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The relationships of vegetation and bird communities with landforms and geomorphic processes on the Central Niagara Escarpment (Ontario)

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THE RELATIONSHIPS OF VEGETATION AND BIRD COMMUNITIES WITH LANDFORMS AND GEOMORPHIC PROCESSES ON THE CENTRAL NIAGARA ESCARPMENT

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Abstract

This study has examined the relationships between geomorphic form and process, vegetation composition and dynamics, and avian populations for landscapes in the central Niagara Escarpment, Southern Ontario. This includes an area extending from Speyside Conservation area near Milton to Mono Cliffs Provincial Park north of Orangeville. Data was collected for geomorphic form and process parameters, vegetation species and structural parameters, and avian species. The physical parameters included a combination of landform characteristics including slope angle, aspect, and landscape position and geomorphic processes, such as creep and debris slides, measured as a level of disturbance. Human levels of disturbance were also measured for comparative purposes. Eleven vegetation structural parameters were measured, such as deciduous/coniferous ratio, stem density, snag density and canopy cover. This data was collected for 29 land units, divided between upland, slope and valley segments, at 11 sites along the Escarpment. Sampling for the avian populations took place during the breeding season between 1996-1999. Vegetation and bird associations were classified using cluster analysis (TWINSPAN). An ordination analysis (CANOCO) was also completed to determine the relationships between the biological components and biophysical form and process. The results of these analyses were combined with field observations to create a set of landscape units. These units were presented within a descriptive model to describe the relationships within the Escarpment landscape systems.

The results of this study found strong relationships between vegetation associations and landscape position. These patterns were related to disturbance and stress from natural and human processes. Avian populations were strongly related to the

vegetation patterns of coniferous and deciduous cover, but there was not as strong a correspondence with landscape position and the levels of disturbance and stress. Natural disturbance created the greatest variation on species in the slope units, while human disturbance was a stronger control on upland sites. Stream gradient and the extent of floodplain were the main controls in the valley units. Overall, Escarpment landscape systems are dynamic and complex. They are composed of a strongly heterogeneic series of landscape units, which is evident in the diversity of forest and avian components. Management strategies need to recognize the role of natural and human processes in creating this heterogeneity and to develop policies that maintain the spatio-temporal pattern of the disturbance regimes.

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1.0 Introduction

Environmental explanations of plant and animal distributions have had a distinct life-science orientation focusing on controls such as competition and food availability (Huggett, 1995; Osterkamp et al., 1995). Explanations based on the combinations of biological and physical processes have been more limited (e.g., Hack and Goodlett, 1960). The integration of physical processes and organisms has been more successful in plant ecology than in wildlife ecology. Plant distribution theories have focused on species striving to achieve a balance between biotic controls, primarily competition, and abiotic controls, identified as a combination of environmental stress and disturbance (e.g., Southwood, 1977; Grime, 1979). The integration of vegetation and physical processes has been increasing in the field of disturbance ecology which recognizes the role of physical disturbance, such as fire or wind, in many ecosystems in maintaining long-term system equilibrium (e.g., Pickett and White, 1985; Sprugel, 1991; Reice, 1994). In this context, the relationships between vegetation dynamics and processes associated with landforms and geomorphic processes have been investigated for a number of geomorphic environments such as floods and floodplains (Nanson and Beach, 1977; Hupp and Osterkamp, 1996; Hughes, 1997) and wind and hurricanes (Sprugel, 1991; Foster and Boose, 1992; Carlton and Bazzaz, 1998).

There have been fewer attempts to combine physical processes with wildlife studies or incorporate these relationships into wildlife management. The distribution of wildlife is primarily considered as a direct response to the biotic components of the land or their habitat, determined by the principle sources of food and cover, and therefore has a direct linkage to the vegetation component (see Block and Brennan, 1993). A significant body of research has focused on specific biotic characteristics such as vegetation structure (MacArthur and MacArthur, 1961; Karr and Roth, 1971; Mills et al., 1991) and resource availability, especially food sources (Wiens, 1986; Burke and Nol, 1998). However, habitat could also be considered as the combination of the relationships between wildlife and the vegetation-geomorphic system. The relationship between wildlife and geomorphology has primarily considered wildlife as an agent of geomorphic processes such as an erosive force (Imeson, 1976; Viles, 1988; Butler, 1995). There have been fewer studies that consider the response of wildlife to landforms (Vaughn, 1978; Reid and Weatherhead, 1988; Matheson and Larson, 1998; Powell and Mitchell, 1998) and fewer that integrate wildlife patterns with geomorphic processes (Feinsinger et al., 1988).

In geomorphology, geomorphic form and process have been combined in the land system, which recognizes the spatial and temporal integration of land-forming processes at the scale of the landscape (e.g., km^2) (Mitchell, 1991; Huggett, 1995). This system emphasizes the underlying processes in shaping and maintaining the individual components of the land, identified as land units in this thesis, such as a cliff face or stream valley, and the overall shape of the landscape. The land system identifies the connectivity between topographical units by geomorphic processes and can be defined by the movement of material from upper to lower surfaces (Scheidegger, 1986). Land systems have been used to describe the morphology and processes of glacial surges (Evans and Rea, 1999) and slope development from weathering and mass movement (Scheidegger, 1986; Huggett, 1995). However, there has been less emphasis on the integration of vegetation into these systems and little consideration of wildlife (Mitchell, 1991).

Some studies have integrated vegetation communities with the land system (e.g., Hack and Goodlett, 1960), but often the focus has been on a specific landform or process such as debris slides in slope systems (Flaccus, 1959; Veblen and Ashton, 1978; Veblen et al., 1980; Milne and Moss, 1988). Landforms and geomorphic processes have been identified as important controls of ecosystems, especially at the landscape level or meso-scale where land-shaping processes have been identified as the dominant control (Swanson et al., 1988; Bailey, 1996). In light of this, it is surprising to find how limited the research has been on integrating biological components with landforms (McGarigal and McComb, 1992; Mitchell, 1999) and, more so, land-shaping processes. This is especially evident in investigations of the role of geomorphic form and process in shaping the spatial and temporal patterns of wildlife. Despite the strong relationship between land and habitat, there have been few attempts to bridge the gap between geomorphology and wildlife ecology within a landscape ecology perspective.

There is an increasing body of work on the landscape ecology of organisms. However, at the landscape scale and especially in North American studies, the focus has been on a bioecological approach to landscape ecology. In wildlife management, much of the research at the landscape scale has centred on loss of habitat, especially the spatial pattern of contiguous habitat (e.g., Kroodsma, 1982; Knick and Rotenberry, 1995; Huhta et al., 1998). This is especially true in research on the causes for recent declines in avian populations (Askins et al., 1990; Kirk et al., 1997). For example, declines are attributed to loss of forest interior (Forman et al., 1976), increased predation and parasitism (Terborgh, 1989), and urbanization (Friesen et al., 1995). Much of this work has focused on the loss of mature or interior habitat. The emphasis has been on maintaining stable habitats such as old growth interior forest and, consequently, research has focused on land cover or habitat heterogeneity initiated by human and biological processes. Less attention has been given to the processes within these systems that create disturbance and heterogeneity. Recently, it is recognized that other more transient or dynamic habitats are also at risk and have the greatest potential for species loss (Askins, 2000; Hunter et al., 2001). These habitats can be the result of change initiated by disturbance such as geomorphic processes (Feinsinger et al., 1988) or stress, such as exposure or geologic structure (Reid and Weatherhead, 1988). It is therefore important to gain a better understanding of the processes that create and maintain these environments.

A connecting thread between these biological and physical systems that should encourage integration is a strong foundation in the systems approach to understanding ecological and geomorphic phenomena (e.g., Tansley, 1935, Chorley and Kennedy, 1971). Spencer and Whatmore (2001) note the similarity of the concerns of ecological and geomorphological research, as both fields struggle with understanding system change in space and time (e.g., Levins, 1992; Phillips, 1995; Humphries, 2000). This is evident in the parallel shift in thinking from simple closed systems to complex open systems, where flows, networks and change become of prime importance (Spencer and Whatmore, 2001). This change in attitude towards environmental systems is also prevalent in the literature of environmental management. Many agree that the management of environmental systems requires adopting a more holistic or ecosystem approach to environmental management (Slocombe, 1993; Grumbine, 1994; McCormick, 1999). One important principle of this approach is the recognition that in many natural systems, change is intrinsic (Holling, 1978; Botkin, 1989) which can result in complex, frequently disturbed biological communities (Agnew and Spencer, 1999). This change requires a shift in management strategies, one in which complexity is recognized as inherent and simplification of the pattern and functioning of a system could overlook the events that lead to the emergence of new phenomena (Kay and Schneider, 1994). This shift also requires an understanding of the interactions of both the forms (i.e., pattern and composition) and processes (i.e., ecological structure and function) of the biophysical components that shape ecosystems (Bourgeron and Jensen, 1994; Slocombe, 1998). One way of promoting this integration could come by improving the understanding of the linkages between the processes of a combined biophysical system. A process approach would take into account the dynamic state of the natural environment by considering the impact that integrated processes will have on the system over time. This can be achieved by adopting a geoecological approach, the study of the landscape system into which the bioecological aspects are integrated as one of a series of components. By incorporating process information into a land system framework, the resource manager is able to appreciate the dynamics, the constant changes, in these processes so that an understanding of inevitable, natural change will direct successful management strategies (Moss and Milne, 1998).

