Rioux et al 2009; Zuckerberg and Porter 2010), amphibian species (Mazerolle et al 2005; Eigenbrod et al 2008), mammals (Long et al 2005; Ritchie et al 2009), and aquatic species (Stephenson and Morin 2009). Research has further shown that there is a strong linkage between regional forest cover and stream health. Studies of watersheds with at least 65% forest cover in Washington State were associated with minimally impacted streams or a healthy aquatic insect community (Booth 2000, Booth et al. 2002), while a study of stream health in Maryland has shown that stream health ratings of ‘good’ required less than 10% impervious cover and at least 60% forest cover in the riparian zone (Goetz et al. 2003). Collectively, studies indicate that the amount of forest cover required for maintaining ecosystem health will depend on both regional conditions and the species being considered.

There is some literature that indicates that the total amount of wetland cover is important for maintaining ecosystem function. Watersheds containing less than 10% wetland cover are more sensitive to incremental loss of wetland area than those containing more than 10% wetland cover (Johnston et al 1990; Johnston et al 1994). A review by Mitsch and Gosselink (Mitsch and Gosselink 2000) further indicated that the optimal amount of wetlands in temperate zone watersheds should be 3-7% for optimization of ecosystem values such as flood control and water quality enhancement. Ultimately, the amount of wetland cover to maintain ecosystem function on the landscape depends on a variety of factors, including topography, soil types, wetlands location, land use, and the historical extent of wetlands in the area (Mitsch and Gosselink 2000; Zedler and Kercher 2005; Flanagan and Richardson 2010).

Currently there is no known literature on the amount of successional (or meadow) cover required in eastern North America to maintain ecosystem function. Successional habitat contributes to maintaining species that rely on meadow, open country or grassland habitat, including birds, insect species, mammals, plants and reptiles (Vickery et al 1994; Bay 1996; Fuller and DeStefano 2003; Solymár 2005; Grixti and Packer 2006; Wentworth et al 2010). Determining the amount of open country habitat required to maintain species on the landscape is compounded by a variety of factors. For example, open country bird species will also breed in some types of agricultural habitat (e.g. pastures and hayfields). Depending on the management practices undertaken, these non-natural land use types can provide suitable habitat to maintain bird populations. Successional areas have also traditionally been viewed as marginal habitat as they have been impacted by human modification, and are often targeted for restoration projects to increase natural forest and wetland cover on the landscape. Nevertheless, successional areas remain important as they maintain a unique complement of species, and contribute to the total proportion of natural and semi-natural cover in the watershed.

1.3.2 Habitat Area

Larger natural areas have been shown to provide habitat for a greater number of species than smaller natural areas (Burke and Nol 2000; Lee et al 2002; Donnelly and Marzluff 2006; Henderson et al 2008; Cottam et al 2009). Larger areas contain more resources to meet the needs of a species throughout their life cycle and support more species as they contain a greater diversity of habitat types (Findlay and Houlahan 1997; Burke and Nol 1998; Gutzwiller 2002; Donnelly and Marzluff 2006; Keller and Yahner 2007). The importance of habitat size is confounded by overall levels of natural cover on the landscape, where an aggregation of small patches can act as a large patch. Nevertheless, habitat size can have important impacts on the species composition in a given area, particularly for area sensitive species or species with restricted dispersal abilities (Lee et al 2002; Jacquemyn et al 2003; Taki et al 2008).

With respect to woodland communities, there is a considerable amount of literature that indicates that bigger areas support greater species richness and abundance (Burke and Nol 2000; Lee et al 2002; Golet et al 2001; Henderson et al 2008; Cottam et al 2009). Larger woodlands are more likely to contain interior habitat that is free from negative edge effects (Burke and Nol 1998; Ries et al 2004; Hoover et al 2006; Ritchie et al 2009; Falk et al 2011), and are also more likely to have higher habitat heterogeneity to support species needs throughout their life cycle. Literature regarding woodland size often finds that woodlands above a certain size threshold (ranging from 100ha to >5000ha) are important in maintaining biodiversity (Burke and Nol 2000; Mancke and Gavin 2000; Nol et al 2005; Henderson et al 2008; Weber et al 2008). In the Severn Sound Area of Concern (AOC) it was estimated that a 200ha forest would support over 80% of the regional forest bird species (Tate 1998 cited in Environment Canada 2013).

Larger wetlands are also associated with greater species richness and diversity, and contribute to the maintenance of habitat heterogeneity on the landscape (Findlay and Houlahan 1997). Nevertheless, wetlands of all areas and hydroperiods are recognized as being important to maintain wetland function (Snodgrass et al 2000; Egan and Paton 2004; Babbitt 2005; Burne and Griffin 2005; Houlahan et al 2006; Pearce et al 2007; Smith and Chow-Fraser 2010). Wetlands as small as 0.05ha were shown to provide important breeding habitat for wood frog and spotted salamanders in a Rhode Island study (Egan and Paton 2004). A study conducted in Ontario wetlands found that wetland area was related to increased plant species diversity (Houlahan et al 2006). However, many small wetlands were found to provide habitat for uncommon species, and no two wetlands surveyed contained the same species complement (Houlahan et al 2006). Wetlands of all areas have also been demonstrated to be important for marsh and waterbird species (Pearce et al 2007; Smith and Chow-Fraser 2010).

Finally, the amount of successional habitat can be a determinant of species composition on the landscape. Many grassland bird species are area sensitive, indicating that they need a minimum amount of habitat for successful breeding. A survey conducted in New York State describes the minimum habitat area for several grassland bird species, including Bobolink (5-10ha; *Dolichonyx oryzivorus*), Grasshopper Sparrow (30ha; *Ammodramus savannarum*), Eastern Meadowlark (15-20ha; *Sturnella magna*) and Savannah Sparrow (20-40ha; *Passerculus sandwichensis*; Jones et al 2001). In addition, aggregated areas of smaller patches of both meadow and agriculture may provide sufficient habitat for bird species. Less is currently known about area requirements for other species which utilize successional habitat.

1.3.3 Interior Habitat

In addition to habitat area, the amount of interior habitat can be important for species persistence and survival. The interior area of a community type is defined as the area within that community beyond a specified edge distance. Woodland interior is well studied in the scientific literature, but less so for non-wooded wetland (e.g. marsh) and successional communities (however see discussions on habitat size above). The amount of interior within a woodland is an important predictor of habitat quality (Forman 1995; Burke and Nol 2000; Mancke and Gavin 2000; Austen et al. 2001), and may support species which prefer to nest in high quality interior forest, such as ovenbird (*Seiurus aurocapillus*) or wood thrush (*Hylocichla mustelina*; Nol et al 2005). Interior habitat is less affected by negative edge effects such as microclimate changes such as changes in light, heat, and moisture (Chen et al. 1999, Meyer et al. 2001). Impacts of edge effects have primary been demonstrated for bird species, with edges influencing avian nest predation and brood parasitism (Burke and Nol 1998; Batáry and Báldi 2004; Falk et al 2011). In addition, edge impacts have been demonstrated for amphibians (Demaynadier and Hunter 1998) mammals (Ritchie et al 2009), and plants (Tallmon et al 2003; McDonald and Urban 2006). Edge structure can further influence seed dispersal and invasive species disturbance

(Cadenasso and Pickett 2001; McDonald and Urban 2006). In addition, interior areas are less likely to be impacted by some types of human disturbance and the effects of adjacent land uses, such as encroachment, noise and roads (Ries et al 2004; Eigenbrod et al 2008; Goodwin and Shriver 2010; McWilliam et al 2010).

1.3.4 Connectivity and Linkage

Recent literature indicates that the amount of natural cover on the landscape is more important than habitat isolation areas in explaining species diversity (Fahrig 2003; Watling and Donnelly 2006). Nevertheless, natural connectivity between habitats has been shown to influence persistence for some species, particularly those with limited dispersal abilities (Dupré and Ehrlén 2002; Honnay et al 2002; Piessens et al 2005). Woodland herbaceous plants with ant dispersed seeds have been shown to have relatively short dispersal distances, including 10m for white trillium (*Trillium grandiflorum*; Kalisez et al 1999) and 35m for wild ginger (*Asarum canadense;* Cain et al 1998). Pollen from wind pollinated plant species can travel distances from 250-3000m (O'Connell et al 2007). Habitat isolation also impacts forest bird species (Hames et al 2001; Nol et al 2005). In a study of forest bird dispersal from large patches to small patches in southern Ontario, Nol et al (2005) found that for each kilometer increase in distance from the large patch the probability of detecting ovenbird, wood thrush, veery (*Catharus fuscescens*) and rose-breased grosbeak (*Pheucticus ludovicianus*) decreased. A study of gap crossing behaviour of forest songbirds further indicated that birds prefer to travel under forest cover, and all species examined rarely ventured more than 25m from the forest edge (Bélisle and Desrochers 2002).

The distance between wetlands is also important for the survival of some species (Pearce et al 2007; Smith and Chow-Fraser 2010). In a study examining waterbird species in southern Ontario, Pearce et al (2007) found that small wetlands which are close together have similar species richness to larger wetlands. Amphibian abundance is also greater in more connected vernal pools (Veysey et al 2011). Finally, the distance between wetlands and upland forest can be important for breeding, dispersal and foraging habitat (Mazerolle et al 2005; Pearce et al 2007; Eigenbrod et al 2008; Veysey et al 2011). Increased plant species diversity has also been observed in wetlands surrounded by upland forest (Houlahan et al 2006; Flinn et al 2008).

This wide range of dispersal values reported in the literature indicates that depending on the species of interest greater connectivity may be necessary to maintain populations over the long term. Theoretical modeling exercises have indicated that the importance of maintaining connectivity becomes important as overall levels of natural cover decrease below a certain threshold (e.g. 20-30%; Andren 1994; Flather and Bevers 2002; King and With 2002). These models have not been empirically tested to date (Fahrig 2003). Nevertheless, when natural cover is low improving the connectivity of habitats is anticipated to have a net benefit on biodiversity and ecosystem function.

1.3.5 Matrix Quality

The land use matrix surrounding natural areas has a strong influence on the ability of some species to move from one area to another (Jules and Shahani 2003; Kupfer et al 2006). The matrix can influence both the conditions within the natural area, as well as the ability of species to disperse between natural areas. Natural habitats surrounded by a high percent of natural area are likely to support a greater amount of species movement than those surrounded by urbanization or agriculture (Dunford and Freemark 2004; Porej et al 2004; Rodewald and Bakermans 2006; Ritchie et al 2009; Tremblay and St. Clair 2011). In general, the urban matrix tends to have more negative impacts than an agricultural matrix (Borgmann and Rodewald 2004; Dunford and Freemark 2004). The urban matrix has been further shown to influence vegetation community dynamics, with urban plant communities tending to have a higher proportion of non-native and disturbance tolerant species (Moffatt et al 2004; McKinney 2006; Duguay et al 2007).

1.3.6 Riparian Connectivity and Cover

Naturally vegetated riparian areas along streams are important for ecosystem integrity. Riparian zones are defined as the stream channel between the low and high water marks and the terrestrial zone from the high water mark towards the upland area where vegetation may be influenced by elevated water tables or flooding and by the ability of soils to hold water (Naiman and Decamps 1997). Riparian areas provide habitat for flora and fauna (Doyle 1990; Croonquist and Brooks 1993; Tremblay and St. Clair 2011), and are an interface where terrestrial and aquatic ecological processes interact (Nakano and Murakami 2001; Sabo and Power 2002; Bastow et al 2002).

Benefits of natural vegetation along streams include shading to moderate stream temperature, stabilization of stream banks and prevention of erosion, provision of organic materials to streams, removal and regulation of sediment, nutrients and other contaminants from runoff, and flood attenuation and storage (Castelle et al 1994; Naiman and Decamps 1997; Castelle and Johnson 2000; Fischer and Fischenich 2000; Sullivan et al 2007; Gift et al 2010). Riparian areas and associated valleyland systems may also act as corridors for plant and wildlife movement when the adjacent vegetation is both connected and of required width (Seavy et al 2009; Tremblay and St. Clair 2011). In the Credit River watershed, the Credit River Valley is the most contiguous remaining natural corridor to promote species movement. Given the functions that riparian vegetation maintains, a certain amount of natural cover along streams will be required to maintain stream health. The amount of natural cover required to maintain stream integrity depends on the amount of impervious cover (i.e. hardened surfaces) in a watershed (Goetz et al 2003; Baker et al 2006), as well as the intensity of the pressures caused by the adjoining land uses (e.g. low-intensity agriculture vs. high-density residential development). For protecting water quality, many studies recommend minimum vegetated buffers of around 30m (e.g. Hickey and Doran 2004; Zhang et al 2010). Thirty meters of natural vegetation adjacent to streams represents a potential minimum guideline to maintain stream integrity. Depending on local conditions and functions to be maintained, wider strips of natural vegetation may be required to maintain some stream functions (Wenger 1999; Polyakov et al 2005).

1.4 OBJECTIVE: MONITORING QUESTION

Several species and community-level indicators are regularly evaluated to examine the integrity of forest, wetland and riparian communities across the Credit River watershed (Credit Valley Conservation 2010a; Credit Valley Conservation 2010b; Credit Valley Conservation 2010c). Landscape level monitoring represents a higher scale to evaluate trends in ecosystem integrity across the watershed and will assist with interpreting trends in species and community-level indicators. This landscape analysis examined a series of GIS metrics (described above), selected to answer a set of landscape-scale questions related to the integrity of terrestrial ecosystems in the Credit River watershed (Table 1).

This report examines the status of landscape metrics in the Credit River watershed (Table 1). However, at present, it is not possible to compare trends in land use over time due to limitations in the available data. Additional studies may be conducted in the future to examine land use trends (e.g. is natural cover increasing or decreasing?), which would further assist CVC direct planning and management efforts.

The ecological questions examined were based upon a review of the current literature and agency reports, providing a scientific rationale for metrics selected for landscape monitoring. The overall monitoring question being examined in this report is:

WHAT IS THE CURRENT STATUS OF TERRESTRIAL ECOSYSTEMS ACROSS THE LANDSCAPE OF THE CREDIT RIVER WATERSHED?

More specifically, within the Credit River watershed: 1) What is the overall composition of land-cover? 2) What is the area and frequency of occurrence of various natural communities? 3) What is the composition of interior woodland habitat? 4) What is the average proximity of natural communities to one another? 5) What are the characteristics of the matrix exerting surrounding natural communities? and 6) What is the composition of the stream corridor (Table 1).

Table 1. Landscape monitoring framework for the Credit River watershed.

Monitoring Question	Landscape Metric	Classification of Area	Scale of Interest
1. Land Usage • What is the composition of land use and land cover within the Credit River watershed? • Does this differ among physiographic zones or subwatersheds?	Area (ha)	• Land use class: natural, urban, agriculture • Community: forest, wetland, woodland, successional area • ELC community series: all natural communities	• Watershed • Physiographic zone • Subwatershed
2. Habitat Quantity and Area • How many natural and semi-natural communities are there in the watershed (forests, wetlands and successional areas)? • What is the area of woodlands/forests, wetlands and successional areas? • Does the number and area of natural communities differ among physiographic zones or subwatersheds?	Number of patches Patch area (ha)	• Community: forest, wetland, woodland, successional area	• Watershed • Physiographic zone
• How many woodland patches are greater than 200ha within the watershed?	Number of patches	• Community: woodland	• Watershed
3. Interior Woodland Habitat • How much of the watershed supports interior woodland habitat? • Does the amount of interior forest habitat differ among physiographic zones and subwatersheds?	Interior area (ha)	• Community: woodland	• Watershed • Physiographic zone • Subwatershed
4. Nearest Neighbour • What is the distance between natural communities in the Credit River watershed? • Does this differ among physiographic zones in the watershed?	Nearest neighbour (m)	• Community: woodland, forest, wetland	• Watershed • Physiographic zone
5. Surrounding Land Cover: Matrix Quality • What is composition of the land use matrix surrounding natural communities in the Credit River watershed? • Does matrix quality differ among physiographic zones?	Matrix quality (%)	• Habitat patch	• Watershed • Physiographic zone
6. Riparian • What proportion of stream length is naturally vegetated in the Credit River watershed? • Do streams have a naturally vegetated 30m buffer?	Stream length naturally vegetated (%) Percent natural vegetation within 30m buffer (%)	• Land use class: natural	• Watershed • Physiographic zone • Subwatershed

2.0 METHODS

2.1 LAND COVER DATA

For this analysis, the landscape was defined as the terrestrial area within CVC's jurisdiction. The southern Ontario Ecological Land Classification (ELC) system provided the basis for the GIS analysis (Lee et al 1998). The ELC for southern Ontario identifies six nested levels below the Ecoregion level. From the largest to the smallest scale, they are: Site region (or Ecoregion) → System (Terrestrial, Wetland, or Aquatic) → Community Class → Community Series → Ecosite → Vegetation Type (Lee *et al*. 1998). The ELC community series and land use layer is currently the most complete dataset of ecological and non-ecological data across the watershed's terrestrial landscape (Table 2; Fig. A5-A7, Appendix A).

To examine the key terrestrial communities, individual **ELC community series** can be aggregated into different types of **communities**, including: forest, wetland, successional, cultural forest, and woodland. The first four communities (forest, wetland, successional and cultural forest) each contain a distinct combination of **ELC community series** (Tables 3-4). Woodland communities were also examined, and include a combination of forest, cultural forest, and treed wetlands (Tables 3-4). Forest and woodland communities overlap; however both were examined in this analysis, because each of these '*ecological units'* may provide distinct ecological functions. For example, the distribution of some species may be restricted to upland forests (Iverson et al 1997; Richard et al 2000; Fridley et al 2007). However some species may use woodlands (irrespective of their wetness) as their primary habitat preference (e.g. birds; Golet et al 2001; Cadman et al 2007). Furthermore, examining woodlands overall provides a measure of the amount of treed cover on a landscape.

Table 2. Base and Ancillary GIS Data Layers.

Base Data Source	Year	Scale
ELC Community Series and Land Use	2008	1:10,000
Ancillary Data Source	**Year**	**Scale**
Streams and Rivers	2008	1:10,000
Lake Ontario Shoreline	2008	1:50,000
Roads	2008	1:10,000
Crest of Slope	2005	1:10,000
Lake Ontario hazard	2005	1:10,000
Niagara Escarpment Land Use Designation	2003	1:10,000
Oak Ridge Moraine Land Use Designation	2007	1:10,000
Greenbelt Natural Heritage System	Unknown	Unknown
Credit River Watershed Boundary	2008	1:10,000
Credit River Subwatershed	1997-2008	1:10,000
Physiographic Zone	Unknown	Unknown
Orthophotos	2008	1:10,000

For some analyses, communities can also be aggregated into **habitat patches**, which are defined as natural (e.g. forest, wetland) or semi-natural (e.g. cultural meadow) areas separated from other habitat patches by a different land use type or a 20m gap on a

1:10,000 scale air photo (Credit Valley Conservation 1998; Table 3-4; Fig. 1). Habitat patches within the Credit River watershed are shown in Fig. A8 (Appendix A).

Because some non-forested wetland units (i.e. fen and bog) are difficult to distinguish to the community series level through air photo interpretation, these were generally grouped into the ELC community class ‘marsh’ in the analysis. Therefore, information regarding the distribution of wetland communities in the watershed based on the ELC community series class should be interpreted with caution. Nevertheless, it is known that fen and bog represent a very small proportion of total wetland area in the watershed. Information on other natural but rare communities such as prairies or sand barrens was not available for analysis at this scale. In addition, a simplified classification developed by CVC was applied to anthropogenic features. The land use classification splits the remaining, non-natural landscape into two classes, agriculture and urban, which are further subdivided into additional discrete units (Table 5).

The minimum mapping unit was 0.5ha, because this is generally the smallest area that can be determined with accuracy through air photo interpretation at a scale of 1:10,000 (Credit Valley Conservation 1998). Landscape features smaller than 0.5ha were merged with their adjoining feature and were not used in the analyses.

The landscape monitoring analysis presented in this study uses GIS data from air photo interpretation at a relatively coarse scale (1:10,000). A certain degree of error is inherent in air photo interpretation, and field measurements may not correspond exactly to measurements made on the map. An accuracy assessment of ELC mapping for the City of Mississauga involved a random survey of 30% of the City’s area, or 583 samples. Results showed that CVC’s ELC mapping had 90% accuracy, above the generally accepted threshold of 80%, in identifying the following classes: woodland, wetland, successional, aquatic, other natural (e.g. beach/bars), agriculture, open space, residential, commercial/industrial, and educational/institutional (Credit Valley Conservation 2008 unpublished data).

The 2008 ELC layer was selected for analysis as it is consistent with the mapping utilized for the Credit River Watershed Landscape Scale Analysis (LSA) completed as part of Phase I of developing a Natural Heritage System for the CVC (Credit Valley Conservation 2011a). This study evaluated the relative quality of habitat patches within the watershed on a landscape scale and is complementary to the current Landscape Monitoring Report.

Table 3. Definitions used in the landscape analysis, using Ecological Land Classification (ELC) except where indicated.

Habitat patch:
A habitat patch is defined as a contiguous area, boundaries delineated by a ≥2mm gap on a 1:10000 air photo (Credit Valley Conservation 1998). It includes natural and semi-natural communities. Habitat patches were uniquely identified based on their 'Habitat ID'. Fig. 1 provides an example of the structure of a habitat patch.

Community:
A community is defined as a contiguous, relatively homogeneous area, with boundaries delineated by a patch of a different type or by a ≥2mm gap on a 1:10,000 air photo (Credit Valley Conservation 1998). A community consists of one of the following types: forest, wetland, cultural forest, or successional. A fifth community type, woodland, consists of a combination of forest, cultural forest, and treed wetland.

Forest:
A forest is defined as a terrestrial vegetation community with at least 60% tree cover (Lee et al. 1998). In this analysis, the following ELC communities were defined as forest: coniferous forest, deciduous forest, and mixed forest.

Wetland:
A wetland is defined as an area of land that is saturated with water long enough to promote hydric soils or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to wet environments (Lee et al. 1998). The following ELC communities were defined as wetlands: coniferous swamp, deciduous swamp, mixed swamp, marsh, and thicket swamp.

Successional:
A successional patch is human disturbed land dominated by native and non-native graminoid or shrub vegetation (Credit Valley Conservation 1998). The following ELC communities were defined as successional: cultural meadow, cultural savannah, and cultural thicket.

Cultural Forest:
A cultural forest is defined as a cultural community with >35% tree cover; this includes coniferous plantation, deciduous plantation, mixed plantation, and cultural woodland. The definition of plantation excludes areas that are managed for the production of fruits, nuts, Christmas trees or nursery stock (Credit Valley Conservation 1998).

Woodland (PPS definition):
The Provincial Policy Statement (OMMAH 2005) defines woodlands as follows: "Woodlands means treed areas that provide environmental and economic benefits such as erosion prevention, water retention, provision of habitat, recreation and the sustainable harvest of woodland products. Woodlands include treed areas, woodlots, or forested areas and vary in their level of significance".

ELC community series:
An ELC community series is a relatively homogeneous area identified by the type of cover (open, treed, or shrub) as well as plant form (deciduous, coniferous, or mixed) that is characteristic of the area. It is a unit that is normally visible and consistently recognizable on an air-photo or a combination of maps, air-photo interpretation and other remote sensing techniques. Community series are the lowest level in the ELC classification that can be identified without a site visit (Lee et al. 1998). Examples of community series are: deciduous forest, mixed forest, thicket swamp.

Table 4. Classification of major natural and semi-natural land cover types in the Credit River watershed. Based upon Ecological Land Classification (ELC) Community Series.

Land Use Class	Habitat Patch	Community Type	ELC (Ecological Land Classification) Community series	Natural/ Semi-Natural
Natural	Habitat Patch	Forest	Coniferous forest	Natural
			Deciduous forest	Natural
			Mixed forest	Natural
		Wetland	Coniferous swamp	Natural
			Deciduous swamp	Natural
			Mixed swamp	Natural
			Marsh or Bog/Fen	Natural
			Thicket swamp	Natural
		Successional	Cultural savannah	Semi-natural
			Cultural thicket	Semi-natural
			Cultural meadow	Semi-natural
		Cultural Forest	Coniferous plantation	Semi-natural
			Deciduous plantation	Semi-natural
			Mixed plantation	Semi-natural
			Cultural woodland	Semi-natural
		Woodland	Coniferous forest	Natural
			Deciduous forest	Natural
			Mixed forest	Natural
			Coniferous swamp	Natural
			Deciduous swamp	Natural
			Mixed swamp	Natural
			Coniferous plantation	Semi-natural
			Deciduous plantation	Semi-natural
			Mixed plantation	Semi-natural
			Cultural woodland	Semi-natural
		Other Natural	Open Beach/Bar	Natural
			Open Bluff	Natural
			Shrub bluff	Natural
			Treed beach/Bar	Natural
		Open Aquatic [a]	Open Aquatic	Natural

[a] Open Aquatic is a natural community that was not included in the delineation of habitat patch

Table 5. Classification of anthropogenic land cover types in the Credit River watershed

Land use Class	ELC (Ecological Land Classification) Community series
Agricultural & open space	Commercial/industrial open space
	Educational/institutional open space
	Inactive aggregate
	Intensive agriculture
	Manicured open space
	Non-intensive agriculture
	Other open space
	Private open space
	Recreational open space
	Wet meadow
Urban	Active aggregate
	Airport
	Collector
	Commercial/industrial
	Construction
	Educational/institutional
	High density residential
	High rise residential
	Highway
	Landfill
	Low density residential
	Medium density residential
	Railway
	Regional road
	Residential estate
	Rural development
	Urban
	Mixed residential

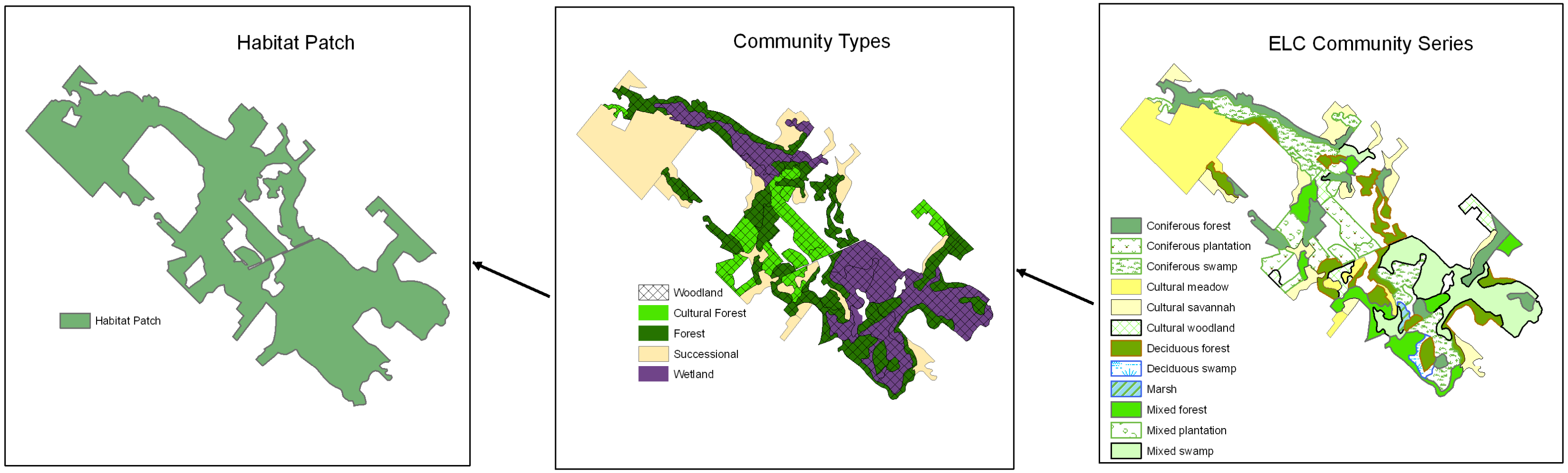

Figure 1. Schematic showing scales of analysis in landscape characterization: habitat patch, community type and ELC community series scales. Habitat patches can be composed of multiple ELC community types, which in turn may be composed of multiple ELC community series. Areas outside a habitat patch may be agricultural, urban or aquatic.

2.2 LANDSCAPE METRICS FOR EVALUATING ECOSYSTEM FUNCTION

2.2.1 Land Use and Land Cover

The composition of habitats within the Credit River watershed was assessed by summarizing the area (ha) of natural and non-natural land cover (i.e. natural) and land use (i.e. non-natural) within the watershed (Tables 4-5). Area was summarized for major land use classes (natural, agricultural and urban), community types (forest, woodland, wetland and successional) and all ELC community series (e.g. deciduous forest). Area of land use and land cover was examined within subwatersheds, physiographic zones, and for the watershed as a whole.

2.2.2 Habitat Quantity and Area

Habitat quantity and area was assessed by summarizing the number of patches and average patch area for community types (forest, woodland, wetland and successional). Habitat quantity and area was examined within the watershed as a whole and by physiographic zones. The number and area of patches within each subwatershed were not examined, as several patches would have crossed one or more subwatershed boundaries. This would have made an estimation of patch number and area difficult to accurately quantify resulting in an inaccurate reflection of ecosystem integrity at this scale.

In addition, to assess the number of large woodland patches in the watershed, the number of woodland patches greater than 200ha within the watershed was summarized.

2.2.3 Interior Habitat

The total interior area (ha) for woodlands was summarized for 100m (i.e. interior area) and 200m (i.e. deep interior area) from the woodland patch edge. The amount of interior woodland area (ha) was examined within physiographic zones, and for the watershed as a whole.

2.2.4 Nearest Neighbour Distance

Euclidean nearest-neighbour distance was calculated as the edge to edge distance (m) between a community type patch and its closest neighbour. Nearest-neighbour distances were calculated for the following community types:

- woodland → woodland
- wetland → wetland
- forest → wetland

The distance between woodlands was summarized to examine the feasibility for species which rely on treed communities to disperse between habitats (Hames et al 2001; Bélisle and Desrochers 2002; Nol et al 2005). Likewise, the ability to disperse between wetland patches is important for the survival of some species (Pearce et al 2007; Smith and Chow-Fraser 2010). Finally, the distance between upland forest and wetland habitats is important for some species to forage, reproduce and disperse (Mazerolle et al 2005; Pearce et al 2007; Eigenbrod et al 2008; Veysey et al 2011). Nearest-neighbour distances between community types were examined for the watershed as a whole, as well as within individual physiographic zones. Nearest-neighbour distance was not examined on the subwatershed scale, as several patches crossed one or more subwatershed boundaries.

2.2.5 Matrix Quality

Matrix quality surrounding habitat patches was calculated for a 2km external buffer around each habitat patch using the following formula: percent natural area*(1) + percent agricultural area*(0) + percent urban area*(-1) (Toronto and Region Conservation Authority 2007). This formula recognizes the relative order of permeability of various land covers, with natural being most permeable, agricultural being relatively neutral (permeable for some species and impermeable for others) and urban being relatively impermeable compared to natural and agricultural land cover (Tables 4-5). The values for matrix quality range from -1 to +1, where -1 represents a patch completely surrounded by urban land cover, while +1 represents a patch completely surrounded by natural land cover. A patch surrounded completely by agriculture would have a matrix quality score of 0, which is intermediate between that for a completely urban and a completely natural matrix.

The habitat patch was chosen as the unit of analysis for this metric, rather completing a separate matrix analysis for each individual community (i.e. woodland, wetland and successional). This was justified as natural and semi-natural areas do not necessarily act as a barrier for species movement depending on the species of interest, and many species utilize multiple habitats to complete their life-cycles (e.g. Gibbons 2003; Veysey et al 2009). The matrix quality for habitat patches was examined within each physiographic zone, as well as at the watershed scale. As the extent of matrix quality for a given patch may cross one or more subwatershed boundaries, this metric was not examined at this scale.

2.2.6 Riparian Metrics

Riparian metrics examined include the percentage of stream length (1^{st} order and above) which is naturally vegetated (Fig. 2) and the amount of natural vegetation adjacent to streams within a 30m stream corridor (Fig. 2) were both summarized (as in Environment Canada 2013). Each of these parameters was summarized for subwatersheds, physiographic zones and the watershed as a whole. In addition, these riparian parameters were each summarized separately for first to third order streams, and streams classified as fourth order and above, at the watershed-scale.