The Niagara Escarpment presents an excellent opportunity to investigate these challenges in landscape ecology and geomorphology and to apply these ideas within a land management framework. The pattern of geology and glacial deposits of the Escarpment leads to a complex landscape of landforms and geomorphic processes which is matched by a high diversity of organisms and habitats. It is a dynamic landscape system with a complex of landscape units that are maintained by the dynamics of physical processes (Moss and Milne, 1998). The Escarpment landscape can be considered within the framework of the geomorphic land system. The topography of the land has a strong pattern of upland, face or Escarpment slope and valley. In places, the landscape face is distinguished by an abrupt break in the slope and for many, these large cliffs are the defining feature of this landform. Yet there are many sections of the Escarpment where there is a more gradual grade between highland and lowland, identified by various patterns of convex-concave slope forms, and there is a strong exchange of energy and matter along an altitudinal gradient (Mitchell, 1991).

Several studies of the vegetation and geomorphic form and process at specific sites on the Escarpment have established relationships between cliff faces and vegetation cover, specifically eastern white cedar (*Thuja occidentalis*) (Larson et al., 1989; Larson and Kelly, 1991; Kelly and Larson, 1997) and slope processes and forest dynamics (Moss and Rosenfeld, 1978; Moss and Nickling, 1980; Milne and Moss, 1988). However, the Escarpment landscape consists of the combination of uplands on bedrock plains or moraine surfaces that extend beyond the rim of the slope or cliff; the face itself, including steep cliff faces, small buried bedrock exposures and long convex-concave slopes; and lowlands and stream channels that drain below the Escarpment. There has been little investigation of the biophysical relationships between forests and geomorphic form and processes for these combinations of land units. Past research on the biophysical system has been centred on the Escarpment slope system (Moss and Milne, 1998). To achieve a more thorough understanding of the Escarpment landscape requires expanding the scale of focus beyond just the slope system to include the upland and valley land units.

Very few studies have linked wildlife to the Escarpment land system. Matheson and Larson (1998) examined the pattern of bird populations for several cliff communities. They described the influence of the cliff rim and face of the Escarpment as a narrow, natural edge which attracts a unique association of birds with a higher diversity than adjacent plateau forests. They also found the talus slopes similarly attracted bird species not found in the surrounding forests. The Escarpment provides some of the most intact and least disturbed tracts of forest-interior habitat for birds in southern Ontario and consequently is recognized as a critical source area for bird species such as forest-interior, neotropical migrants; this has management implications beyond the boundary of the Escarpment management area. Some Escarpment ecosystems have been identified as essential for providing replacement individuals to smaller species-poor woodlots or sinks in the agricultural and urban landscapes that surround this landform. The importance of these metapopulations has been studied for several forest-interior species (Wyatt et al., 1998).

It is a timely opportunity to consider the integration of wildlife into a geoecological study of the Escarpment system. Several recent initiatives have focused on bird indicator species and the role of the Escarpment (Couturier et al., 1998; Credit Valley Conservation, 1999). These reports have attempted to associate species with habitat, but are limited to a description of the dominant vegetation and only examine the relationships at a regional scale. They do not consider the complexity of local landform pattern and process. The Escarpment landforms and processes create successional shrub and forest communities as well as edge communities along structural and disturbance boundaries. These disturbance habitats and associated species have been identified as in decline in eastern North America and require specific management attention (Askins, 2000; Hunter et al., 2001). Many areas along the Escarpment also have human-modified forests created by forestry and planting initiatives. These coniferous plantations are currently in varying states of management and maturity and are experiencing change from human and natural processes.

Overall, the central Escarpment landscape is a complex of land units shaped by different combinations of natural and human processes or disturbances. This region presents an opportunity to develop an understanding of these biophysical relationships which could be applied to other similar landscape complexes throughout southern Ontario and eastern North America, especially where rural resource landscapes are in transition. This knowledge can also be extended to other similar natural environments including extensions of the Escarpment in Ontario as well as the United States (Tovell, 1992; Cowell, 1995). There are also other landscapes dominated by shallow limestone plain or alvars for which this information could be useful in developing the relationships between wildlife, vegetation and landform (Belcher et al., 1992; Schaefer, 1995; Grimm, 1997).

The Escarpment landscape has a complex pattern of land use ranging from natural and protected areas to sites of resource production, recreation and urban sprawl. The encroaching human pressure on this landscape is forcing land managers to assess development and conservation strategies to successfully maintain this landscape. The Niagara Escarpment has been legislated as a formal planning area that incorporates identifiable important natural areas with a variety of human land uses. These lands are administered following the Niagara Escarpment Plan. The Plan, introduced by the Niagara Escarpment Commission (NEC) (1979), is the principal planning document governing land use patterns above and below the Escarpment and envelops a considerable variety of land uses beyond the protected lands of the Escarpment slope. Therefore, the complex of landscape units that create the Escarpment landscape corresponds to the levels of land pattern in the planning strategy.

1.1 Objectives

A number of directives were introduced in the preceding section that should be investigated within the Niagara Escarpment landscape to improve the state of knowledge of the biophysical systems and to provide valuable information to assist in land management decisions. Two of these will be considered in this thesis: extending the scale of geoecological research on the geomorphic form and process and vegetation dynamics of the Niagara Escarpment from the slope and cliff units to include upland and valley land units; and integrating a wildlife component into this geoecosystem at the scale of the landscape. These will be addressed by completing the following set of objectives.

(i) To determine the relationships between geomorphic form and process and the dominant vegetation composition and dynamics for upland, face and valley segments of the central Niagara Escarpment.

(ii) To determine the relationships between the species composition of bird populations and the combined vegetation/geomorphic systems identified in the first objective.

(iii) To create a set of landscape units based on the combination of geomorphic, vegetation and bird components and produce a descriptive model of the Escarpment landscape based on these units.

For the purposes of clarity, definitions of the terminology used in this study with reference to patterns in the landscape are identified here. Landscape system refers to the complex of biophysical and human components and processes that shape the land at the scale of km^2. The units that combine to form the landscape system will be described as landscape units. These are homogeneous entities that form the basic unit of these systems. In general, these units are characterized as (a) upland or plateau, (b) the face, which can include steeplands, either convex-concave slopes or cliff faces and (c) valleys or lowlands. Land system will refer to lands that form a related complex of landform and geomorphic processes; the basic unit of this system is the land unit. This will also refer to the combination of geomorphic and vegetation systems previously described for the Escarpment (Moss and Milne, 1998). It should be noted that there can be a broad overlap between the application of these terms in the literature, as with terms such as landscapes and ecosystems (Huggett, 1995; Forman, 1997).

Several papers have provided information on the biophysical relationships for specific sites on the Escarpment face in the southern and northern regions of the Niagara Escarpment (Moss and Rosenfeld, 1978; Moss and Nickling, 1980; Milne and Moss, 1988), but there has not been a detailed study of the geomorphic processes and vegetation dynamics for the central region. This area is dominated by land systems that include either glaciated convex-concave slopes or a buried face, cave-crevice pattern (Moss and Milne, 1998). These types of land systems have not been studied in the same detail as the cliff or steep slope systems (e.g., Moss and Nickling, 1980; Milne and Moss, 1988). Information on the geomorphic/vegetation relationships on these systems will be combined with the previous work to improve the understanding of the relationships within these biophysical systems.

There is little knowledge of the relationships between the Escarpment land systems and the distribution of birds (e.g., Matheson and Larson, 1998). The variety of geomorphic processes and landform structures operating on the Niagara Escarpment creates a complex of vegetation cover that can change significantly over short distances as well as time scales (Milne and Moss, 1998). Therefore, traditional models of bird populations and habitat based on vegetation cover could be difficult to apply in these environments, such as cliff systems (Matheson and Larson, 1998), and a more successful understanding of the habitat can be achieved by combining the vegetation analysis with an investigation of the landforms within a framework that incorporates a process approach and considers the importance of disturbance and stress on the distribution of the biophysical components.

It was decided to use avian populations as the wildlife component for several reasons. As mentioned, there have been several research projects targeting bird species on the Escarpment and adjacent lands (Courterier et al., 1998; Credit Valley Conservation, 1999); information gained in this thesis could be useful to assist in local and regional planning initiatives. As well, there has been considerable concern on the decline of avian populations in eastern North America from loss of habitat (Askins, 2000). The combination of natural process and human management creates many disturbed sites which could provide a baseline for future projects. As well, the concentration of concern for these avian declines has led to an increase in the understanding of bird ecology at the landscape scale which provides a knowledge base to understand relationships observed in this study. Birds are often used as indicator species to monitor environmental change for a number of biological and pragmatic reasons. They are easily identified and are well known organisms in terms of their general ecology and behaviour (Furness and Greenwood, 1993). They have a higher diversity compared to some other species such as mammals, which increases the potential for interpretation of results. Finally, there are several programs in place, including the Forest Bird Monitoring Program, which have a number of sites located on the Escarpment. The results of this study could contribute to these programs or be combined with other research projects.

As outlined in the introductory paragraphs, the main direction of research on the controls of the distribution of organisms has been on biological processes, but there has been an increasing number of studies that consider integrating biophysical processes to achieve a better understanding of dynamic and complex environmental systems. To assist in developing a proper approach to study the integration of these processes, it is necessary to review the current state of research both on the general theories within plant and animal ecology as well as the state of knowledge for biophysical systems on the Niagara

Escarpment. Chapter Two brings together the current research within these areas and addresses the areas of integration, and focuses on the general concepts of ecosystem management with emphasis on the ecological and landscape system characteristics relevant to this study. It also introduces the importance of change or flux in the landscape and the importance of disturbance in causing change or cycling in the vegetation cover, and reviews the main physical controls that influence patterns in the biological components of the landscape, including plant and animal ecology as well as their relationships to landform geomorphology. As this covers a broad range of information, this chapter focuses on how and where these fields have been integrated, specifically the distribution or spatial ecology at the landform scale and disturbance and stress ecology as related to geomorphic form and process.

Chapter Three continues this theme by introducing background information on the integration of biophysical systems specific to the Niagara Escarpment land system. The body of this section focuses on the integration of geomorphic processes and vegetation dynamics to provide the reader with the present state of knowledge on the inter-relationships of these systems. A review of specific relationships between geomorphic processes and vegetation dynamics at sites on the Bruce Peninsula (Moss and Nickling, 1980), Niagara Peninsula (Moss and Rosenfeld, 1978) and Blue Mountain (Milne and Moss, 1988) is presented, followed by an overview of the slope types identified as one measure of different land units (Moss and Milne, 1998).

Chapter Four includes a description of the study area and research sites and the rationale for choosing the combinations of upland, face and valley land units. This chapter also presents the method for the collection of field data pertaining to geomorphic processes, vegetation characteristics and forest dynamics, and bird populations as well as a description of the analyses performed on this data. Geomorphic and landform features are examined for landform characteristics such as slope angle and aspect, as well as a qualitative assessment of the extent and role of natural and human disturbance to the land units.

The statistical analysis included several steps. First, the characteristics of the vegetation and birds were classified separately using TWINSPAN (Hill, 1979) to develop general patterns of groupings of the biological components and then the land units. These groups were further analyzed by Analysis of Variance and Discriminant Analysis (SPSS, 1999) to establish relationships between specific characteristics, such as bird groups and coniferous cover. Finally Canonical Correspondence Analysis (CANOCO, version 4) (ter Braak, 1998) was performed to establish general trends relating the vegetation and bird populations to environmental controls.

Chapter Five presents the results of the statistical analyses. The results of the classifications of the bird and forest associations are described and the relationships between the geomorphic, vegetation and avian components are considered. The results of the ordination analyses identify the environmental controls of the distribution of the vegetation and avian species. A detailed description of each site combining the information on birds, vegetation and landforms is presented in Appendix A. This includes site and species observations obtained during the field work that were useful in determining the general relationships in the discussion.

The patterns determined in these two general analyses were combined with the observational data to develop a series of descriptive models in Chapter Six. Models of the inter-relationships of the biophysical components and processes were developed including the upland, face and valley units. This was combined with the information on the bird populations to create Escarpment landscape units. In Chapter Seven, several considerations of this work are discussed including applications to avian wildlife management on the Escarpment. The importance of this work is also considered from a management perspective for the Niagara Escarpment. The final section of this chapter provides a summary of the project, and selected conclusions and recommendations from this work.

Chapter Two
Vegetation, Bird and Land Systems

2.0 Introduction

A considerable body of work in vegetation and avian systems has concentrated on the role of biological interactions in influencing the distribution of organisms. This relationship has been especially prevalent in wildlife management. However, the increased awareness of the importance of disturbance and stress in creating change to ecosystems and landscapes has turned attention to the importance of physical processes operating within the system as well as considering different forms of system equilibrium. In this chapter, an overview of the role of physical processes in the distribution of organisms is presented to develop a foundation for the consideration of the relationships between the biological and physical systems of the Niagara Escarpment. This review will examine the environmental controls of the distribution of vegetation and birds and the role of physical disturbance in initiating change in these biological systems. Finally, the focus will narrow to review the research that has combined geomorphic form and process of slope systems with these biological systems.

Vegetation distribution is considered as a response to the controlling factors of spatial distribution and community functioning that includes both static and dynamic processes, or those that maintain short-term equilibrium and those that are important for the long-term change or cycling of vegetation cover. Specifically, the response of vegetation to disturbance and stress by geomorphic processes are examined with the focus on slope systems including gap replacement and mass movements such as debris slides.

Avian distribution is examined along a similar structure. General factors, such as resource and habitat partitioning and competition, are reviewed as well as the controlling factors for the distribution of birds at the landscape scale. This section concludes with a discussion on the limited research on the relationships of birds and slope systems.

To begin, an overview of the general concepts of the landscape and land system are presented, including the basic principles of this concept and a discussion of the consideration of a process approach to understanding concepts such as stability and equilibrium. The first section introduces landscape systems, including a review of relevant ecosystem characteristics including stability or equilibrium as well as stress and disturbance and their roles in ecosystem processes. These characteristics are considered in context with the integration of biological and physical systems - the combination of the structures and functions of the biophysical system which forms the landscape system. The basic component of the landscape system, the landscape unit, is also introduced and examined with respect to spatial and temporal scales.

2.1 Ecosystem and Landscape

As noted in the introduction there have been calls for integrating ecological principles into environmental management (Slocombe, 1993; Grumbine, 1994; Kay and Schneider, 1994; McCormick, 1999). Several key characteristics important to this thesis will be discussed here. The most fundamental is understanding the holistic nature of the land system. This requires understanding the interactions between the forms (i.e., pattern and composition) and processes (i.e., structure and function) of the biophysical components that shape the land systems (Moss, 1983; Slocombe, 1998) and incorporating ecosystem functions and processes into management strategies and plans. This requires strengthening the role of ecosystem concepts such as stability, stress and disturbance in defining and understanding land and resource management systems. Two other important changes required in this transition are accepting the importance of integrating the biotic and abiotic components of the system and enlarging the scale at which these systems are studied and managed. It has become essential not only to examine the woodlot and field but also the watershed and landscape.

2.1.1 Landscape Structure and Function

The interdependence of wildlife, vegetation and the physical environment within the ecosphere focuses on the role of geographical space - the landscape. The word 'landscape' commonly alludes to many different things: a picture of a view of natural inland scenery, a vista of natural scenery seen by the eye, and the landforms of a region seen as a whole (Huggett, 1995). It should be considered in a holistic manner and as a perceptible part of the terrestrial environment (Pedroli, 1999). From an ecological perspective, the landscape is the land surface and its associated habitats viewed at medium scales or simply a spatially heterogeneous area or environmental mosaic (Turner and Gardiner, 1991). Study of the landscape also embraces the dynamics of spatial heterogeneity, the spatial and temporal interactions and exchanges across heterogeneous landscapes, as well as the response to spatial heterogeneity by biotic and abiotic processes (Risser et al., 1984). The landscape system may be defined as any landscape unit in which the biosphere, toposphere, atmosphere, pedosphere, and hydrosphere, together with the biological, geomorphological, climatological, pedological, and hydrological processes that create them, are seen as a unitary whole (Huggett, 1995). Huggett's concept of geoecosystems underscores the connection between the biotic and abiotic components of a geoecosystem and serves to counterbalance the biological emphasis on landscapes that has been the primary focus in much landscape ecology research.

At the scale of the landscape, the principal focus has been a bioecological approach to landscape ecology. This tends to focus on the significance of spatial dimensions to plant and animal community-scale ecology. Geographic approaches to landscape analysis have not been effectively integrated into much of the thinking that currently prevails in landscape ecology. This requires a more geoecological approach: the study of land and landscape system into which the bioecological aspects are integrated as one of a series of components (Moss and Milne, 1999).

Landscape ecologists are most often concerned with the causes and effects of spatial patterning in ecosystems. The viewpoint is largely biological; landscape ecologists tend to focus on the biotic component of geoecosystems. As Richling (1999) notes, the term ecosystem is most frequently understood as an ecological structure and is investigated by ecologists on the assumption that biota are the prime focus. The ecologist, then, is primarily concerned with the quantities of matter and energy that pass through a given ecosystem and with the rates at which they do so. Of almost equal importance, however, are the kinds of organisms present in any particular ecosystem and the roles that they occupy in its structure and functions. Ecosystems are further characterized by a multiplicity of regulatory mechanisms which, in limiting the numbers of organisms present and influencing their physiology and behaviour, controls the quantities and rates of movement of matter and energy. Processes of growth and reproduction, agencies of mortality (physical as well as biological), patterns of immigration and emigration, and habits of adaptive significance are among the more important groups of regulatory mechanisms (Evans, 1956). However, the underlying principle of ecosystem research is to regard the ecosystem as including not only the organism-complex but also the whole complex of physical factors forming the environment (Tansley, 1935).