These parameters estimate the amount of natural area adjacent to the stream, which has been shown to influence stream health (e.g. Diana et al 2006; Mayer et al 2007). Nevertheless, it is not possible to map the riparian zone from air photo interpretation. In the future additional measures may need to be considered to quantify riparian health at the landscape scale.

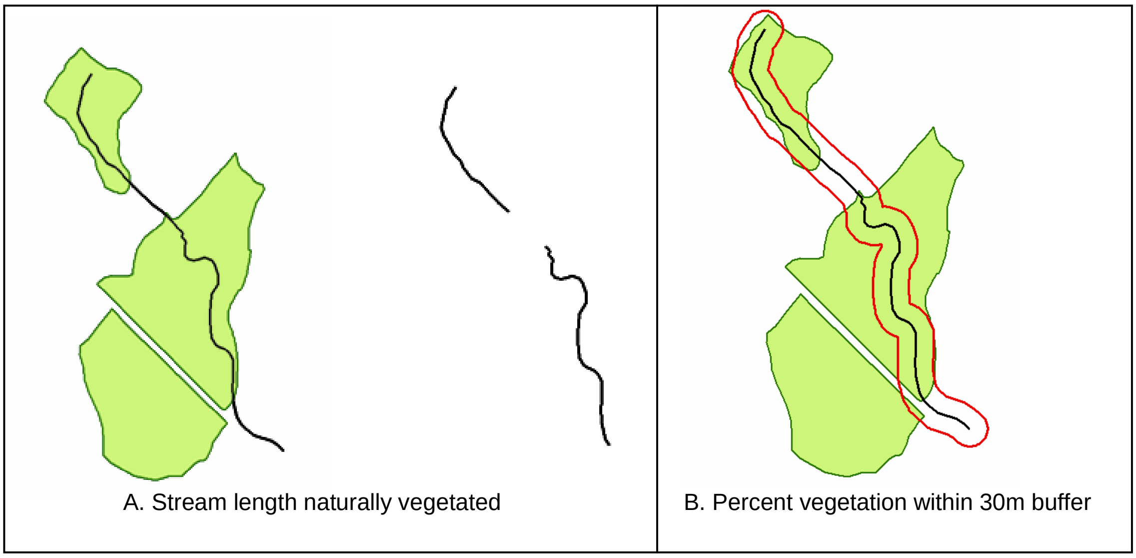

Figure 2. Riparian landscape metrics, including (A) length of stream naturally vegetated, and (B) amount of natural vegetation within 30m buffer adjacent to streams.

3.0 RESULTS AND DISCUSSION

3.1 LAND USE AND LAND COVER

Monitoring Question: What is the composition and distribution of land use and land cover within the Credit River Watershed? Does this differ among physiographic zones or subwatersheds?

- The Credit River watershed is comprised of 34% natural and semi-natural communities, 37% agriculture and 29% urban area
- Land use and land cover composition is similar between the middle and upper watersheds with over 40% agriculture, over 40% natural and semi-natural communities, and 15% urban in both zones. The lower watershed is composed of a much greater portion of urban cover at 56%
- Land cover greatly varies at the subwatershed scale, with natural cover ranging from a low of 7% (Carolyn Creek) to a high of 56% (Credit River: Cheltenham to Glen Williams). Urban land use ranges from a low of 8% (East Credit River) to a high of 79% (Lake Ontario Shoreline: East Tributaries)

Estimates of land use based on 2007 aerial photography indicate that the Credit River watershed is comprised of 19% natural communities, 15% semi-natural communities, 37% agriculture, and 29% urban land use (Fig. 3; Fig. A5-A7, Appendix A). The distribution of land use types is similar between the upper and middle watersheds, where land use is 15% urban cover and the remainder of land is evenly composed of agriculture, and natural and semi-natural area. In contrast, over half of the lower watershed is covered by urban land use (56%). The remaining area is occupied by 27% agriculture and 17% natural and semi-natural communities (Fig. 3).

Examining the distribution of land use within subwatersheds, it is clear that land use is not evenly distributed across the Credit River watershed (Fig. A9, Appendix A). Natural cover is highest (34%) in the Credit River – Forks of the Credit to Cheltenham subwatershed, located in the middle watershed and containing areas designated as Niagara Escarpment and Protected Countryside. Carolyn Creek contains the lowest natural cover (1%) and is located in the lower watershed within the City of Mississauga.

The spatial distribution of natural and semi-natural habitat in the Credit River watershed is driven by historic land use patterns, as well as current land use designations (e.g. Greenbelt Pan) and current pressures. Currently over half (56%) of natural and semi-natural area has some form of protection under provincial legislation, including area that has been designated as part of the Greenbelt Natural Heritage System (Greenbelt Plan), Oak Ridges Moraine Natural Core and Natural Linkage Area (ORMCP) or Escarpment Natural Area (Niagara Escarpment Plan). Across the watershed many forest and wetland remnants are associated with valleylands in areas considered hazard land that cannot be developed. In addition, some urban centers contain protected natural areas such as Cawthra Woods and Meadowvale Station Woods in the City of Mississauga. Given that natural and semi-natural cover is 34% and the majority of cover in the watershed is urban and agricultural area (66%), managing existing natural and semi-natural patches for connectivity is particularly important to ensure their long term integrity (Andrén 1994).

3.1.1 Woodland Cover and Woodland Type in the Credit River Watershed

The Credit River watershed contains 21% woodland cover, which can be broken down into 12% forest, 4% treed swamps and 5% cultural woodlands and plantations across the watershed (Fig. 4; Fig. A10, Appendix A). Upland forests in the watershed are primarily deciduous, representing 61% of forest cover, with the remaining 39% split between mixed and coniferous forest (Fig. 4). The middle watershed contains the greatest woodland cover on the landscape (25%), followed by the upper (17%) and lower (7%) watersheds (Fig. A11, Appendix A). All woodland types are found in all physiographic zones, including: deciduous, coniferous and mixed forests, swamps, plantations and cultural woodlands.

The amount of treed cover can impact species persistence and survival (reviewed in Section 1.3.1). Based on a review of current science Environment Canada has produced revised Forest Guidelines that recognize that the amount of cover required is species specific, and recommend a range of targets from 30%-50% forest cover (Environment Canada 2013). Thirty percent forest cover is considered high-risk where only a proportion of potential species may be supported and aquatic ecosystems would be somewhat healthy. Alternately, 50% cover would be a low-risk approach that would be likely to support many of the potential species on the landscape and healthy aquatic ecosystems. The Credit River watershed is considerably below historical levels of treed cover estimated to be approximately 87% pre-European settlement (Credit Valley Conservation and University of Guelph 2003). Given that woodland cover is 21%, it is possible that there has been in a decrease in area-sensitive species in the watershed, as well as decreased ecosystem integrity in some remaining natural areas.

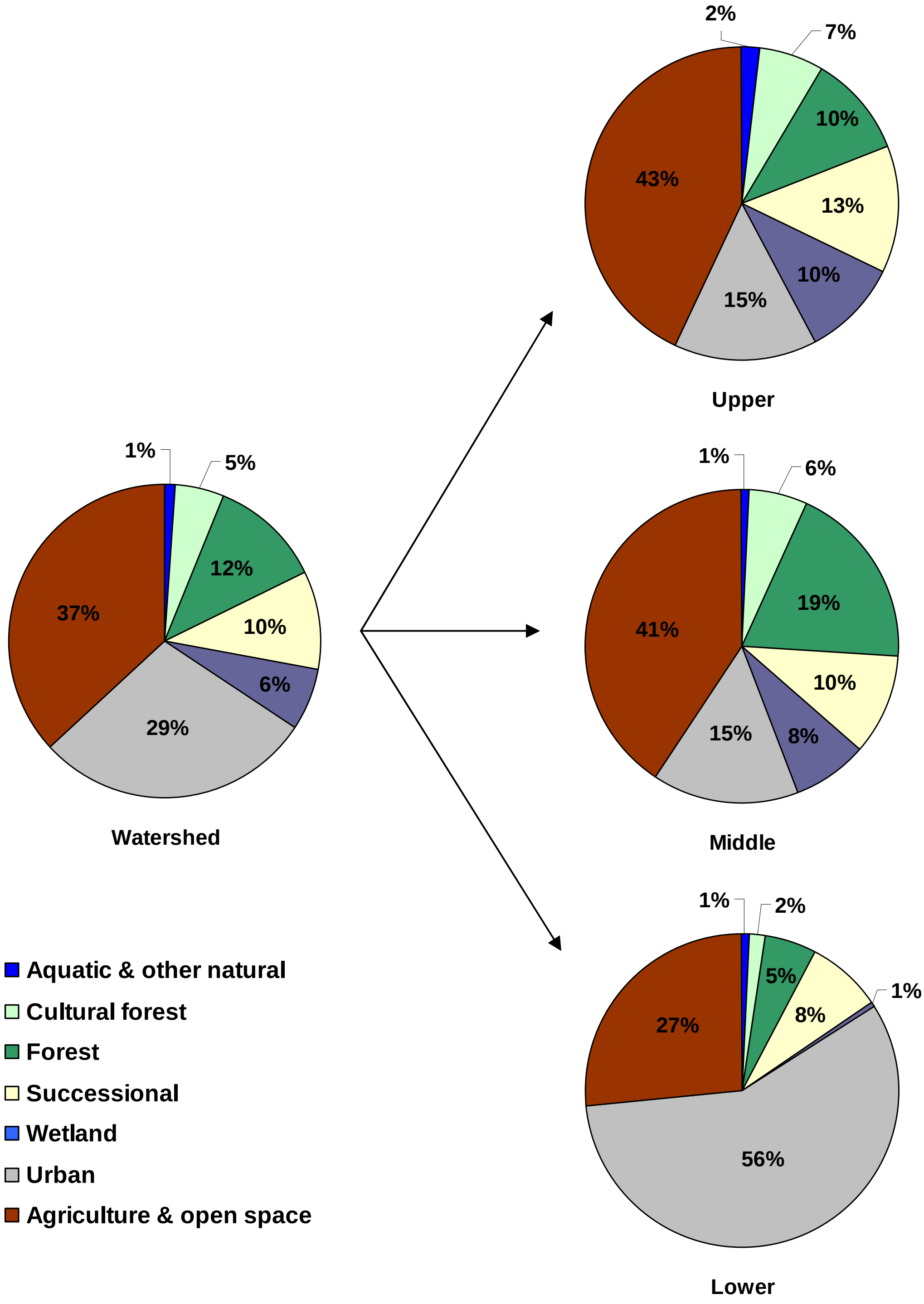

Figure 3. Land cover types in the Credit River watershed.

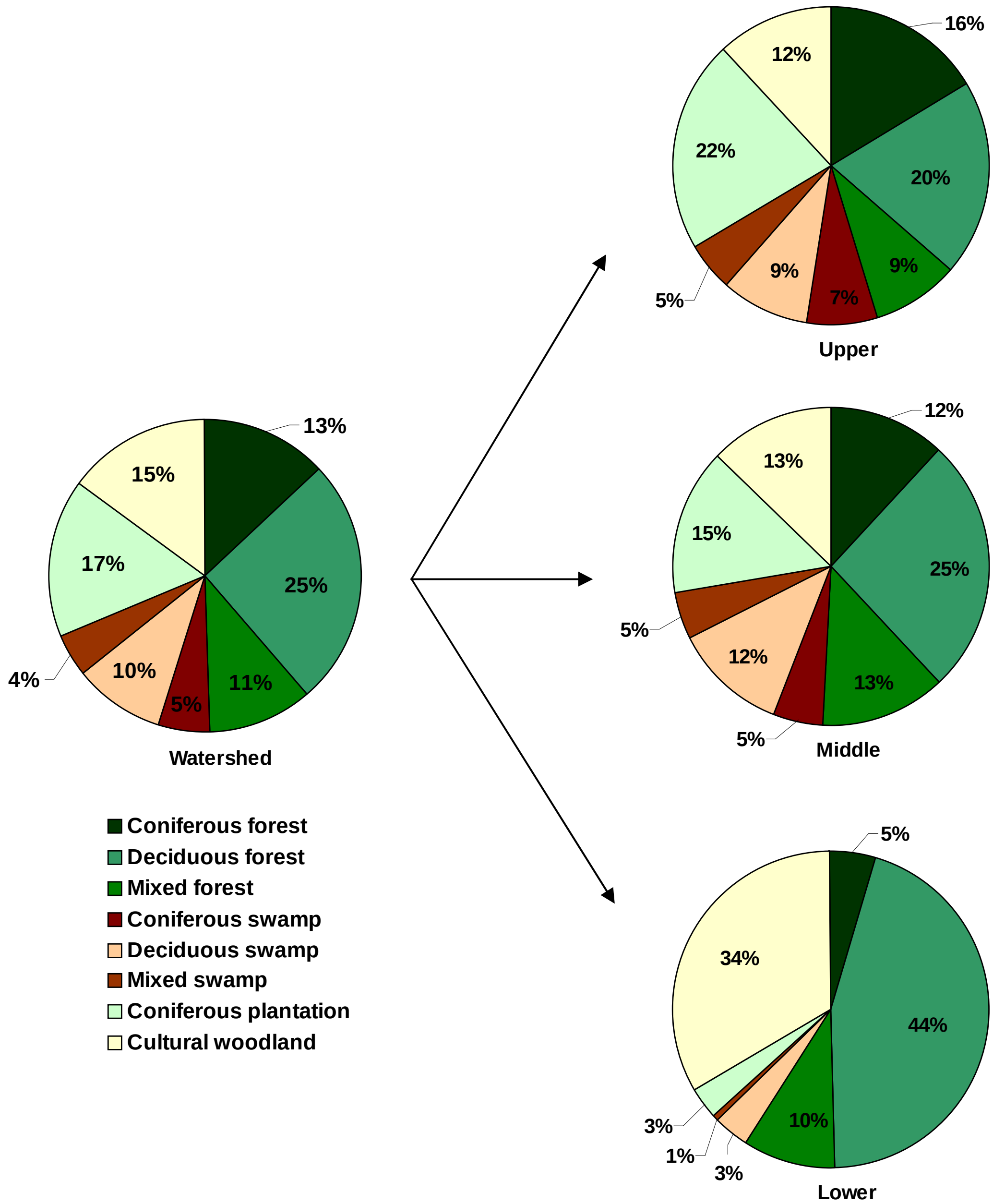

Figure 4. Woodland composition in the Credit River watershed as a percentage of total woodland area. Mixed and deciduous plantations comprise less than 1% of total woodland area and are not indicated.

3.1.2 Wetland Cover and Wetland Type in the Credit River Watershed

Six percent of the Credit River watershed is composed of wetland communities (Fig. 5; Fig. A12, Appendix A). Eighty-two percent of wetlands in the Credit River watershed are swamps, with most of the remaining 18% being marshes. Less than 1% can be identified as bogs (fens have not been mapped at the community series level). The middle and upper watershed contain similar wetland cover of 8% and 10% respectively, while the lower watershed contains only 1% wetland cover (Fig. 3). The majority of remaining wetlands (57%) in the lower zone are marshes, while the majority of wetlands in the middle and upper watersheds are swamps (Fig. 5). Wetlands in the upper and middle zones are mainly part of larger wetland complexes, consisting of groups of wetlands which function as biological and hydrological units (Ontario Ministry of Natural Resources 1993).

The amount of wetland cover required in a watershed is strongly dependant on historic landscape conditions, as maintenance of wetland conditions is dependant on local topography, soils and hydrology (Mitsch and Gosselink 2000; Zedler and Kercher 2005; Flanagan and Richardson 2010). Environment Canada guidelines recommend that either (a) a minimum of 10% wetland cover in a watershed and 6% wetland cover in each subwatershed, or (b) 40% of historic watershed wetland coverage should be protected and restored (Environment Canada 2013). In the Credit River watershed, 6 subwatersheds have greater than 6% wetland cover (Black Creek, Caledon Creek, East Credit River, Orangeville, Shaw's Creek, Silver Creek and West Credit River). Three additional subwatersheds (Credit River: Cheltenham to Glen Williams, Forks to Cheltenham and Melville to Forks) have 3-6% wetland cover. The remaining 14 subwatersheds have <3% wetland cover (Fig. A13, Appendix A). Credit Valley Conservation's Wetland Restoration Strategy estimated that 17% of the Credit River watershed was lowland communities, including 10.4% wetland coverage at the time of European settlement. As of 2006, approximately 67.2% of the pre-settlement wetlands were estimated to be retained. Agriculture and built-up uses accounted for almost identical losses. Additional restoration is needed in several subwatersheds to provide adequate wetland coverage to maintain ecosystem function.

3.1.3 Successional Cover and Successional Area Types of the Credit River Watershed

Ten percent of the watershed is covered by successional communities, defined as cultural meadows, cultural thickets and cultural savannahs (Fig. 3; Fig. A14, Appendix A). Cultural woodlands can also be considered as successional communities because they are in the process of transitioning to fully functioning forests. However, for the purpose of this report these communities are discussed under woodland cover. The majority (77%) of successional communities in the watershed are cultural meadows and are generally representative of areas that were used for agriculture. The proportion of successional area is roughly equal among physiographic zones with 13%, 10% and 8% successional cover in the upper, middle and lower watersheds (Fig. 3). In the lower zone, successional cover represents the majority of remaining land use that has not been converted to urban, agriculture or open space. These successional areas represent the best opportunities for restoration in the urban context, though many are likely currently zoned as vacant lands for future development. Cultural meadow composes the majority of successional cover in each zone, and the middle zone also contains a large portion of cultural savannah (Fig. 6).

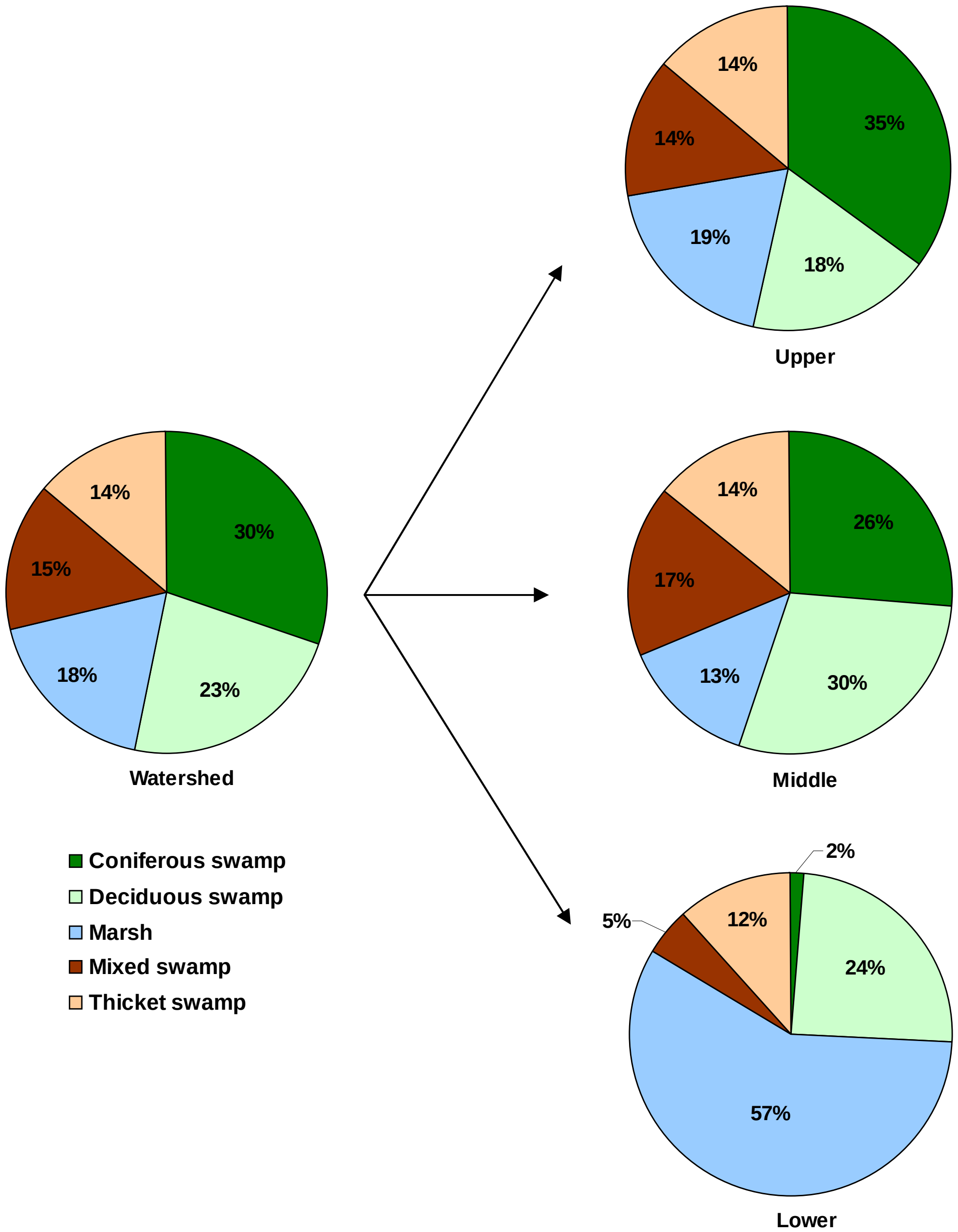

Figure 5. Dominant wetland communities in the Credit River watershed as a percentage of total wetland area. Bogs comprise less than 1% of wetland cover and are not indicated.

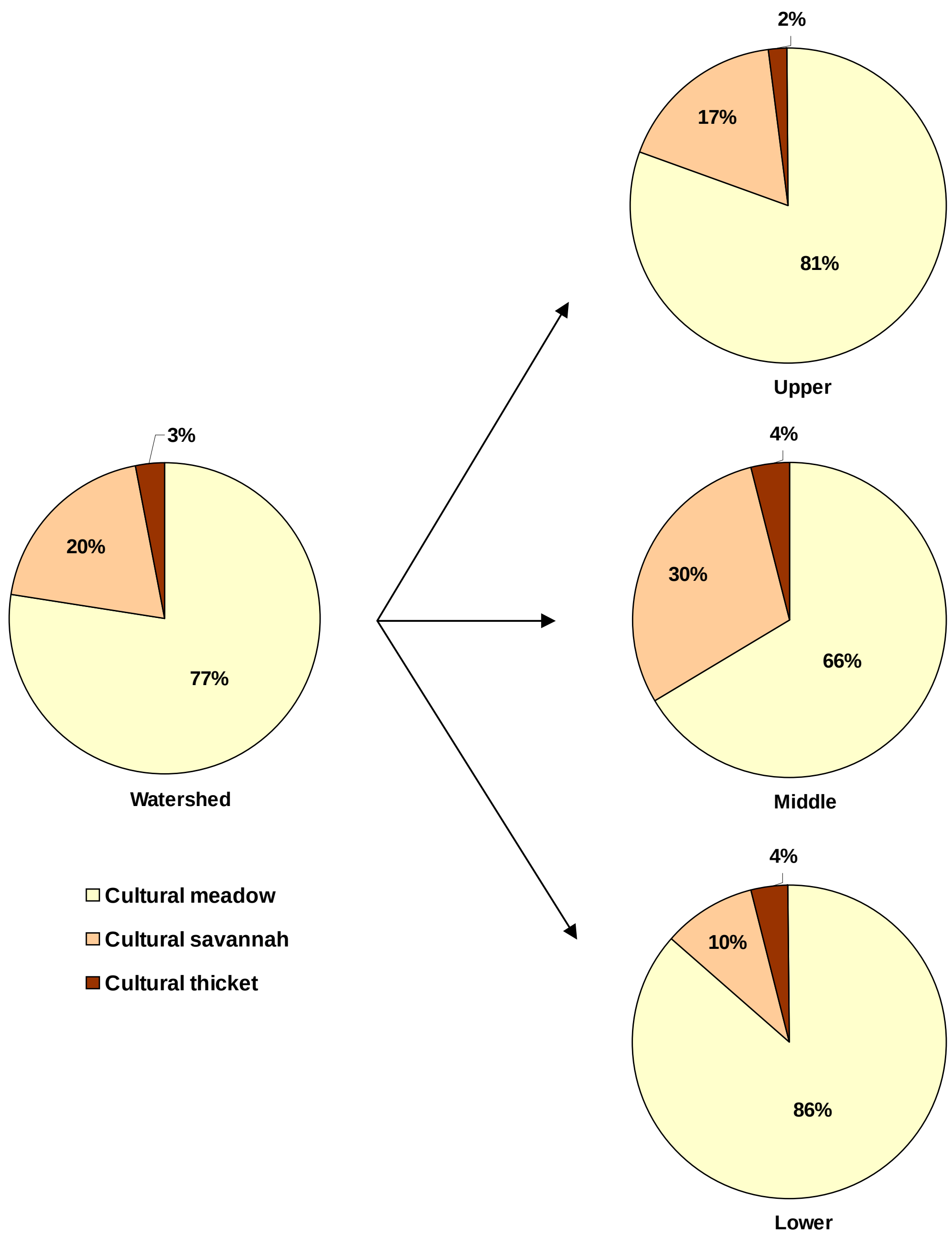

Figure 6. Semi-natural community composition of the Credit River watershed.

3.2 HABITAT QUANTITY AND AREA

Monitoring Question: How many natural and semi-natural communities are there in the Credit River watershed? What is the area of woodlands, wetlands and successional areas in the watershed? Does the number and area of natural and semi-natural communities differ among physiographic zones?

- There are 2019 woodlands with a median area of 2.3ha; 1051 wetland patches with a median area of 1.7ha, and 2158 patches of successional areas with a median area of 1.9ha
- The lower watershed contains fewer, and generally smaller, natural communities than the middle and upper watersheds

3.2.1 Number and Area of Woodlands

There are a total of 2019 woodland communities in the Credit River watershed. Average woodland area is 9.8ha, with woodlands ranging in area from less than 0.5ha to 581ha (Fig. 7). The lower watershed contains the smallest number of woodlands (464) when compared to the middle (717) and upper (838) watersheds (Fig. 10; Table 6). The woodlands in the lower zone are smaller and more fragmented than woodlands in the upper and middle zones (Fig. 7; Table 6). The upper watershed contains the greatest number of woodlands, which are smaller on average than woodlands in the middle zone. This reflects the pattern of land use change which has occurred within the upper zone of increasing fragmentation and decreasing patch area. The middle watershed contains the largest portion of unfragmented habitat, as is reflected by the fact that all of the woodlands greater than 250ha are contained either entirely or partly within the middle zone.

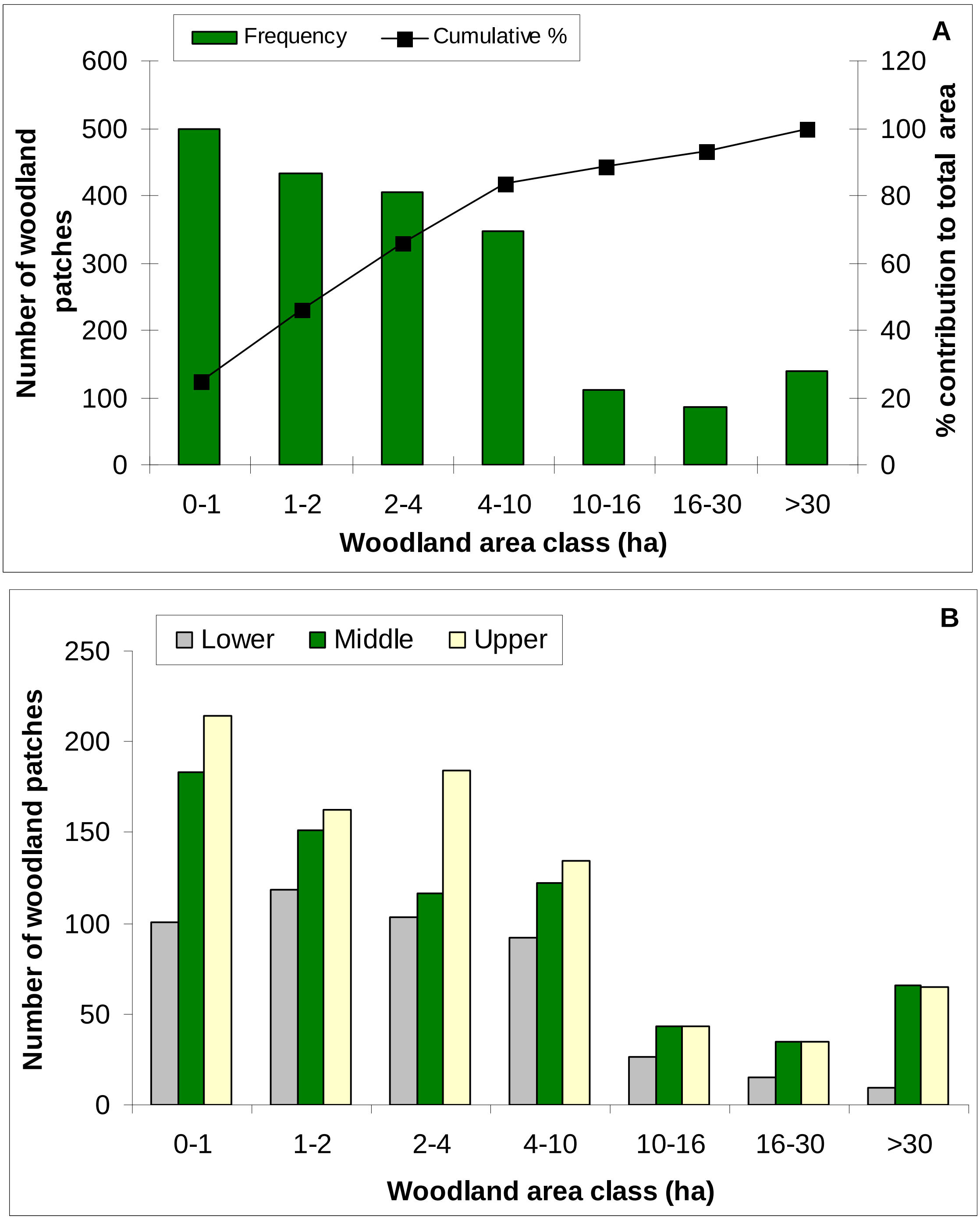

Figure 7. Woodland area class-distribution in the Credit River watershed for (a) all woodlands across the watershed, and (b) within each physiographic zone. (More than one woodland community may form a single woodland patch).

Table 6. Woodland area distribution in the physiographic zones of the Credit River watershed, including average woodland area, woodland area range, and the number of woodlands above given area thresholds.

Area	Average Area (ha)	Area Range (ha)	Woodland Cover (%)	Number of woodlands (#)				
				>2ha	>4ha	>16ha	>20ha	>50ha
Lower zone	4.73	0.5 - 68.1	7	245	142	24	16	5
Middle zone	13.98	0.01 - 580.8	25	383	266	101	89	42
Upper zone	9.09	0.01 - 174.7	17	461	277	100	89	38
Watershed-wide	**9.83**	**0.01 - 580.8**	**21**	**1089**	**685**	**225**	**194**	**85**

In addition to considering the overall area of woodlands across the landscape, the number of woodlands greater than 200ha was examined. The Credit River watershed has seven woodlands greater than 200ha ranging from 256ha to 581ha in area and covering 2.6% of the watershed (Fig. A15, Appendix A). These seven patches contain 33% of the watershed's interior woodland area (100m from edge), and 64% of the watershed's deep interior woodland (200m). The large forests are predominantly deciduous, with pockets of coniferous and mixed forest, and are located primarily in the middle watershed, with three patches extending into the upper watershed. Four of the seven patches are either a part of, or surrounding, Forks of the Credit Provincial Park, with the south-western extent of these patches extending to Belfountain Conservation Area. These large patches are adjacent to one another on the landscape, but are separated by major roads. These patches cover the Credit Forks Lowland Area of Natural and Scientific Interest, as well as the Credit Forks Provincially Significant Wetland Complex. The other three large forest patches are part of the Silver Creek-Terra Cotta Forest Complex. These patches cover portions of three Areas of Natural and Scientific Interest, including the Caledon Mountain Slope Forest, Terra Cotta Forest and Silvercreek Valley. In addition, The Caledon Mountain PSW and Acton-Silvercreek PSW form portions of these large patches. These patches are also adjacent to one another, and separated by the road network.