In comparison, the study of the abiotic portion of landscapes has its roots in physical geography, geomorphology, geology, and pedology. There is a strong history of systems approach in understanding the form, behaviour, and historical context of physical landscapes which can be important in understanding and integration with ecological systems at several temporal and spatial scales. Landforms such as floodplains and alluvial fans, and geomorphic processes such as stream erosion and deposition, are important parts of the setting in which ecosystems develop and material and energy flows take place (Parker and Bendix, 1996; Hughes, 1997). Land facets are recognizable, homogeneous components of a landform and are defined in terms of geology, water regime, topography, and sometimes by vegetation (Mitchell, 1991). Related and recurring assemblages of land facets produce the land system, an important construct that emphasizes the transfer of energy and matter through landscapes and the genetic relationships between facets. For example, lowlands are often formed by the deposition of material from surrounding uplands (Mitchell, 1991). The recognition of these links within the land system by geomorphic processes is an important concept and is useful in determining the long-term changes in landscapes (Scheidegger, 1986; Evans and Rea, 1999). Over the long term, geomorphic processes create landforms; over a shorter term, landforms are boundary conditions controlling the spatial arrangement and rates of geomorphic processes (Swanson et al., 1988).

Ecosystems respond to both landforms and geomorphic processes. The history of geomorphic processes may be expressed directly in the composition and structure of vegetation, where geomorphic events and vegetation develop together (Phillips, 1995). Geomorphic processes operating before the establishment of existing vegetation, or those subtly coexisting with the vegetation, may have their greatest influence on vegetation through controlling patterns of soil properties across a landscape, such as catenas or toposequences (Hack and Goodlett, 1960; Swanson et al., 1988; Phillips, 1995).

2.1.2 Stability, Disturbance and Stress

There has been a strong tradition of `balance' or `equilibrium' in ecology throughout the past 100 years (McIntosh, 1985; Sandell et al., 1991). The equilibrium view of the world has always attempted to explain phenomena like violent population fluctuations over time as deviations from the system's resting point. Stability has been a debated concept in ecology because of the difficulty in distinctly defining the term in an ecological sense. The term 'stability' embodies a variety of ecosystem characteristics which can differ depending on the type of system. The term primarily refers to the maintenance of a system, its ability to remain in the landscape despite the presence of external and internal stresses and disturbances. The equilibrium has been assumed to be stable, meaning the system will eventually return to its resting point after perturbations. Therefore, regular and persistent fluctuations over long periods seem to violate balance and equilibrium. However, stability can refer to the response to disturbance in the landscape, or can define dynamic stability, the result of gradual change that leads to a change which can be abrupt when a threshold is crossed. Stability can also be considered as scale-dependent; the state at a site or within a patch in a landscape may appear stable at the larger spatial scale when considered in the context of the larger landscape. The stability of a patch within the landscape can be dependent on conditions in the surrounding matrix or landscape (Forman, 1995).

A static measure, in capturing a single moment, could be interpreted as suggesting the system is in a relatively stable equilibrium with local, minor adjustments. In contrast, a time series of measures captures the dynamic nature of the system. It implies that biophysical processes or fluxes are great enough that change is measurable over the short term. Therefore, the concept of stability can be viewed as a combination of static and dynamic processes reflected in the population of the biotic components as well as in the arrangement of habitats, patterns of landforms and vegetation or, broadly speaking, the landscape.

One of the more important developments in ecological theory has been the recognition of change as part of the functioning of an ecosystem. Cyclical change has been recognized in studies on vegetation communities for many years (e.g., Watt, 1947; Sprugel, 1976), which led to new concepts of stability and equilibrium in ecosystems (Loucks, 1970; Pickett, 1980). A great body of work has evolved from this research centring on the importance of disturbance or disturbance theory (e.g., Bormann and Likens, 1979; Pickett and White, 1985; Reice, 1994), and subsequently the management of land systems (e.g. Baker, 1992; Perera and Euler, 2000).

In the past, major disruptions to land cover by events such as hurricanes, fires and landslides were considered disasters - external forces that upset the normal functions of the land. Now it is generally accepted that these disturbances are part of the natural system and are actually essential for the maintenance and functioning of many natural environments (Pickett and White, 1985; Reice, 1994). Disturbance can be defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (Pickett and White, 1985). The complex issue of species diversity and ecosystem stability is beyond the scope of this paper, yet there are certain aspects of the argument that are useful in developing an understanding of system relationships such as those found on the Niagara Escarpment. Van Voris et al. (1980) states that it has long been held that increased complexity (e.g., species complexity) of an ecosystem should be correlated with increased stability. In general, disturbance promotes species diversity in natural systems by creating patchiness or heterogeneity in the environment (e.g., Connell, 1978). Species diversity often peaks at some intermediate time after disturbance, expressed as the intermediate disturbance theory (Fox, 1979), but diversity can also increase or decrease along disturbance gradients (Pollock et al., 1998).

Alternatively, stress is described as the deviation or displacement of the ecosystem from the nominal state (Odum et al., 1979). It seems clear that in general, 'stress' can be considered as a stimulus on a biological system and can be measured as the subsequent reaction of the system (Pickering, 1981). Rapport et al. (1985) used stress to denote an external force, or stimulus that causes changes in the ecosystem; it causes the ecosystem to respond, or entrains ecosystemic dysfunctions that may exhibit symptoms. The effect of stress on an ecosystem is described as 'response', though one could use perturbation, dysfunction, or distress syndrome as approximate equivalents.

Rapport et al. (1985) noted not all stresses threaten the continued viability of ecosystems. Many ecosystems, as Vogal (1980) documents, depend on stress for their persistence. The stresses upon which organisms and systems are dependent are often repetitive and become expected or anticipated events that are part of natural systems. In these systems, stress and disturbance combine to create the spatial structure that can be both static and dynamic.

2.2 Landscape Systems

The landscape can be considered as the combination of separate environmental systems such as the biosphere, lithosphere and hydrosphere. The integration of these at the level of land management is found in studies on landscape or geoecological systems. One of the strengths of this approach is the integration of biological and physical processes into a more functional understanding of land systems. Landscape ecologists define landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron, 1986), which is similar to the land system described by geomorphologists (Mitchell, 1991). Similarly, geoecosystems are composed of the interacting ecosystems such as forest and field. The smallest homogeneous landscape units visible at the spatial scale of a landscape are variously termed ecotopes, biotopes, geotopes, facies, facets, habitats, sites, tesserae, land units, landscape units, landscape cells, landscape prisms, or landscape elements (Forman and Godron, 1986; Mitchell, 1991; Huggett, 1995).

The term 'patch' has also been employed to describe a discrete and internally homogeneous entity most often in the spatial context of wildlife habitat; an area that differs from its surroundings in nature of appearance (Wiens, 1976; Forman and Godron, 1986). Hierarchical mosaics of patches within landscape occur over a broad range of scales (Wiens, 1976; Senft et al., 1987). Pickett and White (1985) described components of patch structure as a relatively discrete spatial pattern, but do not establish any constraint on patch size, internal homogeneity or discreteness. Forman and Godron (1986) noted that patches vary widely in size, shape, type, heterogeneity and boundary characteristics.

In Canada, there has been considerable work to develop integrated, ecological approaches to land unit description and classification to assist in land use planning. Within the Escarpment region, for example, Credit Valley Conservation (CVC) has been mapping watersheds following the Ecological Land Classification (ELC) system (Lee et al., 1998; Credit Valley Conservation, 2000). The goal of these types of classification schemes is to identify recurring ecological patterns in the landscape in order to reduce complex natural variation to a reasonable number of meaningful ecosystem units (Bailey et al., 1978). However, these classification approaches are based on a morphological approach which distinguishes units on the basis of static criteria such as the dominant vegetation cover. This approach simply defines the areal extent of the unit and does not consider the change of states and processes within the unit's limits (Richling, 1999).

2.2.1 Scale

Increased understanding of ecological systems has been achieved by realizing that patterns and processes are strongly scale-dependant (Ricklefs, 1987; Urban et al., 1987; O'Neill, 1989; Levin, 1992; Böhning-Gaese, 1997). For example, patterns in species diversity are influenced by the spatial and temporal scale at which the organisms and the processes that determine species composition operate (Böhning-Gaese, 1997). These processes create patterns in habitat which can be observed at different scales (Lord and Norton, 1990, from Fahrig and Merriam, 1994). A new set of processes has emerged that structures communities, or at least a new scale at which processes can influence population and diversity. Natural habitats have become heavily fragmented in many urbanizing landscapes, creating new habitat patterns and increasing the concerns and importance for the spatial features of habitats. With fragmentation there is greater variability in habitat size - the arrangement of the patches and the amount of edge in the forest (e.g., Forman and Godron, 1986).