In a preliminary ranking of site quality in the Credit River watershed, Silver Creek, Forks of the Credit and Terra Cotta Forests were ranked in the top four forest monitoring sites in the Credit River watershed (Credit Valley Conservation 2010c). Additional data collected by CVC indicates that these large forest patches contain area-sensitive and interior breeding bird species, including ovenbird, pileated woodpecker (*Dryocopus pileatus*), black-and-white warbler (*Mniotilta varia*), and scarlet tanager (*Piranga olivacea*). They are also home to several species at risk and locally rare plant species including American hart's-tongue fern (*Asplenium scolopendrium var. americanum*), eastern leatherwood (*Dirca palustris*), black-fruit mountain-ricegrass (*Oryzopsis racemosa*), and Goldie's woodfern (*Dryopteris goldiana*).

3.2.2 Number and Area of Wetlands

The Credit River watershed contains 1051 wetland patches, with the majority being less than 4ha in area (Fig. 8). Individual wetland patches range from 0.5ha to 246ha (Fig. 8). The average wetland area is 5.6ha, and more than half (56%) of all wetlands in the watershed are less than 2ha. There are two wetland patches greater than 100ha in area: one which is 125.1ha and comprises a portion of the Alton-Hillsburg Provincially Significant Wetland complex, and another patch (approximately 246ha) located in the Caledon Lake Provincially Significant Wetland complex.

The lower watershed contains significantly fewer wetlands than the other two physiographic zones, as a large number of wetlands have been lost in this highly urbanized region (Table 7). The majority of remaining wetlands in this area are associated with the Credit River, in areas that are not subject to development. The lack of wetland coverage within this zone is a cause for concern because areas which have lost a large percentage of wetland coverage show decreases in flood abatement, water quality and biodiversity services (Zedler 2003).

Table 7. Wetland area distribution in the physiographic zones of the Credit River watershed, including average wetland area, wetland area range and percent cover in each physiographic zone.

Area	Average Area (ha)	Number of Patches (#)	Area Range (ha)	Wetland Cover (%)
Lower zone	2.8	72	0.5 - 16.3	1%
Middle zone	4.7	516	0.1 – 70.4	8%
Upper zone	7.1	463	0.2 – 246.4	10%
Watershed-wide	**5.6**	**1051**	**0.1 – 246.4**	**6%**

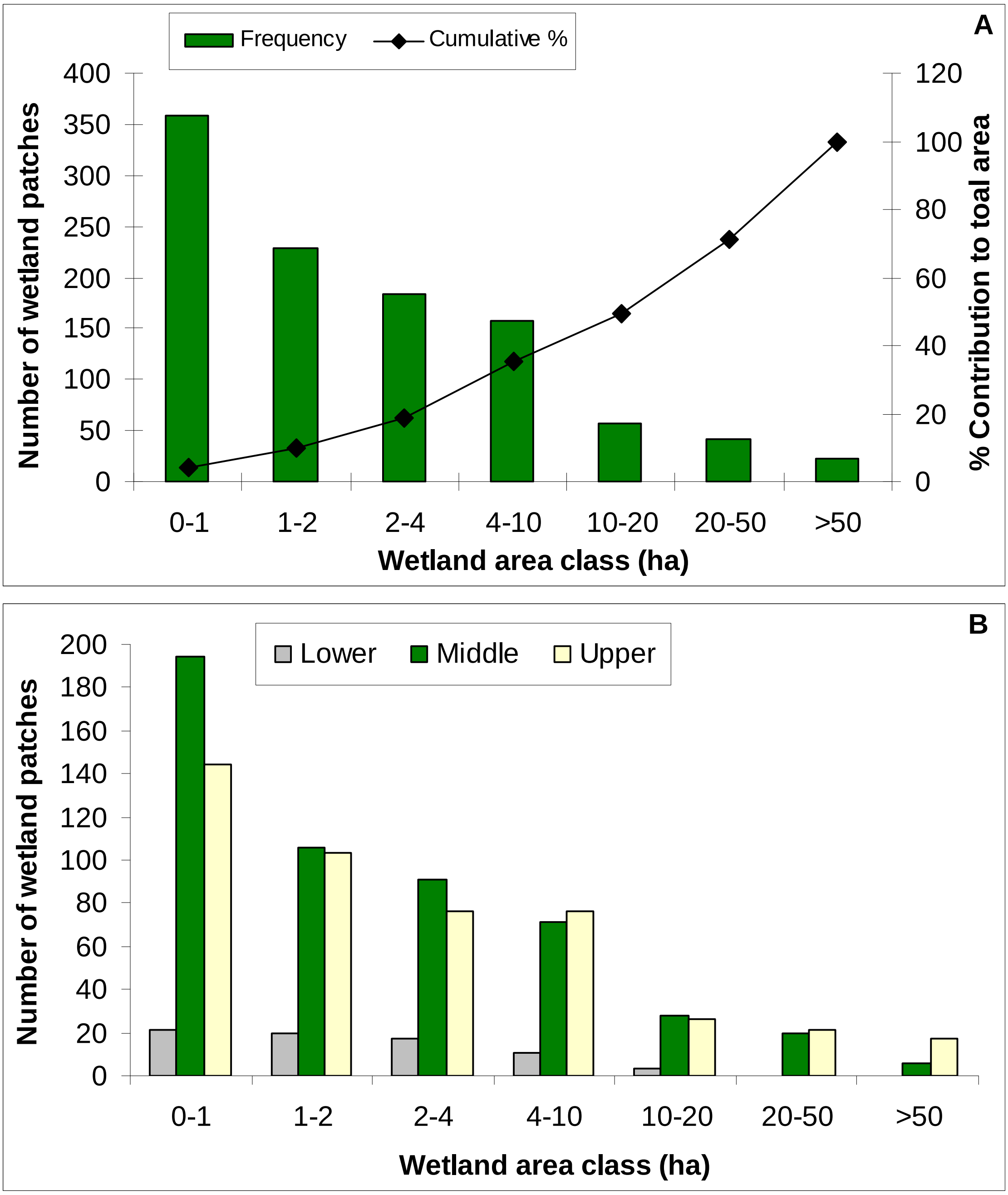

Figure 8. Wetland area class distribution in (a) the Credit River watershed, and (b) lower, middle and upper zones. (More than one wetland community may form a single wetland patch).

3.2.3 Number and Area of Successional Areas

Overall, there are 2158 successional areas within the Credit River watershed, which are roughly evenly distributed among the lower (664), middle (805), and upper (689) zones (Fig. 9). The upper watershed generally supports larger successional areas (mean 6.3ha), than the middle (mean 4.0ha) and lower (mean 3.6ha) zones. The majority of successional areas (by number) within the watershed are less than 5ha (Fig. A16, Appendix A), and only 11% of patches are greater than 10ha. Although representing a smaller number of successional habitats, successional areas greater than 10ha represent 53% of total available successional area, and 5% of total watershed area. These patches are of sufficient area to provide habitat for several grassland bird species (Vickery et al 1994; Bay 1996; Jones et al 2001). Depending on habitat quality and species presence these areas present candidates for managing and protecting open country habitat on the landscape.

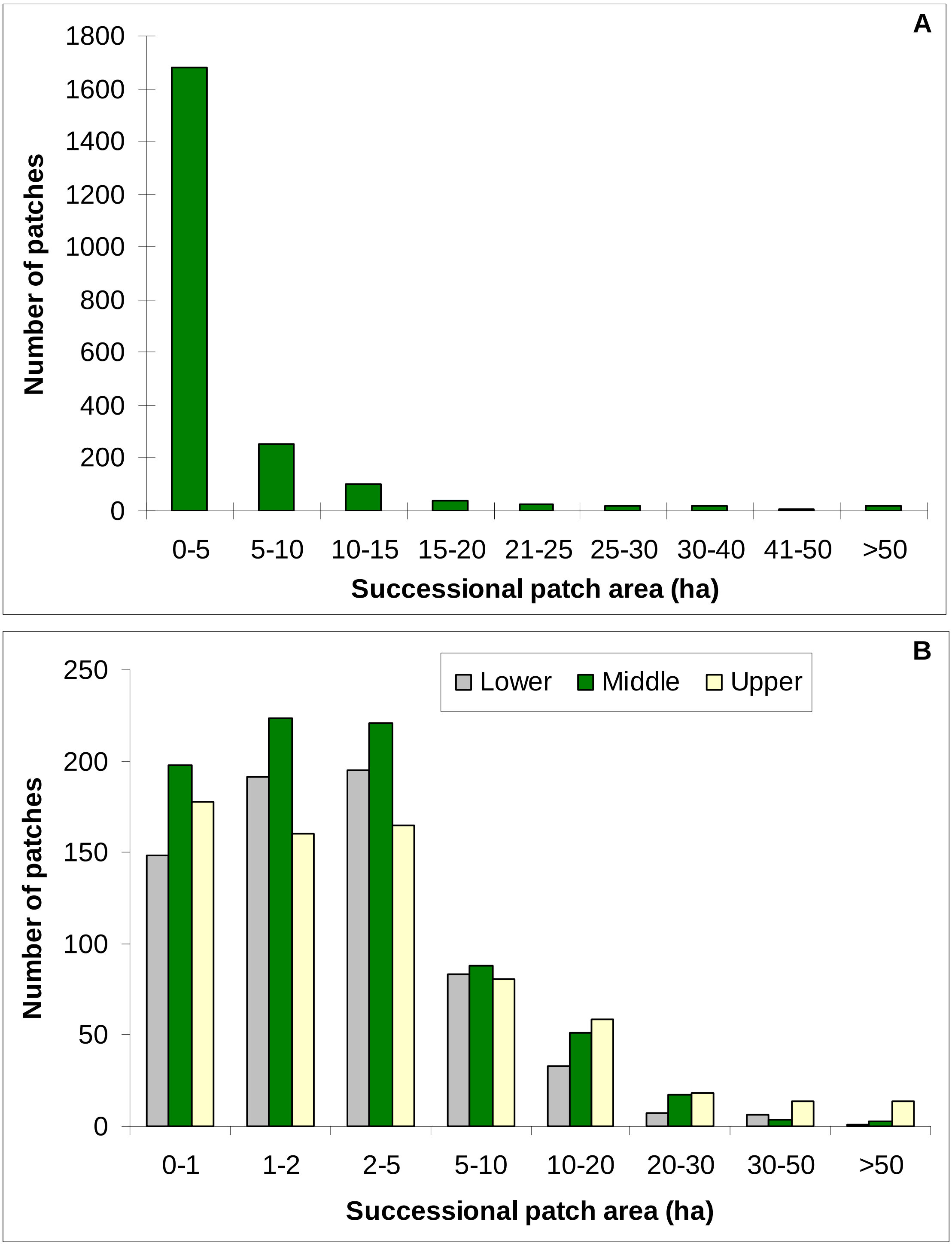

Figure 9. Successional area class distribution in (a) the Credit River watershed, and (b) lower, middle and upper zones.

3.3 INTERIOR HABITAT

Monitoring Question: How much of the watershed supports interior woodland habitat? Does the amount of interior forest differ among physiographic zones?

- The Credit River watershed contains 2804ha of woodland which is greater than 100m from the woodland edge (interior), representing 3.0% of watershed area
- The middle watershed contains the majority of the watershed's interior habitat, containing 61% of 100m and 75% of 200m interior habitat. The majority of the remaining interior habitat is found within the upper watershed, while the lower zone only contains 1% of the 100m interior and no 200m interior habitat

The watershed contains 2804ha (3.0%) of woodland interior area 100m from edge, and 0.6% (529ha) woodland deep interior area defined as forest area that is 200m from the forest edge (Fig.10; Fig. A17, Appendix A). As the middle watershed contains the largest amount of woodland habitat, it follows that it also contains the greatest amount of interior habitat (Fig. 11). The middle watershed contains 61% of the watershed's 100m interior habitat, and 75% of the watershed's 200m interior habitat (Fig. 11). The majority of the remaining interior habitat (38%) is found within the upper watershed, while the lower zone only contains 1% of the watershed's 100m interior habitat, and no 200m interior habitat (Fig. 11). The virtual absence of woodland interior in the lower zone provides further evidence that this area has been significantly impacted by habitat removal, and that the remaining woodlands in this zone are small and fragmented. In contrast, the largest woodlands in the watershed (found in the middle and upper watersheds) are home to the majority of forest interior habitat (Fig. A17, Appendix A).

Figure 10. Area of non-interior, interior (100-200m) and deep interior (>200m) forest habitat in (a) the Credit River watershed, and (b) the lower, middle and upper zones.

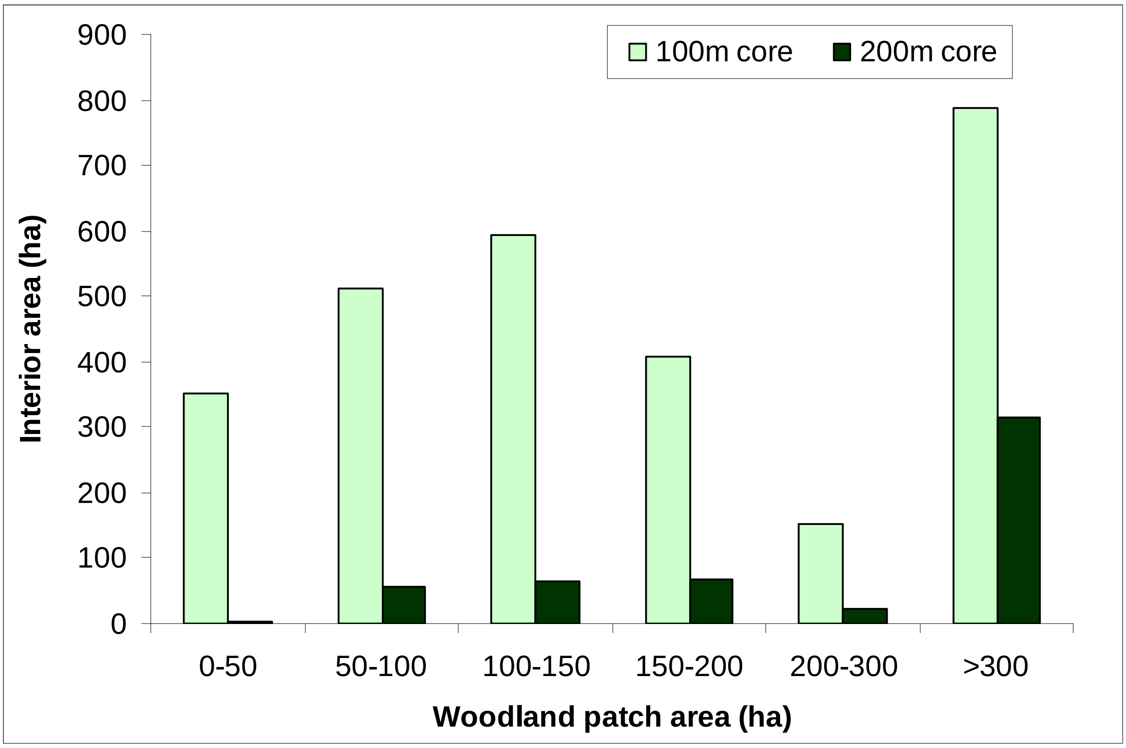

Figure 11. Interior woodland area within woodland patch area classes in the Credit River watershed.

The importance of maintaining interior habitat free of negative edge effects has been widely documented (Forman 1995; Chen et al 1999; Burke and Nol 2000; Meyer et al 2001; Batáry and Báldi 2004; Nol et al 2005; Falk et al 2011). Given that there is only 2.96% interior woodland area in the watershed, interior area may be considered rare and edge effects in woodlands are likely having a substantial impact on natural communities (Hartley and Hunter 1998; Cadenasso and Pickett 2001; Batáry and Báldi 2004). Species that are dependant on interior forest habitat or are sensitive to edge effects are at higher risk of extirpation from the watershed. Although there is no ideal proportion of interior habitat that should be contained in a watershed (more is generally better), Environment Canada guidelines recommend that a minimum of 10% of interior forest cover 100 meters from the edge should be maintained (Environment Canada 2013). This guideline assists with ensuring that high quality natural areas (e.g. more diverse and less disturbed) are protected through landscape-scale natural heritage planning (Environment Canada 2013). Small woodland core areas should be protected through natural heritage systems planning, and targeted for expansion through future stewardship or restoration efforts.

3.4 NEAREST NEIGHBOUR

Monitoring Question: What is the distance between natural communities in the Credit River watershed? Does this differ among physiographic zones in the watershed?

- Woodlands are an average of 74m away from one another across the watershed, with woodlands in the middle and upper zones closer to one another than those in the lower zone
- Wetlands are an average of 135m away from one another, with wetlands in the upper zone in closer proximity, than those in the middle or lower zones
- Upland forests are an average of 280m away from wetlands in the watershed, with wetlands and forests in the upper and middle zones in closer proximity, than those in the lower zone

The distance between woodland communities was examined because it is important for the dispersal of species which rely on treed communities (e.g. Driscoll et al 2005; Nol et al 2005). In the Credit River watershed, woodlands are on average 74m away from other woodlands, with the most isolated woodland located 1281m from any other woodland (Table 8). Forests in the middle and upper watersheds were located closer to each other (mean 57m and 58m, respectively) than are woodlands in the lower watershed (mean 128m).

Table 8. Nearest neighbour distances between natural communities in the Credit River watershed.

Area	**Woodland → Woodland**		**Wetland → Wetland**		**Forest → Wetland**	
	Average Distance (m)	Maximum Distance (m)	Average Distance (m)	Maximum Distance (m)	Average Distance (m)	Maximum Distance (m)
Lower zone	128	1281	572	4380	808	3253
Middle zone	57	769	114	1553	192	1763
Upper zone	58	699	91	1647	128	1745
Watershed-wide	**74**	**1281**	**135**	**4380**	**280**	**3253**

The distance between wetlands was also examined because it influences the ability of species to disperse which rely on wetland habitats (e.g. Pearce et al 2007; Veysey et al 2011). Wetlands in the Credit River watershed are on average 135m away from each other, with a maximum distance between wetlands of 4.4km. Wetlands in the upper watershed are in closer proximity to each other than wetlands in the middle watershed or lower watershed (Table 8). Through examining the spatial distribution of wetlands in the Credit River watershed, it is clear that wetlands are spatially clustered across the landscape (Fig. A12, Fig. A18, Appendix A). This clustering is primarily due to the physiography of the landscape (e.g. moraines or melt water channels) forming large provincially significant wetland complexes that are protected from development. In fact, 91.2% of wetland area may be hydrologically connected to a stream reach within the watershed. In such cases, at least part of the wetland patch falls within 30m of a watercourse.

Finally, the distance between upland forests (i.e. coniferous, deciduous or mixed forests according to ELC) and wetlands (i.e. swamp, marsh, bog, fen) was examined, as several species move between wetland and upland forest communities during various parts of their life cycles (e.g. foraging and breeding; Mazerolle et al 2005; Pearce et al 2007; Eigenbrod et al 2008; Veysey et al 2011). Forests and wetland communities in the Credit River watershed are an average of 280m away from one another. Approximately half of forests (49.0%) are directly adjacent to a wetland, and an additional 8.7% are separated by less than 100m. The maximum distance from a forest to a wetland is 3.3km, and wetlands in the lower watershed are separated from upland communities by greater distances than communities in the middle and upper zones (Table 8).

The impact of habitat isolation will vary between species, however there are very few studies that address the minimum distances required for species persistence. Nevertheless, habitat isolation will ultimately result in decreased ecosystem functioning, as an isolated woodland or wetland will not be able to support a full complement of species. For forest bird species which may disperse easily over several kilometres, woodlands in the watershed appear to be sufficiently connected to allow for dispersal and sustain populations (Nol et al 2005; Driscoll et al 2005). For amphibians, whose dispersal ranges may be limited to several hundred meters, or extend up to 1 or 2km, some woodland and wetland patches in the watershed will be isolated and inhospitable to dispersal (Berven and Grudzien 1990; Helferty 2002; Gibbs et al 2005). Plant species with limited dispersal activities are more sensitive to fragmentation, and may need contiguous habitat to allow for dispersal (Dupré and Ehrlén 2002; Honnay et al 2002; Piessens et al 2005). The ability of species to disperse is further confounded by the land use matrix surrounding natural habitats (discussed below). Populations in isolated patches are likely to have reduced long-term viability.

3.5 MATRIX QUALITY

Monitoring Question: What is the impact of the land use matrix on natural communities in the Credit River watershed? Does matrix quality differ among physiographic zones?

- The amount of urban area surrounding habitat patches in the watershed ranges from 3% - 86%, with matrix quality ranging from -0.81 – 0.70
- Habitat patches in the lower zone are surrounded by a greater amount of urban cover than habitat patches in the middle and upper zones

Matrix quality analysis indicated that habitat patches in the Credit River watershed are surrounded by a range of matrix types, with matrix quality values ranging from -0.81 to 0.71 (Fig. 12). This is reflected by the range of 3% - 86% urban cover surrounding habitat patches. Thirty-one percent of habitat patches are surrounded by more than 50% urban land use, indicating that these patches have significant barriers to dispersal across the landscape. An additional 28% of patches are embedded in an agricultural landscape, with more than 50% agricultural cover. The remaining habitat patches are either surrounded by more than 50% natural area (15% of patches), or are surrounded by a variety of land use types (26% of patches). These results indicate that the majority of habitat patches in the watershed are surrounded by a relatively impermeable or semi-permeable matrix.

Overall, the matrix quality values observed across the watershed indicate that some areas are fragmented, particularly in the lower watershed, indicating that the ability of some species to disperse across the watershed may be restricted (Fig. 12). Several studies have demonstrated that the amount of available habitat within a specified radius (generally within 2km) surrounding a natural area can influence species persistence and survival (Houlahan and Findlay 2003; Gibbs et al 2005; Hermann et al 2005; Mazerolle et al 2005; Donnelly and Marzluff 2006). Increasing connectivity where possible to allow for species dispersal will supports species persistence over the long term, reduce the likelihood of genetic bottlenecks, and allow for adaptation to disturbances and habitat changes on the landscape (Fahrig and Merriam 1994; Honnay et al 2002; Baggio et al 2011).

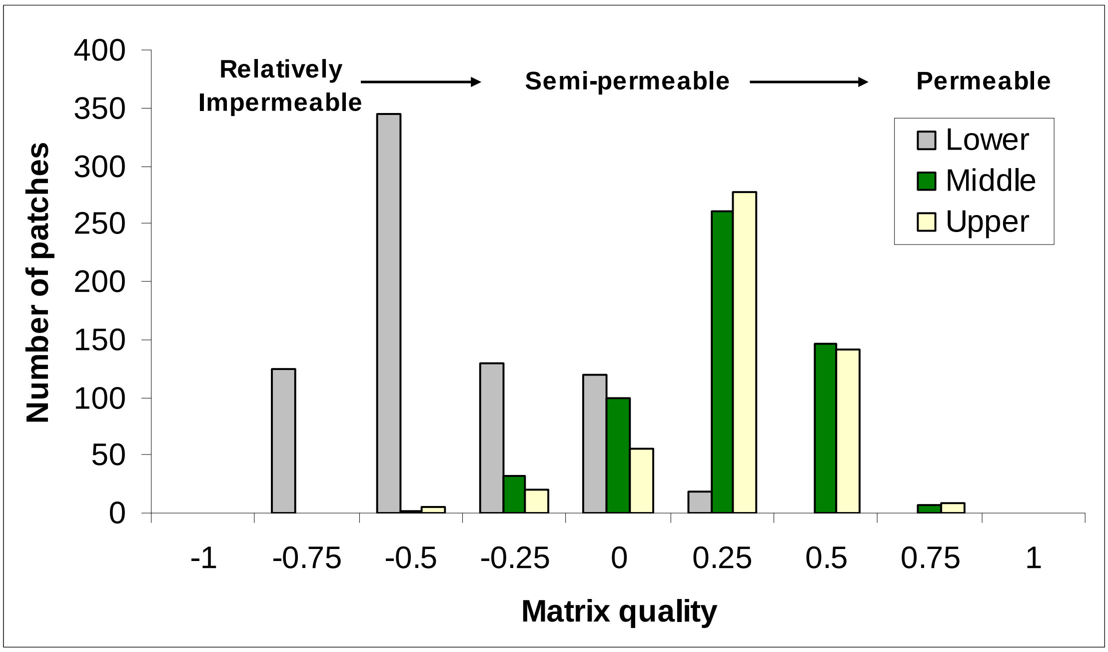

Figure 12. Matrix quality for individual habitat patches within physiographic zones of the Credit River watershed, showing the range of values from patches surrounded by predominantly urban area, to patches surrounded by predominantly natural area.

3.6 RIPARIAN COVERAGE

Monitoring Question: What proportion of stream length is naturally vegetated in the Credit River watershed? Do streams have a naturally vegetated 30m buffer?

- 74% of stream length, and 68% of the area within 30m of streams, in the Credit River watershed is naturally vegetated
- The lower zone contains less natural vegetation adjoining streams than the middle and upper zones
- Sixteen of the twenty-three subwatersheds have >75% natural vegetation along their stream length, though only 6 subwatersheds contain >75% natural vegetation within a 30m stream corridor along the watercourse

Within the Credit River watershed, 74% of streams are naturally vegetated and 68% of the area adjoining streams are naturally vegetated within a 30m stream corridor (Fig. A19-A20, Appendix A). Watercourses in the upper watershed are more naturally vegetated (considering both metrics), followed closely by the middle watershed and then the lower watershed (Table 9). Watercourses within the lower watershed fall below 75% for both riparian landscape measures (Table 9).

The target for naturally vegetated stream length in the Credit River Watershed Fisheries Management Plan is 90% of streams should have a naturally vegetated stream length (Ontario Ministry of Natural Resources and Credit Valley Conservation 2002). Currently, no physiographic zone or subwatershed has met this target (Table 9-10).

Table 9. Naturally vegetated watercourse length, and percentage of watercourse containing 30m naturally vegetated buffer, in the Credit River watershed and physiographic zones.

Geographic Region	Watercourse length naturally vegetated (%)	Vegetated 30m Buffer (%)
Credit River watershed	**74**	**69**
Upper zone	82	78
Middle zone	75	71
Lower zone	63	56

[a] >75% = green; <75% = yellow; Environment Canada How Much Habitat is Enough Guidelines (2013)

At a subwatershed scale, 17 subwatersheds have greater than 75% vegetation adjacent to streams (Fig. A19, Appendix A; Table 10).When the amount of natural vegetation within 30m of the stream is examined, eight subwatersheds contain greater than 75% vegetation within the 30m stream corridor (Fig. A20, Appendix A; Table 11). On the other hand, three subwatersheds (Credit River - Glen Williams to Norval, Huttonville Creek and Levi Creek) contain less than 50% natural vegetation adjacent to their streams and less than 50% natural vegetation within 30m from the stream (Table 10). Huttonville and Levi Creeks are both located within the lower zone, and Glen Williams to Norval is located in the middle zone below the Niagara Escarpment boundary and encompasses most of the town of Georgetown. These three subwatersheds are currently dominated by agricultural land use and are under increasing development pressure.

The amount of natural vegetation along watercourses also varies with stream order. Within CVC's jurisdiction, 82.6% of watercourses are classified as lower order (3rd order and below; sometimes considered headwater streams). Lower order watercourses in the watershed are 71% naturally vegetated and contained 66% natural vegetation within a 30m buffer. Higher order watercourses (4th order and above; generally the Credit River and its main branches) have greater coverage of natural vegetation adjacent to watercourses (85%), and 85% of the 30m buffer adjacent to streams is naturally vegetated (Table 11). These higher order watercourses are more likely to be in a defined valley, making land-clearing less likely in these areas.

It is of note that several subwatersheds in the lower zone, particularly those within the City of Mississauga, have greater than 75% naturally vegetated stream lengths (Table 10). For example, the Lake Ontario East and West tributaries, which capture the streams draining directly into Lake Ontario, contain greater than 75% natural vegetation adjacent to the stream. These areas are dominated by urban land use, and the stream order has been heavily modified due to the loss of headwater streams (i.e. naturally occurring lower order streams have been removed through the development process). In addition, streams are often piped under ground during urbanization making landscape characterization of riparian health difficult. Monitoring data collected at a finer scale of resolution (i.e. site level) in the lower zone indicates that water quality is generally poor to fair, baseflows are poor and the hydrologic regime has been moderately to highly altered (Credit Valley Conservation 2007a). Data from the riparian component of CVC's Terrestrial Monitoring Program further indicate that the riparian zones are impaired within this area, with a decrease in native ground vegetation species observed in the lower zone (Credit Valley Conservation 2011b). Collectively, these results indicate that the vegetated stream parameters examined at the landscape scale in this report may not be ideal indicators of riparian health when applied within an urban context.

Table 10. Naturally vegetated stream length, and percentage of stream containing 30m naturally vegetated buffer, within subwatersheds of the Credit River watershed. [a]

Subwatershed Name	Subwatershed Number	Physiographic Zone	Length naturally vegetated (%)[a]	Vegetated 30m Buffer (%)
Carolyn Creek	2	Lower	82	70
Churchville Tributary	8b	Lower	86	75
Credit River - Norval to Port Credit	9	Lower	70	70
Fletcher's Creek	5	Lower	61	52
Huttonville Creek	7	Lower	39	33
Lake Ontario Shoreline East Tributaries	22	Lower	78	61
Lake Ontario Shoreline West Tributaries	21	Lower	81	65
Levi Creek	6	Lower	44	37
Loyalist Creek	1	Lower	89	68
Mullett Creek	4	Lower	62	52
Sawmill Creek	3	Lower	77	69
Springbrook Tributary	8a	Lower	74	64
Black Creek	10	Middle	77	71
Credit River - Cheltenham to Glen Williams	12	Middle	77	75
Credit River - Forks of the Credit to Cheltenham	20	Middle	77	73
Credit River - Glen Williams to Norval	14	Middle	43	41
East Credit River	13	Middle	83	79
Silver Creek	11	Middle	76	71
Caledon Creek	16	Upper	78	73
Credit River - Melville to Forks of the Credit	18	Upper	81	76
Orangeville	19	Upper	84	79
Shaw's Creek	17	Upper	84	80
West Credit River	15	Upper	82	79

[a] >75% = green; <75% = yellow; Environment Canada How Much Habitat is Enough Guidelines (2013)

Table 11. Stream length and percent naturally vegetated stream length in the Credit River watershed[a]

Credit River watershed[a]	Total Stream Length (km)	% Stream Naturally Vegetated	Vegetated 30m Buffer (%)
All Streams	**1693**	**74%**	**69%**
1-3 Order	1399	71%	66%
>4th Order	294	85%	85%

[a] Credit River watershed was defined here to includes all streams in CVC's jurisdiction draining directly into Lake Ontario.

[b] >75% = green; <75% = yellow; Environment Canada How Much Habitat is Enough Guidelines (2013)

Furthermore, it is important to consider that a 30m width is not likely wide enough to fulfill all riparian functions (Castelle and Johnson 2000; Lee et al 2004; Buffler et al 2005). For example, several hundred meters adjacent to a stream may be necessary to maintain riparian habitat (Spackman and Hughes 1995; Fischer and Fischenich 2000; Semlitsch and Bodie 2003). Additional work is still needed in many areas of the Credit River watershed to ensure riparian and aquatic health is protected over the long term.

4.0 CONCLUSIONS

Landscape level monitoring of natural ecosystems within the Credit River watershed provides a foundation for monitoring trends and patterns in ecosystem health over time. As the Credit River watershed is undergoing rapid land use change, it is recommended that landscape level monitoring should be repeated approximately every five years. Future analyses may include examining trends over time, as well as integrating landscape level and site level data to evaluate the influence landscape change is having on communities and species in the watershed.

Table 12. Summary of landscape metrics for assessing ecosystem integrity in the Credit River watershed, and comparison with available habitat guidelines[a].