Consequently, trends in ecological research have emphasized concepts such as nested hierarchies and cumulative effects in ecosystems. In response it is necessary to extend the basic principles of ecology to the landscape scale. For example, stability has to be defined with respect to landscape. When ecological studies have been extended to the landscape scale, they often simply examine biological components at a larger scale. However, it is usually not possible to extend the spatial scale to the landscape and apply similar concepts. The landscape has a holistic nature and consequently the pattern of the landscape is a reflection of the interaction of processes. It is suggested that identifiable system processes are in place that are greater than just the combination of landscape elements (Risser et al., 1984).

In general, when population and community ecology are extended to the scale of the land system, it has been through recognition of the role of patches in enhancing the stability of the population or community. Bormann and Likens (1979) have shown that although a woodlot may never reach equilibrium, a landscape of sufficient scale can converge to an equilibrium mosaic with relative constancy in the fraction of the area occupied by various successional states. Similarly, the geomorphologists, Schumm and Lichty (1965) found that physical forces shaping the course of a river are disruptive at a fine-time scale, continuously moving the system away from its current state. At the larger scales, the forces act to equilibrate the overall course of the river, which remains constant for long periods of time (O'Neill, 1989). For example, the removal of biomass from a system constitutes disturbance (Pickett et al., 1989). If a small percentage of leaf biomass was removed from an ecosystem, the compartments and flows defining the ecosystem would still persist, although the sizes of various compartments and flows might be altered. Hierarchy theory, with its emphasis on scale of resolution and recognition of the role of observer perception (see Allen and Starr, 1982; O'Neill et al., 1986) might permit an equally arbitrary conversion of disturbance to non-disturbance purely by shifting the scale of observation (Pickett et al., 1989).

As stated, ecological phenomena are sensitive to the scale of investigation and therefore a better understanding of species pattern would be achieved through the integration of scales at which species pattern and processes are examined (e.g., Cody, 1975; Wiens et al., 1986). The problem of scale linkage, linking processes which operate over fundamentally different time scales, is a critical one in geomorphology, biogeography, ecology, climatology, and other geo- and biosciences (Böhning-Gaese, 1997). Single-scale studies yield information that is valid only within the scale studied, and they are limited when it comes to detailing responses to fragmentation at larger or smaller scales (e.g., Kotlier and Wiens, 1990; Orians and Wittenberger, 1991). If only one scale is used in habitat selection studies, some important patterns may be missed since organisms may respond in different ways to different levels of habitat in a hierarchically structured landscape (Wiens, 1986; Wiens et al., 1987; Jokimäki and Huhta, 1996). A multiscale approach is important because the various factors that affect individuals and species may act at different spatial scales (Sedgwick and Knopf, 1992; Steele, 1992; Jokimaki and

Huhta, 1996). It is important to determine at which scale environmental factors and biological communities interact and if these factors have scale-invariant or scale-variant effects (Böhning-Gaese, 1997).

2.2.2 Space/Time Relationships

Land system processes have also most often been considered at two time-space scales: evolutionary and process-response (Phillips, 1995). The evolutionary scale is concerned with very broad spatial and temporal scales and with problems such as the coevolution of the bio-, litho-, hydro-, and atmospheres over millennial time scales (Huggett, 1995; Phillips, 1995). At this scale, the geographic distribution and height of landmasses broadly control distributions of plants and animals through influences on environmental gradients of temperature and moisture and on corridors of migration during environmental change (Swanson et al., 1988). At the evolutionary scale, local geomorphic and ecological processes are not a factor; major events and episodes of tectonic movements and organic evolution take center stage (Phillips, 1995).

Many studies focus on local-scale diversity, the richness and evenness of taxa in a homogeneous area (e.g., Monk, 1967; DeJong, 1975). Other studies extend the scale of analysis to examine the change, or species turnover, among a suite of homogeneous samples (e.g., woodlots) in a region (e.g., del Moral and Fleming, 1979). Studies of species diversity or species turnover at the site or local scale have often ignored the spatial pattern of vegetation types in the landscape mosaic, a pattern that is critical in defining the structure of the landscape. Research at the scale of landscapes is needed to bridge the gap between the results obtained at the widely different scales of habitats and regions. It is essential to identify factors that determine species diversity at the scale of landscapes because most management decisions concerning the conservation of species richness are passed at this scale (Böhning-Gaese, 1997).

The process-response scale is concerned with spatial and temporal scales appropriate to the dynamics and mechanics of geomorphic and ecological processes, and with problems such as geomorphic responses to vegetation change, and ecological adaptations to geomorphic disturbances (Viles, 1988; Thornes, 1990; Phillips, 1995). Phillips (1995) states the intermediate time scales are far more problematic. At the time scales appropriate to studies of landscape evolution or earth surface system responses to regional- and global-scape environmental change, response and relaxation times of landforms and ecosystems may differ dramatically (Huggett, 1991; Phillips, 1995). Swanson et al. (1988) call for rigorous examination of interactions among geomorphology, ecosystems, and landscapes at the spatial scales of hectares to thousands of square kilometres to further the understanding of landscape ecology and ecosystem structure and function.

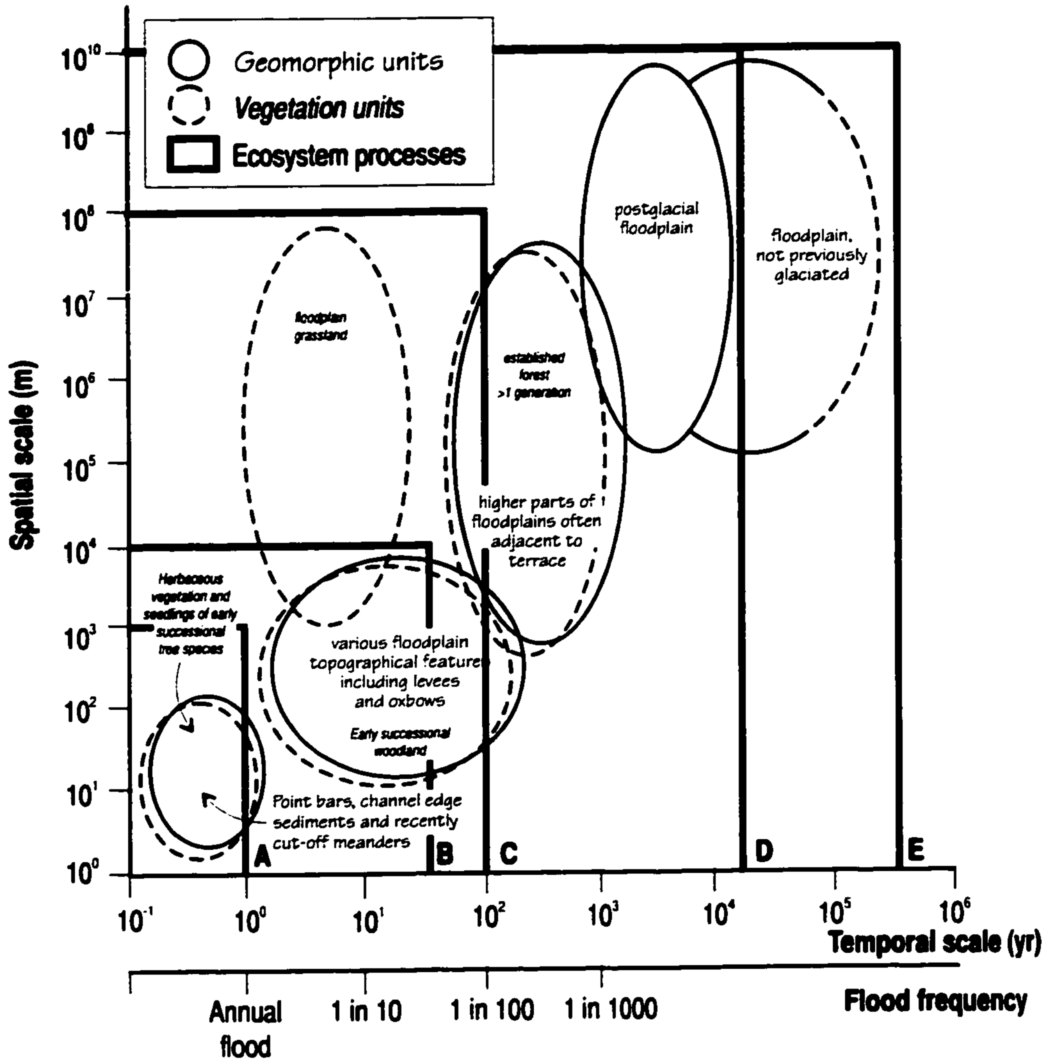
Traditionally, research on wildlife populations has been conducted at two spatial scales. In studies on within-habitat diversity, traditionally conducted by ecologists, species richness is calculated over small sites (generally 0.0025 to 0.4 km^2) (MacArthur and MacArthur, 1961; MacArthur, 1964; Karr, 1968; Recher, 1969; Karr and Roth, 1971; Roth, 1976). In contrast, biogeographers traditionally study regional species diversity over large scales (generally 400-50,000 km^2), for example, the importance of climatic variables such as potential evapotranspiration, mean annual temperature, and solar radiation in predicting species richness (e.g., Wright, 1983; Currie, 1991).