Parameter	Guideline/Threshold[a]	Watershed-wide	Lower	Middle	Upper
Woodlands					
Percent cover[b]	30% = High Risk	21%	7%	25%	17%
Average area	No threshold	9.8 ha	4.7 ha	14.0 ha	9.1 ha
Patches >200ha[c]	1	7	0	7	0
Interior (% of watershed/zone)[d]	10% 100m	2.96%	0.10%	3.79%	3.04%
Nearest neighbour (average distance)	No threshold	74m	128m	57m	58m
Wetlands					
Percent cover[e]	10%	6%	1%	8%	10%
Average area	No threshold	5.6 ha	2.8 ha	4.7 ha	7.1 ha
Nearest neighbour (average distance)	No threshold	135m	572m	114m	91m
Successional Areas					
Percent cover	No threshold	10%	8%	10%	13%
Average area	No threshold	4.6ha	3.6ha	4.0ha	6.3ha
Riparian Areas					
Naturally vegetated stream length[f]	90%	74%	63%	75%	82%
30m buffer (percentage of stream with naturally vegetated 30m buffer)	Streams should have a naturally vegetated 30m buffer	69%	56%	71%	77%

[a] Thresholds and colour code for forests and wetlands adapted from Environment Canada How Much Habitat is Enough Guidelines (2013). Riparian threshold from Credit River Watershed Fisheries Management Plan (90% streams should be naturally vegetated)
[b] Percent woodland cover: 0-30% - red, 30-50% - yellow, >50%green
[c] Patches >200ha: >=1 – green, 0 – red
[d] Watershed interior cover >10% - green, <10% - yellow
[e] Percent wetland cover: >10% - green, <10% - yellow
[f] Riparian metrics >90% - green, <90=% yellow

Given that natural cover in the watershed is below 50%, the spatial arrangement of natural areas becomes increasingly important (Andrén 1994; Flather and Bevers 2002; King and With 2002). This emphasizes the importance of developing and maintaining a connected watershed Natural Heritage System (Credit Valley Conservation 2011a; TEEM Program Phase III, in Progress). Planning for a natural heritage systems allows for protection, restoration and enhancement of important natural heritage features and areas, and also plans for where natural cover should be to enhance biodiversity and ecosystem function. Subwatershed studies completed by Credit Valley Conservation provide a more detailed characterization of local areas, recommend local landscape targets and provide specific recommendations for restoration. As the total amount of natural cover is low in the watershed, the remaining cover may not provide sufficient high-quality habitat to ensure long-term survival for the full complement of existing species. Increasing natural cover where possible should be a continued restoration goal across the watershed.

To enhance ecosystem function at the landscape scale, increasing connectivity to allow for species dispersal, as well as increasing the amount of core area in the watershed will be very important. Rural stewardship efforts play a very important role in maintaining natural features and functions in these areas (http://www.creditvalleyca.ca/your-land-water/). Increasing connectivity and protecting large core areas will further protect biodiversity and increase ecosystem resilience in the face of climate change (Varrin et al 2007; Beier and Brost 2010).

The impacts of urbanization in the watershed are apparent, as clear differences exist in the distribution of natural areas between the heavily urbanized lower watershed and both the more protected middle zone and the less developed upper zone (Table 12). Overall, the lower zone contained less natural and semi-natural cover than the other two physiographic zones, and the remaining habitat patches were smaller and more fragmented (Table 12). Urban natural heritage systems are important to protect biodiversity and ecosystem function, protect examples of rare species and ecosystems, provide urban residents with access to natural areas, increase resilience to climate change, and reduce impacts from the urban heat island effect (Douglas et al 2011; Stone et al 2012). In this regard, CVC is working with the Toronto and Region Conservation Authority to provide Conservation Authority Natural Heritage System mapping for Brampton (in prep), and has also completed a Landscape Scale Analysis for the City of Mississauga (http://www.creditvalleyca.ca/watershed-science/plants-animals-communities/natural-heritage-system-credit-river-watershed/). In addition, managing the land use matrix surrounding natural areas can provide additional ecosystem functions across the landscape. For example, tree planting in urban areas surrounding natural areas can remove pollutants from the atmosphere, store carbon, reduce heating and cooling demands, and provide supporting habitat for some species (Morris 2010; Lerman and Warren 2011; Toronto and Region Conservation Authority 2011). Opportunities for managing and improving the ecosystem integrity of the urban matrix should be encouraged where possible (http://www.creditvalleyca.ca/your-land-water/green-cities/).

As continued urban growth is planned for the Credit River watershed, indices of landscape health are anticipated to decline over the coming years. As such, habitat creation, restoration and protection will be essential to counteract the anticipated impacts of urban growth and ensure long-term ecosystem integrity at the landscape scale within the Credit River watershed.

REFERENCES

Allan, D.J., Erickson, D.L., Fay, J. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37:149-161.

Andrén H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat. Oikos 71:355-366.

Askins, R.A. and M.J. Philbrick. 1987. Effect of changes in regional forest abundance on the decline and recovery of a forest bird community. Wilson Bulletin 99:7-21.

Austen, M.J.W., Francis, C.M., Burke, D.M. and Bradstreet, M.S. 2001. Landscape context and fragmentation effects on forest birds in southern Ontario. Condor 103:704-714.

Babbitt, K.J. 2005. The relative importance of wetland size and hydroperiod for amphibians in southern New Hampshire, USA. Wetlands Ecology and Management 13:269-279.

Baggio, J.A., Salau, K., Janssen, M.A., Schoon, M.L., Bodin, O. 2011. Landscape connectivity and predator-prey population dynamics. Landscape Ecology 26:33-45.

Baker, M.E., Weller, D.E., Jordan, T.E. 2006. Improved methods for quantifying potential nutrient interception by riparian buffers. Landscape Ecology 21:1327-1345.

Bastow, J.L., Saob, J.L., Finlay, J.C., Power, M.E. 2002. A basal aquatic-terrestrial trophic link in rivers: Algal subsidies via shore-dwelling grasshoppers. Oecologia 131:261-268.

Batáry, P. and Báldi, A. 2004. Evidence of an edge effect on avian nest success. Conservation Biology 18:389-400.

Bay, M.D. 1996. Breeding birds in early successional oldfields: The effect of area on community structure. Proceedings of the Oklahoma Academy of Science 76:67-73.

Beier, P. and Brost, B. 2010. Use of land facets to plan for Climate Change: Conserving the arenas, not the actors. Conservation Biology 24:701-701.

Bélisle, M. and Desrochers, A. 2002. Gap-crossing decisions by forest birds: An empirical basis for parameterizing spatially-explicit, individual-based models. Landscape Ecology 17:219-231.

Bervin, K.A. and Grudzien, T.A. 1990. Dispersal in the wood frog (*Rana sylvatica*): Implications for genetic population structure. Evolution 44:2047-2056.

Booth, D.B. 2000. Forest cover, impervious-surface area, and the mitigation of urbanization impacts in King County, Washington. Prepared for King County Water and Land Resources Division. Seattle, Washington. 18 p.

Booth, D.B., Hartley, D., Jackson, R. 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. Journal of the American Water Resources Association 38:835-845.

Borgmann, K.A. and Rodewald, A.D. 2004. Nest predation in an urbanizing landscape: The role of exotic shrubs. Ecological Applications 14:1757-1765.

Brown, W.P. 2007. Body mass, habitat generality, and avian community composition in forest remnants. Journal of Biogeography 34:2168-2181.

Buffler, S., Johnson, C., Nicholson, J., Mesner, N. 2005. Synthesis of design guidelines and experimental data for water quality function in agricultural landscapes in the Intermountain West. Appendix C. USDA Forest Service. Paper 13. 61p.

Burke, D.M. and Nol, E. 1998. Influence of food abundance, nest-site habitat and forest fragmentation on breeding ovenbirds. Auk 115:96-104.

Burke, D.M. and Nol, E. 2000. Landscape and fragment size effects on reproductive success of forest –breeding birds in Ontario. Ecological Applications 10:1749-1761.
Burne, M.R. and Griffin, C.R. 2005. Habitat associations of pool-breeding amphibians in eastern Massachusetts, USA. Wetlands Ecology and Management 13:247-259.
Cadenasso, M.L. and Pickett, S.T.A. 2001. Effect of edge structure on the flux of species into forest interiors. Conservation Biology 15:91-97.
Cadman, M.D., Sutherland, D.A., Beck, G.G., Lepage, D., Couturier, A.R. 2007. Atlas of the breeding birds of Ontario 2001-2005. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources , and Ontario Nature, Toronto, xxii + 706 p.
Cain, M.L., Damman, H., Muir, A. 1998. Seed dispersal and the Holocene migration of woodland herbs. Ecological Monographs 68:325-347.
Castelle, A.J., Johnson, A.W., Conolly, C. 1994. Wetland and stream buffer size requirements. Journal of Environmental Quality 23:878-882.
Castelle, A.J. and Johnson, A.W. 2000. Riparian vegetation effectiveness. National Council for Air and Stream Improvement Technical Bulletin No 799. 29p.
Chapman, L.J. and Putnam, D.F. 2007. Physiography of southern Ontario. Ontario Geological Survey, Miscellaneous Release--Data 228. ISBN 978-1-4249-5158-1.
Chen, J., Saunders, S.C., Crow, T.R., Naiman, R.J., Brosofske, K.D., Mroz, G.D., Brookshire, B.L., Franklin, J.F. 1999. Microclimate in forest ecosystem and landscape ecology. Bioscience 49:288-297.
Cottam, M.R., Robinson, S.K., Heske, E.J., Brawn, J.D., Rowe, K.C. 2009. Use of landscape metrics to predict avian nest survival in a fragmented midwestern forest landscape. Biological Conservation 142:2464-2475.
Cox, W.A., Thompson, F.R., Faaborg, J. 2012. Landscape forest cover and edge effects on songbird nest predation vary by nest predator. Landscape Ecology 27:659-669.
Cushman, S.A. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological Conservation 128:231-240.
Credit Valley Conservation (CVC). 1956. Credit Valley Conservation Report. Department of Planning and Development, City of Toronto. 24 May 1956. 709p.
Credit Valley Conservation (CVC). 1998. Credit Watershed Natural Heritage Project. Detailed methodology for identifying, mapping and collecting field data at a watershed and subwatershed scale. Version 3.
Credit Valley Conservation (CVC). 2003. Integrated watershed monitoring program: 2003 summary report. Technical report. Credit Valley Conservation.104 p.
Credit Valley Conservation (CVC) and University of Guelph. 2003. Mapping presettlement vegetation from surveyors' records.
Credit Valley Conservation (CVC). 2006. Credit Valley Conservation Strategic Plan 2006. 85p plus appendices.
Credit Valley Conservation (CVC). 2007a. Credit River Water Management Strategy Update – Making it work. May 2007. 24p.
Credit Valley Conservation (CVC). 2007b. Interim Watershed Characterization Report for the Credit River Watershed. 28 February 2007. x + 169p plus appendices.
Credit Valley Conservation (CVC). 2010a. Terrestrial Monitoring program overview. Credit Valley Conservation 42p.

Credit Valley Conservation (CVC). 2010b. Monitoring wetland integrity within the Credit River Watershed: Status and trends. Credit Valley Conservation Terrestrial Monitoring Program Report. 2003-2009. 284p.

Credit Valley Conservation (CVC). 2010c. Monitoring forest integrity within the Credit River Watershed: Status and trends. Credit Valley Conservation Terrestrial Monitoring Program Report. 2003-2009. 352 p.

Credit Valley Conservation (CVC). 2011a. Towards a Natural Heritage System for the Credit River Watershed. Phases 1 & 2: Watershed characterization and Landscape Scale Analysis. Final Technical Report. February 2011. vii + 132 p plus appendices.

Credit Valley Conservation (CVC). 2011b. Terrestrial Monitoring Annual Report 2010. 171p.

Croonquist, M.J. and Brooks, R.P. 1993. Effects of habitat disturbance on bird communities in riparian corridors. Journal of Soil and Water Conservation 48:65-70.

Diana, M., Allan, J.D., and Infante, D. 2006. The influence of physical habitat and land use on stream fish assemblages in southeastern Michigan. American Fisheries Society Symposium 48:359-374.

Demaynadier, P.G. and Hunter, M.L. Jr. 1998. Effects of silviculture edges on the distribution and abundance of amphibians in Maine. Conservation Biology 12:340-352.

Donnelly, R. and Marzluff, J.M. 2006. Relative importance of habitat quantity, structure, and spatial pattern to birds in urbanizing environments. Urban Ecosystem 9:99-117.

Dougan and Associates, Snell and Cecile Environmental Research, and AMEC/Philips Engineering LTD. 2009. Credit Valley Conservation Authority Wetland Restoration Strategy. 72p plus appendices.

Douglas, I., Goode, D., Houck, M., Wang, R. (eds). 2011. The Routledge Handbook of Urban Ecology. Routledge, New York, NY. 664p.

Doyle, A.T. 1990. Use of riparian and upland habitats by small mammals. Journal of Mammalogy 71:14-23.

Driscoll, M.J.L., Donovan, T., Mickey, R., Howard, A., Fleming, K.K. 2005. Determinants of wood thrush nest success: A multi-scale, model selection approach. Journal of Wildlife Management 69:699-709.

Ducks Unlimited Canada. 2010. Southern Ontario wetland conversion analysis. Final report March 2010. Ducks Unlimited Canada. 51p.

Dunford, W. and Freemark, K. 2004. Matrix matters: Effects of surrounding land uses on forest birds near Ottawa, Canada. Landscape Ecology 20:497-511.

Duguay, S. Eigenbrod, F., Fahrig, L. 2007. Effect of surrounding urbanization on nonnative flora in small forest patches. Landscape Ecology 22:589-599.

Dunford, W. and Freemark, K. 2004. Matrix matters: Effects of surrounding land uses on forest birds near Ottawa, Canada. Landscape Ecology 20:497-511.

Dupré, C. and Ehrlén, J. 2002. Habitat configuration, species traits and plant distributions. Journal of Ecology 90:796-805.

Egan, R.S. and Paton, P.W.C. 2004. Within-pond parameters affecting oviposition by wood frogs and spotted salamanders. Wetlands 24:1-13.

Eigenbrod, F., Hecnar, S.J., Fahrig, L. 2008. The relative effects of road traffic and forest cover on anuran populations. Biological Conservation 141:35-46.
Environment Canada. 2013. How much habitat is enough? Third Edition. 127p.
Fahrig L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61:603-610.
Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: A synthesis. Ecological Applications 12:346-353.
Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review in Ecology Evolution and Systematics 34:487-515
Fahrig, L., and Merriam, G. 1994. Conservation of fragmented populations. Conservation Biology 8:50-59.
Falk, K.J., Nol, E., Burke, D.M. 2011. Weak effect of edges on avian nesting success in fragmented and forested landscapes in Ontario, Canada. Landscape Ecology 26:239-251.
Findlay, C.S. and Houlahan, J. 1997. Anthropogenic correlates of species richness in Southeastern Ontario wetlands. Conservation Biology 11:1000-1009.
Fischer, R.A. and Fischenich, J.C. 2000. Design recommendations for riparian corridors and vegetated buffer strips. EMRRP Technical Notes Collection (ERDC TN EMRRP-SR-24), U.S. Army Engineer Research and Development Center, Vicksburg, M.S.
Flanagan, N.E. and Richardson, C.J. 2010. A multi-scale approach to prioritize wetaldn restoration for watershed-level water quality improvement. Wetlands Ecology and Management 18:695-706.
Flather, C.H. and Bevers, M. 2002. Patchy reaction-diffusion and population abundance: The relative importance of habitat amount and habitat arrangement. The American Naturalist 159:40-56.
Flinn, K.M., Lechowicz, M.J., Waterway, M.J. 2008. Plant species diversity and composition of wetlands within an upland forest. American Journal of Botany 95:1216-1224.
Forman, R.T.T. and Godron, M. 1986. Landscape ecology. Wiley, New York.
Forman, R.T.T. 1995. Land Mosaics: The ecology of landscapes and regions. Cambridge University Press, Cambridge.
Fridley, J.D., Vandermast, D.B., Kuppinger, D.M., Manthey, M., Peet, R.K. 2007. Co-occurrence based assessment of habitat generalists and specialists: A new approach for measurement of nice width. Journal of Ecology 95:707-722.
Fuller, T.K. and DeStefano, S. 2003. Relative importance of early-successional forests and shrubland habitats to mammals in the northeastern United States. Forest Ecology and Management 185:75-79.
Gibbons, J.W. 2003. Terrestrial habitat: A vital component for Herptofauna of isolated wetlands. Wetlands 23:630-635.
Gibbs, J.P., Whiteleather, K.K., Schueler, F.W. 2005. Changes in frog and toad populations over 30 years in New York State. Ecological Applications 15:1148-1157.
Gift, D.M., Groffman, P.M., Kaushal, S.S., Mayer, P.M. 2010. Denitrificaiton potential, root biomass, and organic matter in degraded and restored urban riparian zones. Restoration Ecology 18:113-120.

Goetz, S.J., Wright, R.K., Smith, A.J., Zinecker, E., Schaub, E. 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analysis in the mid-Atlantic region. Remote Sensing of Environment 88:195-208.