Various authors have attempted to quantify biological and physical components and processes along space and time continua (Shugart, 1984; Swanson et al., 1992; Hughes, 1997). As discussed, both biological and physical processes operate over varying spatial and temporal scales, often depending on the magnitude and frequency of the process and in general, the energy input (Moss and Rosenfeld, 1978; Swanson et al., 1992). For example, depending on the scale at which a floodplain or its biophysical component parts are considered, a spatiotemporal hierarchy of organization can be constructed to show that as the spatial scale of viewing is increased, temporal stability (or turnover time) also appears to increase (Figure 2.1) (Hughes, 1997).

2.3 Vegetation Systems

2.3.1 Species and Community Organization

Many plant species grow under a wide range of conditions while others require quite specific environments dictated by limits of energy, moisture and nutrients. Thus, the presence of a full-grown plant at a site should not be considered random but rather reflects a plant's ability to become established and subsequently tolerate site conditions (Zimmermann and Thom, 1982; Osterkamp et al., 1995). In general, the distribution of plants is related to the pattern of environmental factors along continuous gradients. Each species has a distinct optimum and range of tolerance for each factor, as evident in its productivity or some other growth attribute. As one moves away from the optimum, environmental factors become less favourable. In the marginal zones, unfavourable conditions cause physiological stress leading to depressed growth and reproduction (Burrows, 1990). Consequently, the site-level distribution of a species may be viewed as



A Primary succession of herbaceous vegetation and early successional woody species-associated with annual flood.

Primary and secondary floodplain succession-associated with medium-magnitude/frequency floods.

Long-term floodplain succession, widespread erosion and reworking of sediments--assocated with high-magnitude/low-frequency floods.

Species migration upstream/downstream, local species extinction, long-term succession on terraces, life-history strategies-associated with climate and base-level change, and the influence of postglacial relaxation phenomena on hydrological and sediment inputs to floodplain.

Figure 2.1 The organization of floodplain components and processes as a spatiotemporal hierarchy (from Hughes, 1997).

the physiographic response of individual plants to highly localized micro-environments within an area.

This pattern of location in plants can be compared to habitat selection in animals, but unlike the intimate relation with foraging, species packing and coexistence that is the foundation of studies on mobile animals (Rosenzweig, 1991), there is no equally developed habitat selection theory for plants. However, 'choice habitats' can be identified for all species based on response to biological or environmental pressures, such as the presence of required mates, pollinators, dispersers and symbiants, and the absence or limited presence of herbivores, predators and pathogens, while environmental pressures are based on the supply of required resources including food and climate (Bazzaz, 1996). Some expressions of these pressures are presented as classifications of species to environmental pressures. Important developments in establishing general theories on life history strategies include the r-K strategists proposed by MacArthur and Wilson (1967) that have been used to differentiate between early- and later-successional plants (Odum, 1969). Tilman (1982, 1986) used resource ratios to explain vegetation change, especially the relationship between nitrogen and light. He proposed that an area changes with succession from a low-nitrogen and high-light environment to a high-nitrogen and low-light environment. Grime (1977) introduced three primary strategies in plants that can be arranged in juxtaposition on a triangle with the tips representing competition, stress-tolerance and ruderal (Figure 2.2a). Expanding on this approach, Southwood-Greenslade graphed disturbance against stress, with biological competition moving through the stress-disturbance space, increasing in importance from high stress and high disturbance to low

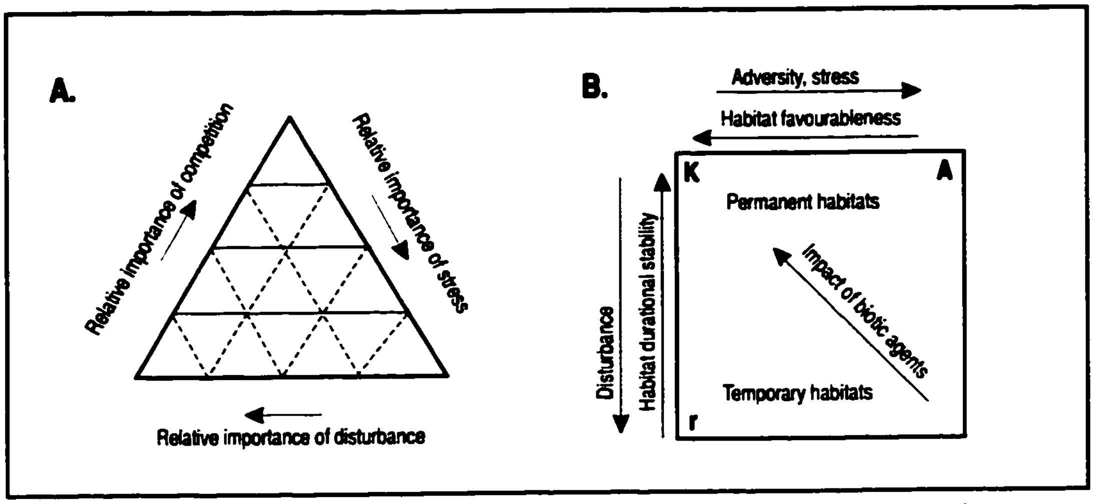


Figure 2.2 Habitat templates for plants based on relative importance of competition, stress, and disturbance A. (Grime 1977), B.(Southwood-Greenslade) from Southwood (1988).

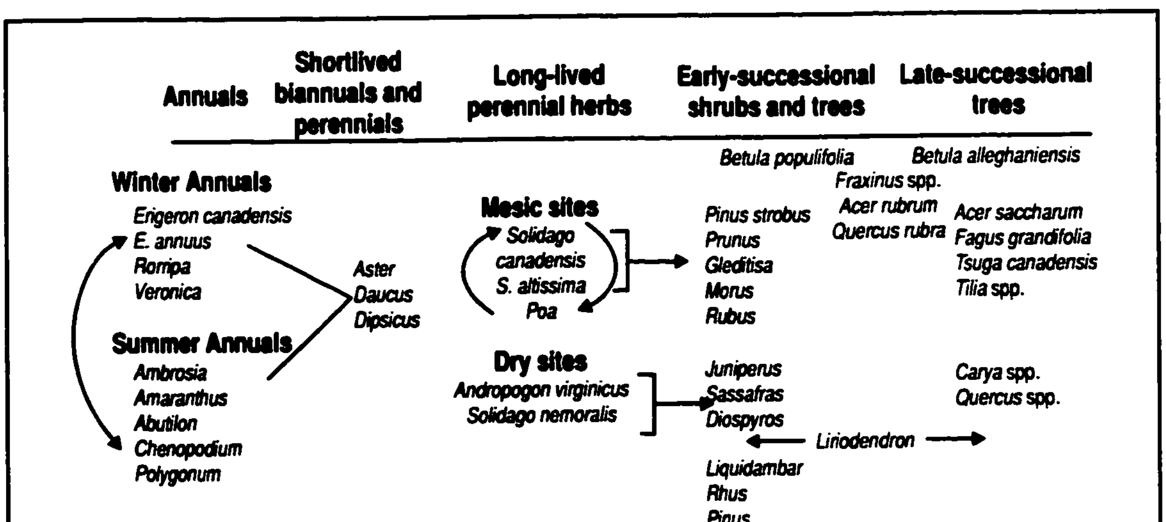


Figure 2.3 Directional pattern of vegetation change in temperate successions in eastern North America (from Bazzaz, 1996).

stress and low disturbance (Figure 2.2b). These three species types - r, K and A - are positioned at the left-hand corners and the top right in this case (Southwood, 1977).

The level at which plant distributions are examined is also important in assessing the controls of vegetation. At the landscape level, vegetation communities are distributed in response to landscape heterogeneity of the micro-environmental and biological stresses and processes that initiate disturbance. Landforms, or specifically regional topography, provide one of the best correlations of vegetation and soil patterns at the scales of land systems (Bailey, 1996; Waring and Running, 1998). Landforms control the processes of stress and disturbance by several means. Levels of stress are determined by: (i) environmental variables such as moisture and nutrients; and (ii) the flow of components such as energy and material. Similarly, disturbance processes will be controlled by: (i) the frequency and spatial pattern of external disturbances such as fire; and (ii) the spatial pattern and rate or frequency of geomorphic processes (Swanson et al., 1988).

In these strategies, stress is related to deficiencies or excesses in environmental parameters and will vary depending on the specific species. There are varying degrees to which different plant species cope with the relative stresses which the environment places on the vegetation as a whole. Examples of stresses include cold, heat, drought, waterlogging, and effects on temperature and water loss, shortage of nutrients, excess nutrients, limitation of access to light, excess light, and presence of toxic substances (Burrows, 1990).

In comparison, plants are also affected by disturbances such as fire, floods, landslides, avalanches, wind and grazing that cause physical harm by damage to or removal of tissues or materials. In plant ecology, disturbance is viewed as a mechanism for initiating succession through biomass destruction (e.g., Grime, 1979), increased space availability (Sousa, 1984), and changes in resource availability patterns (Bazzaz, 1983; Bazzaz, 1996).

Stress and disturbance which generally affect plants in negative ways may be grouped together as environmental pressures. Severe stress and disturbance affect vegetation on widely variable scales of space and time. The intensity of disturbance may also be expressed as a gradient for each disturbing factor, ranging from minimal to lethal. They may affect only one plant or the populations of one species, or patches of various sizes or vast areas. They may occur only once, occasionally, frequently or continuously (Burrows, 1990).

2.3.2 Vegetation Change

Stress and disturbance act in combination to control the resulting structure of the vegetation community and, consequently, the land unit. Depending on the landform pattern and efficacy of specific geomorphic processes, different vegetation communities will dominate a land unit. When stress factors are the dominant control, the system can be described as having a static structure while units affected by events such as fire or landslides have a dynamic structure. Static and dynamic structures are relative terms that differentiate between the rate of change of the vegetation or habitat structures (i.e., stable or long-term change versus successional response to disturbance). This does not preclude change from the static structure. The ecosystem processes operating to maintain this unit do not generate large-scale change but rather impacts that will remove individuals. Therefore, the structures differentiate between sites of low-energy, long-term change and sites dominated by high-energy processes.

Whitmore (1989) proposed that in all forests there is a cycle initiated by disturbance and that this cycle consists of gap, building and mature phases. Johnson (1985) contends it is now widely recognized that natural disturbances occur with a frequency short enough that most long-lived trees will die of some form of disturbance rather than old age. Similarly, Bazzaz (1996) states that in natural plant communities, particularly at the landscape scale, disturbance is common and therefore successional change is so prevalent that no population will exist in the same habitat for a long time. Forests are now recognized as spatial or shifting mosaics of structural phases which change over time as a result of dynamic processes (Bormann and Likens, 1979; Whitmore, 1989).

The ecology of forests and forest dynamics are dependent on changes or openings in the forest cover produced by agents of varying intensity and spatial extent. This includes biotic and physical processes such as grazing (e.g., Royama, 1984) or fire (e.g., Suffling et al., 1988). These processes are considered essential for rejuvenating many systems by increasing productivity and initiating new growth in a fresh rooting surface rich in nutrients (e.g., Frissell, 1973). The agents of forest structure and dynamics in eastern North American forests occur over a wide range of magnitudes in space and time. Burrows (1990) identifies these as: weakening and death of single trees or small patches; widespread elimination of a prominent species; weakening and death of numerous individuals, or patches, over areas of several to many hectares but maintenance of the general character of the forest (e.g., defoliating insects); and virtually complete destruction of large areas of forest caused by major disturbing factors (e.g., hurricanes, fire).

Some general patterns of species dominance and vegetation change have been identified for deciduous forests in eastern North America (e.g., Oosting, 1942; Horn, 1971; Pickett, 1980; from Bazzaz, 1996). Bazzaz (1996) notes that this has been particularly true on abandoned agricultural lands and has identified five phases as depicted in Figure 2.3. The general pattern is a directional change through a sequence of annuals, short-lived biannuals and perennials, long-lived perennial herbs, early-successional shrubs and trees, and finally late-successional trees. Usually during the final stage of this system, there is internal cycling of the late-successional forest through the processes of gap dynamics. If the gaps are large enough, it can send the system back to other levels of the flow chart.

2.3.3 Gap Dynamics

The opening of gaps in the forest canopy, when individual trees are weakened or killed by natural causes, is a normal phenomenon in mature forests. Trees of any age may die of stress brought about by environmental variation (e.g., drought) or biological competition. Old trees usually die of the accumulated weakening effects of damage by wind, ice, wood-borers, fungal rot and stress. Canopy gaps are formed by trees which die and remain standing for a time, or by falling live trees which often knock down other surrounding trees (Burrows, 1990).

Treefall gaps create a distinct microhabitat that differs from the understory of surrounding forest in vegetation structure (e.g., foliage density, tree size distributions), plant species composition, microclimatic conditions, and resource abundance (Geiger, 1950; Denslow, 1980; Brokaw, 1982; Chazdon and Fetcher, 1984; Martin and Karr, 1986; Carlton and Bazzaz, 1998). Microclimatic conditions within a gap are a function of gap size (in relation to canopy height), shape, orientation, and vegetation structure, particularly with respect to how these factors determine the daily duration of direct insolation. The amount of light and precipitation reaching the ground and daily temperatures are higher in gaps than in adjacent forest understory (Geiger, 1950; Chazdon and Fetcher, 1984). By contrast, relative humidity is lower in gaps than in forest understory (Denslow, 1980). Differences in microclimate between gaps and forest understory are particularly pronounced close to the ground and are influenced strongly by vegetation structure. Soil temperatures and temperatures close to the ground generally increase with gap size (Geiger, 1950; Denslow, 1980).

A long-standing paradigm in forest ecology has been that forest gaps maintain species diversity (Ricklefs, 1977; Runkle, 1981; Brokaw, 1985; Clark et al., 1993; Schnitzer and Carson, 2001). This theory has been recently debated from work on tropical forest gaps (Hubbell et al., 1999; Tilman, 1999; Schnitzer and Carson, 2001). Increased diversity can be achieved through several processes including colonization by shade-intolerant, pioneer species (e.g., Brokaw, 1985; Dalling et al., 1998; Schnitzer and Carson, 2001), maintaining the diversity of non-pioneer, shade-tolerant tree species through partitioning of heterogeneous resources within a gap (e.g., Ricklefs, 1977; Denslow, 1980; Kobe, 1999), and finally by increasing tree establishment and consequently density, which in turn can lead to higher tree species richness (Denslow, 1995).

Gaps produced by treefall liberate resources and provide colonization opportunities for species which cannot establish themselves in later successional stages (Whitmore, 1989). The increase in light and reduced root competition allow the establishment and growth of juveniles especially by species other than the canopy dominants (Burrows, 1990; Clark et al., 1993; Dalling et al., 1998). Denslow et al. (1998) reported there were higher nutrient pools of nitrogen and phosphorus in surface soils of treefall gaps in a tropical wet forest. Among colonists, differential establishment across the range of regeneration opportunities provided by gaps allows coexistence (Denslow, 1980) and increases species diversity (Kneeshaw and Bergeron, 1998). Cain and Shelton (1995) found tolerant species increased and intolerant ones decreased over time in oak-pine stands in Arkansas. In mature American beech (*Fagus grandifolia*) - sugar maple (*Acer saccharum*) forests in New Hampshire, gap formation led to the establishment of individuals or groups of yellow birch (*Betula alleghaniensis*), which were subsequently replaced by sugar maple (Forcier, 1975). In turn, sugar maple was replaced by beech, originating either as seedlings or as sprouts from beech stumps. The regeneration properties and relative shade tolerance of the juveniles of the tree species determine the cycle of change after gap formation. This supports the intermediate disturbance hypothesis (Connell, 1978), a type of non-equilibrium coexistence, which states that disturbances lead to a predictable successional sequence in which one tree species replaces another. At intermediate rates of disturbance, there will be a range of sites within the landscape that support a diversity of species of different successional stages (Tilman, 1999). As long as the disturbance regime is maintained, a high level of species diversity will exist in the landscape. Where large-scale disturbances are rare, stand dynamics and species diversity are controlled by the creation of gaps due to overstory-tree mortality (Runkle, 1981; Brokaw, 1985; Veblen, 1992). As Whitmore (1989) states, gaps drive the forest cycle.

In comparison, long-term monitoring of hardwood forests in the southern Appalachians of eastern North America determined that several species dominated all size classes in gaps and surrounding forests. There were differences between species growth rates in the understory and in gaps of different sizes as well as survival rates in the undertory and in the canopy, but there was no evidence of a sequential species replacement (Runkle, 1998). Similarly, Lertzman (1992) found gaps in coastal forests of British Columbia were dominated through the life-cycle of the opening by a limited set of shade-tolerant species.

In forests the local disturbance regime exerts a selective pressure on the life histories of forest trees and results in reproductive strategies which enable exploitation of specific gap types (Kimmerer and Young, 1996) and consequently, the community structure of mature forest stands is significantly influenced by the outcome of this competition for regeneration sites early in stand history (Grubb, 1977). Yet some studies have failed to provide evidence that this partitioning of resources exists for the non-pioneer trees within a gap (e.g., Whitmore and Brown, 1996; Hubbell et al., 1999). Hubbell et al. (1999) found in tropical moist forests that spatial and temporal variation in the gap disturbance regime did not explain variation in species richness. Strong recruitment limitation separates the gap disturbance regime from control of tree diversity.