Golet, F.C., Wang, Y., Merrow, J.S., DeRagon, W.R. 2001. Relationship between habitat and landscape features and the avain community of red maple swamps in southern Rode Island. Wilson Bulletin 113:217-227.

Gonzalez, A., Rayfield, B., Lindo, Z. 2011. The disentangled bank: How loss of habitat fragments and disassembles ecological networks. American Journal of Botany 98:503-516.

Goodwin, S.E. and Shriver, W.G. 2010. Effects of traffic noise on occupancy patterns of forest birds. Conservation Biology 25:406-411.

Grixti, J.C. and Packer, L. 2006. Changes in the bee fauna (Hymenoptera: Apoidea) of an old field in southern Ontario, revisited after 34 years. The Canadian Entomologist 138:147-164.

Gutzwiller, K.J. (ed.) 2002. Applying landscape ecology in Biological Conservation. Springer-Verlag. New York, USA. 518p.

Hames, R.S., Rosenberg, K.V., Lowe, J.D., Dhondt, A.A. 2001. Site reoccupation in fragmented landscapes: Testing predictions of metapopulation theory. Journal of Animal Ecology 70:182-190.

Hartley, M.J. and Hunter, Jr., M.L. 1998. A meta-analysis of forest cover, edge effects, and artificial nest predation rates. Conservation Biology 12:465-469.

Helferty, N.J. 2002. Natural heritage planning for amphibians and their habitats. With reference to populations on the south slope of the Oak Ridges Moraine. Natural Heritage Consulting Final Report. 71 p.

Helms, B.S., Schoonover, J.E., Feminella, J.W. 2009. Seasonal variability of landuse impacts on macroinvertebrate assemblages in streams of western Georgia, USA. Journal of the North American Benthological Society 28:991-1006.

Henderson, L.E., Farrow, L.J., Broders, H.G. 2008. Intra-specific effects of forest loss on the distribution of the forest-dependant northern long-eared bat (Myotis septentrionalis). Biological Conservation 141:1819-1828.

Herrmann, H.L., Babbitt, K.J., Baber, M.J., Congalton, R.G. 2005. Effects of landscape characteristics on amphibian distributions in a forest-dominated landscape. Biological Conservation 123:139-149.

Hickey, M.B. and Doran, B. 2004. A review of the efficacy of buffer strips for the maintenance and enhancement of riparian ecosystems. Water Quality Research Journal of Canada 39:311-317.

Honnay, O., Verheyen, K., Butaye, J., Jacquemyn, H., Bossuyt, B., Hermey, M. 2002. Possible effects of habitat fragmentation and climate change on the range of forest plant species. Ecology Letters 5:525-530.

Hoover, J.P., Tear, T., Baltz, M.E. 2006. Edge effects reduce the nesting success of Acadian flycatchers in a moderately fragmented forest. Journal of Field Ornithology 77:425-436.

Houglahan, J.E. and Findlay, C.S. 2003. The effects of adjacent land use on wetland amphibian species richness and community composition. Canadian Journal of Fisheries and Aquatic Sciences 60:1078-1094.

Houglahan, J.E., Keddy, P.A., Makkay, K., Findlay, C.S. 2006. The effects of adjacent land use on wetland species richness and community composition. Wetlands 26: 79-96.

Iverson, L.R., Dale, M.E., Scott, C.T., Prasad, A. 1997. A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forests (U.S.A.). Landscape Ecology 12:331-348.

Jacquemyn, H., Butaye, J., Hermy, M. 2003. Influence of environmental and spatial variables on regional distribution of forest plant species in a fragmented and changing landscape. Ecography 26:768-776.

Jules, E.S., and Shahani, P. 2003. A broader ecological context to habitat fragmentation: why matrix habitat is more important than we thought. Journal of Vegetation Science 14:459-464.

Johnston, C.A., N.E. Detenbeck, and G.J. Niemi. 1990. The cumulative effects of wetlands on stream water quality and quantity. A landscape approach. Biogeochemistry 10:105-141.

Johnston, C.A. 1994. Cumulative impacts to wetlands. Wetlands 14:49-55.

Jones, A.L., Shriver, G., Vickery, P.D. 2001. Regional Inventory of Grassland Birds in New England and New York, 1999-2000. Prepared for National Fish and Wildlife Foundation. 28p + appendices.

Kalisez., S., Hanzawa, F.M., Tonsor, S.J., Thiede, D,A. and Voigti, S. 1999. Ant-mediated seed dispersal alters pattern of relatedness in a population of Trillium grandiflorum. Ecology 80: 2620–2634.

Keller, G.S. and Yahner, R.H. 2007. Seasonal forest-patch use by birds in fragmented landscapes of south-central Pennsylvania. The Wilson Journal of Ornithology. 119:410-418.

King, A.W. and With, K.A. 2002. Dispersal success on spatially structured landscapes: When do spatial pattern and dispersal behavior really matter? Ecological Modelling 147:23-39.

Kupfer, J.A., Malanson, G.P., Franklin, S.B. 2006. Not seeing the ocean for the islands: the mediating influence of matrix-based processes on forest fragmentation effects. Global Ecology and Biogeography 15:8-20.

Larson, B.M., Riley, J.L., Snell, E.A., Godschalk, H.G. 1999. The woodland heritage of Southern Ontario: A study of ecological change, distribution and significance. Federation of Ontario Naturalists, Ontario, Canada.

Lee, H.T., Bakowsky, W.D., Riley, J., Bowles, J., Puddister, M., Uhlig, P., McMurray, F.S. 1998. Ecological land classification of southern Ontario: First approximation and its application. Ontario Ministry of Natural Resources, Southcentral Science Section, Science Development and Transfer Branch. SCSS Field Guide FG-02.

Lee, M., Fahrig, L., Freemark, K., Currie, D.J. 2002. Importance of patch scale vs landscape scale on selected forest birds. Oikos 96:110-118.

Lee, P., Smyth, C., Boutin, S. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70:165-180.

Lerman, S.B. and Warren, P.S. 2011. The conservation value of residential yards: Linking birds and people. Ecological Applications 2: 1327-1339.

Long, E.S., Diefenbach, D.R., Rosenberry, C.S., Wallingford, D.B., Grund, M.D. 2005. Forest cover influences dispersal distance of white-tailed deer. Journal of Mammology 86:623-629.

Mancke, R.G. and Gavin, T.A. 2000. Breeding bird density in woodlots: Effects of depth and buildings at the edges. Ecological applications 10:598-611.

Mayer, P.M., Reynolds, S.K., McCutchen, M.D., Canfield, T.J. 2007. Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality 36:1172-1180.

Mazerolle, M.J., Desrochers, A., Rochefort, L. 2005. Landscape characteristics influence pond occupancy by frogs after accounting for detectability. Ecological Applications 15:824-834.

McDonald, R.I. and Urban, D.L. 2006. Edge effects on species composition and exotic species abundance in North Carolina Piedmont. Biological Invasions 8:1049-1060.

McKinney, M.L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127:247-260.

McWilliam, W., Eagles, P., Seasons, M., Brown, R. 2010. Assessing the degradation effects of local residents on urban forests in Ontario, Canada. Arboriculture and Urban Forestry 36:253-260.

Meyer, C.L., Sisk, T.D., Covington, W.W. 2001. Microclimatic changes induced by ecological restoration of Ponderosa pine forests in northern Arizona. Restoration Ecology 9:443-452.

Mitsch, W.J. and Gosselink, J.G.. 2000. The value of wetlands: Importance of scale and landscape setting. Ecological Economics 35:25-33.

Moffatt, S.F., McLachlan, S.M., Kenkel, N.C. 2004. Impacts of land use on riparian forest along an urban - rural gradient in southern Manitoba. Plant Ecology 174:119-135.

Morris, D.N. 2010. The role of native plant and seed collectors and growers in protecting floral diversity. PhD Thesis. University of Waterloo.

Ministry for Public Infrastructure and Renewal (MPIR), now renamed Ministry of Energy and Infrastructure. 2006. Places to Grow. Growth Plan for the Greater Golden Horseshoe. Queen's Printer for Ontario. 70p.

Naiman, R.J. and Decamps, H. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics. 28:621-658.

Nakano, S. and Murakami, M. 2001. Reciprocal subsidies: Dynamic interdependance between terrestrial and aquatic food webs. Proceedings of the National Academy of Sciences 98:166-170.

Nol, E., Francis, C.M., Burke, D.M. 2005. Using distance from putative source woodlots to predict occurrence of forest birds in putative sinks. Conservation Biology 19:836-844.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364

O'Connell, L.M., Mosseler, A., Rajora, O.P. 2007. Extensive long-distance pollen dispersal in a fragmented landscape maintains genetic diversity in White Spruce. *Journal of Heredity* 98:640-645.

Ontario Ministry of Municipal Affairs and Housing (OMMAH). 2005a. Provincial Policy Statement. Queen's Printer for Ontario. 37p. Available online at http://www.mah.gov.on.ca/Page1485.aspx Accessed 21 June 2010.

Ontario Ministry of Natural Resources (OMNR). 1993. Ontario Wetland Evaluation System, Southern Manual (3rd Edition). 101 pp + Appendices.

Pearce, C.M., Green, M.B., Baldwin, M.R. 2007. Developing habitat models for waterbirds in urban wetlands: A log-linear approach. Urban Ecosystems 10:239-254.

Piessens, K., Honnay, O., Hermy, M. 2005. The role of fragment area and isolation in the conservation of heathland species. Biological Conservation 122:61-69.

Polyakov, V., Fares, A., Ryder, M.H. 2005. Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. Environmental Reviews 13:129-144.

Porej, D., Micacchion, M., Hetherington, T.E. 2004. Core terrestrial habitat for conservation of local populations of salamanders and wood frogs in agricultural landscapes. Biological Conservation 120:399-409.

Reeves, G.H., Hohler, D.B., Larsen, D.P., Busch, D.E., Kratz, K., Reynolds, K., Stein, K.F., Atzet, T., Hays, P., Tehan, M. 2004. Effectiveness monitoring for the aquatic and riparian component of the Northwest forest plan: Conceptual framework and options. USDA Forest Service, general technical report, 84 p.

Richard, M., Bernhardt, T., Bell, G. 2000. Environmental heterogeneity and the spatial structure of fern species diversity in one hectare of old-growth forest. Ecography 23:231-245.

Ries L, Fletcher Jr. RJ, Battin J and Sisk TD. 2004. Ecological responses to habitat edges: mechanisms, models and variability explained. Annual Review of Ecology Evolution and Systematics 35:491-522.

Rioux, S., Bélisle, M., Giroux, J.F. 2009. Effects of landscape structure on male density and spacing patterns in wild turkeys (Meleagris gallopavo) depend on winter severity. Auk 126:673-683.

Ritchie, L.E., Betts, M.G., Forbes, G., Vernes, K. 2009. Effects of landscape composition and configuration on northern flying squirrels in a forest mosaic. Forest Ecology and Management 257:1920-1929.

Rodewald, A.D. and Bakermans, M.H. 2006. What is the appropriate paradigm for riparian forest conservation? Biological Conservation 128: 193-200.

Sabo, J.L., and Power, M.E. 2002. River-watershed exchange: Effects of riverine subsidies on riparian lizards and their terrestrial prey. Ecology 83:1860-1869.

Seavy, N.E., Gardali, T., Golet, G.H., Griggs, F.T., Howell, C.A., Kelsey, R., Small, S.L., Viers, J.H., Weigand, J.F. 2009. Why climate change makes riparian restoration more important than ever: Recommendations for practice and research. Ecological Restoration 27:330-338.

Semlitsch, R.D. and Bodie, J.R. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17:1219-1228.

Smith, L.A. and Chow-Fraser, P. 2010. Impacts of adjacent land use and isolation on marsh bird communities. Environmental Management 45:1040-1051.

Snodgrass, J.W., M.J. Komoroski, A.L. Bryan, Jr. and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod, and amphibian species richness: Implications for wetland regulations. Conservation Biology 14:414-419.

Solymár, B. 2005. A stewardship guide to grasslands in southern Ontario: An introduction for farmers and rural landowners. Ontario Barn Owl Recovery Project Publication. 34p.

Spackman, S.C. and Hughes, J.W. 1995. Assessment of minimum stream corridor width for biological conservation: Species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation 71:325-332.

Stephenson, J.M. and Morin, A. 2009. Covariation of stream community structure and biomass of algae, invertebrates and fish with forest cover at multiple scales. Freshwater Biology 54:2139-2154.

Stone, B., Vargo, J., Habeeb, D. 2012. Managing climate change in cities: Will climate action plans work? Landscape and Urban Planning 107:263-271.

Sullivan, T.J., Moore, J.A., Thomas, D.R., Mallery, E., Snyder, K.U., Wustenberg, M., Wustenberg, J., Mackey, S.D., and Moore, D.L. 2007. Efficacy of vegetated buffers in preventing transport of fecal coliform bacteria from pasturelands. Environmental Management 40:958-965.

Taki, H., Kevan, P.G., Yamaura, Y. 2008. Effects of forest cover on fruit set in the woodland herb, Maianthemum canadense (Liliaceae). Canadian Field-Naturalist 122:234-238.

Tallmon, D.A., Jules, E.S., Radke, N.J., Mills, L.S. 2003. Of mice and med and trillium: Cascading effects of forest fragmentation. Ecological Applications 13:1193-1203.

The Pembina Institute and Credit Valley Conservation. 2009. Natural Credit: Estimating the value of natural capital in the Credit River Watershed. viii + 53 p.

Toronto and Region Conservation Authority (TRCA). 2007. Terrestrial Natural Heritage System Strategy. viii + 57p plus appendices.

Toronto and Region Conservation Authority (TRCA). 2011. Peel Region Urban Forest Strategy. 94p.

Tremblay, M.A. and St. Clair, C.C. 2011. Permeability of a heterogeneous urban landscape to the movements of forest songbirds. Journal of Applied Ecology 48:679-688.

Trzcinski, M.K., Fahrig, L., Merriam, G. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications 9:586-593.

Vance, M.D., Fahrig, L., Flather, C.H. 2003.Effect of reproductive rate on minimum habitat requirements of forest-breeding birds. Ecology 84:2643-2653.

Varrin, R., Bowman, J., Gray, P.A. 2007. The known and potential effects of climate change on biodiversity in Ontario’s terrestrial ecosystems. Queens Printer for Ontario. 58p.

Veysey, J.S., Babbitt, K.J., Cooper, A. 2009. An experimental assessment of buffer width: Implications for salamander migratory behavior. Biological Conservation 142:2227-2239.

Veysey, J.S., Mattfeldt, S.D., Babbitt, K.J. 2011. Comparative influence of isolation, landscape, and wetland characteristics on egg mass abundance of two pond breeding amphibian species. Landscape Ecology 26:661-672.

Vickery, P.D., Hunter, M.L., Melvin, S.M. Jr. 1994. Effect of habitat area on the distribution of grassland birds in Maine. Conservation Biology 8:1087-1097.

Watling, J.I. and Donnelly, M.A. 2007. Fragments as islands: A synthesis of faunal responses to habitat patchiness. Conservation Biology 20:1016-1025.

Weber, T.C., Blank, P.J., Sloan, A. 2008. Field validation of a conservation network on the eastern shore of Maryland, USA, using breeding birds as bio-indicators. Environmental Management 41:538-550.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia. 59p.

Wentworth, K.L., Brittingham, M.C., Wilson, A.M. 2010. Conservation program fields: benefits for grassland and shrub-scrub species. Journal of Soil and Water Conservation 65:50-60.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. In: Ecological integrity and the management of ecosystems. Edited by S. Woodley, K. James and G. Francis. St. Lucie Press. Florida pp. 155-176.

Zhang, X., Liu, X., Zhang, M., Dahlgren, R.A. 2010. A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of Environmental Quality 39:76-84.

Zedler, J.B. 2003. Wetlands at your service: Reducing impacts of agriculture at the watershed scale. Frontiers in Ecology and the Environment 1:65-72.

Zedler, J.B. and Kercher, S. 2005. Wetland resources: Status, trends, ecosystem services and restorability. Annual Review of Environment and Resources 30:39-74.

Zuckerberg, B. and Porter, W.F. 2010. Thresholds in the long-term responses of breeding birds to forest cover and fragmentation. Biological Conservation 143:952-962.