It has also been argued that treefall gaps enhance diversity by increasing tree density, which in turn can lead to higher tree species richness (Denslow, 1995). However, if there is a high mortality following gap closure that is random among species, then diversity caused by gaps would be a transient effect of increased density and would disappear following thinning because density and diversity are typically positively correlated (Denslow, 1995; Schnitzer and Carson, 2001). Hubbell et al. (1999) concluded that increased diversity found in gaps was only a transient effect of increased density and they argued that gaps do not maintain tree diversity in tropical forests. In response, Tilman (1999) argues that diversity within gaps does not need to be higher at a specific point in time as long as species composition within gaps changes through time and disturbance produces a range in gap ages.

2.3.4 Slope Systems

Larger geomorphic processes that initiate change in forest cover have been described as disturbances in confined areas, a reference to the limited spatial impact of many of these processes (Burrows, 1990). These can include such situations as snow avalanches in temperate mountain areas (Burrows and Burrows, 1976), ice-push zones around lakes in northern Canada (Raup, 1975) and wind-exposed sites (Sprugel, 1976). In fluvial systems research has considered the relationships between vegetation distribution and hydroperiod, duration, frequency, depth and season of flooding in different parts of a floodplain (Nanson and Beach, 1977; Hughes, 1997).

How have these concepts of stress and disturbance been pursued in understanding the relationship between vegetation and geomorphology in landscapes that exhibit relatively abrupt changes in elevation or slope systems? As introduced earlier, landform is the dominant control of vegetation structure and dynamics at the landscape scale. The nature of slope systems increases the stress from microclimate and hydrology, as well as the likelihood of geomorphic activity, raising the level of disturbance. The work in this area has concentrated more on site characteristics and species responses to variation in soil moisture and temperature, usually expressed in relation to variations in slope angle and aspect (Parker, 1982; Iverson et al., 1997; Ford et al., 2000).

2.3.5 Micro-environment and Geomorphic Form

Specific patterns of vegetation vary with patterns in landform parameters such as slope angle, shape and aspect, as well as rock types and hydrologic conditions (Hack and Goodlett, 1960). These parameters directly limit or enhance the microclimate and availability of resources. Within a landform, slight differences exist in slope and aspect to create a local climate or topoclimate (Thornthwaite, 1954). Cantlon (1953) found that seasonal variation in temperature and moisture gradients near the soil surface explained the greatest contrast between north- and south-facing slopes. Mowbray and Oosting (1968) described how differences in slope aspect created variation in clay:sand ratios which correlated with the distributions of a number of species. This moderates or increases stress at the site. Vegetation responses can be either taxonomic, such as species that are tolerant of specific soil geochemical conditions, or structural, such as morphological changes in individual plants (e.g., stunted growth) (Shroder and Bishop, 1995).

Local sites can also be differentiated by soil-moisture regimes (Howard and Mitchell, 1985; Bailey, 1996). These sites have been referred to as site types (Hills, 1952) and are associated with zonal, azonal and intrazonal site types related to soil moisture characteristics (Bailey, 1996). Often there is a gradual pattern of soil moisture regimes along slope gradients creating a sequence referred to as a soil catena or toposequence (Major, 1951; Bailey, 1996). For example, Day and Monk (1974) found plant distributions were related to moisture gradients that developed from ridgetop to lower slopes in North Carolina.

In contrast, there has been limited investigation into the relationship of vegetation dynamics to variations in slope form. Hack and Goodlett (1960) introduced this form of study by demonstrating that species composition of the forests in southern Appalachia varied considerably with slope declivity - whether a site is subject to convergent, parallel (straight), or divergent patterns of surface runoff - and that slope form may affect soil moisture independently of aspect. Osterkamp et al. (1995) found for the same landforms that species were dependent on even smaller patterns in soil moisture across the slope due to concentrations of material, such as blocks in drainageways or slope aspect, creating both latitudinally and longitudinally patterns on the slope.

2.3.6 Geomorphic Processes

It is surprising that there has not been more investigation relating vegetation dynamics to geomorphic form and process since landforms control the intensity of key factors important to plants and to the soils that develop with them (Swanson et al., 1988; Osterkamp et al., 1995). There has been research into several aspects of inter-relationships between slope processes and vegetation dynamics, with most of the focus on the movement of material downslope by treefall and debris slides. In slope systems, forest dynamics have been described as a combination of gradual species replacement controlled by low-energy processes such as treefall (Schaetzl et al., 1990; Norman et al., 1995) and high-energy events such as localized mass movements, which initiate new vegetation associations (Flaccus, 1959; Moss and Rosenfeld, 1978). Distinct spatial patterns of forest cover are dependent on the combination of slope processes. In general, slope failure fosters a vegetation mosaic coarser in grain than that produced by individual treefall, but finer than that produced by fire (e.g., Veblen et al., 1992). Where low energy processes dominate, the arrangement of forest communities is typically perpendicular to the slope profile, running along elevational gradients. So when the landscape has simple form but great topographic relief, ecotones tend to parallel contours due to orographic effects, topographic shading and other factors. Where topography is complex, the pattern of patches and ecotones is also complex. Where the potential energy of the landscape is high and the processes have high-energy expenditure, patches and ecotones created by geomorphic disturbances are prominent features of vegetation patterns. These disturbances create long narrow patches, with most of the ecotone parallelling flow paths (Swanson et al., 1992).

Treefall and Mass Movement

In forested slopes, sediment transport by tree uprooting is a common process and can be the dominant mechanism of mass movement (Denny and Goodlett, 1956; Mills, 1984). On steep slopes, trees are more likely to fall downslope, thereby transporting sediment attached to roots or the root plate in that direction. Soil that slumps off the displaced root plate may form an adjacent mound of sediment and soil, resulting in a net downslope transport of surficial sediment. A pit, marking the former location of the roots, often is left after the bole has rotted away. These mound and pit pairs can be widespread in forested regions and have been described by many authors (e.g. Cremeans and Kalisz, 1988; Schaetzl, 1990; Moss and Milne, 1995; Norman et al., 1995).

The amount of soil displaced laterally and vertically during uprooting is a function of several variables: (i) slope angle; (ii) angle and aspect of fall with respect to slope; (iii) amount of backward rotation of the root plate during fall; and (iv) volume of the root plate. Although backward rotation of the root plate during or shortly after treefall may cause much of the soil to be effectively transported backwards into the pit, this process is less likely to occur when trees fall downslope (Schaetzl et al., 1989). Root plate volume is also a function of the following: (i) tree size, age and species (e.g. Mills, 1984); (ii) whether the tree was living or dead (Swanson et al., 1982; Cremeans and Kalisz, 1988); and (iii) the tendency for the soil to adhere to the roots, which is in large part a function of rooting pattern, soil water content at the time of uprooting and soil texture (Norman et al., 1995). On steeper slopes, treethrow becomes an important agent of mass wasting. Less material from the root plate slumps back into the pit, especially on slopes greater than 47°. Because mounds tend to be elongated in the downslope direction as slopes steepen, soil/sediment on steep slopes, displaced by treethrow, moves substantially farther downslope before it becomes quasi-stabilized (Norman et al., 1995).

Debris Slides

Disturbance of the pre-existing vegetation and alteration of the physical environment are the main impacts of slope failure on associated vegetation patterns (Parker and Bendix, 1996). Contrasts in plant species composition and physical characteristics are often apparent between landslide scars and the surrounding vegetation (Veblen and Ashton, 1978), although considerable spatial variation in plant cover and physical variables are also evident within landslide scars (Milne and Moss, 1988; Parker and Bendix, 1996). The redistribution of regolith that occurs during slope failure creates different physical environments within the resulting scar, usually located at the scar head and depositional area, which promote spatial variation in both resource availability and conditions for seedling establishment (Parker and Bendix, 1996). For example, on the scar there is lower organic matter content and available calcium, magnesium, and potassium as well as higher light levels, more extreme temperatures, greater moisture stress due to enhanced evapotranspiration, and continuing substrate instability (Flaccus, 1959; Reddy and Singh, 1993).

In the depositional zone, a rooting medium, typical of secondary succession is created that can be quite productive (Van Hulst, 1978). These have been found to be important in rejuvenating systems by increasing productivity and initiating new growth by providing a fresh rooting surface rich in nutrients. This provides colonization opportunities for species that cannot establish themselves in later successional stages. The dynamic nature of these processes creates a spatial and temporal pattern in the vegetation cover, so that the land is a patchwork pattern of stands of different ages. Successional growth in these stands includes the elimination and replacement of species, creating an overall pattern of varying ages and species composition. The variation in these processes also alters the land either permanently or temporarily, which increases the habitat complexity. The result is a land system with a variety of species and habitats of varying ages, productivity, and other community characteristics. Therefore, the dynamic nature of these processes is critical in creating a complex land system and providing sites for revitalizing the biotic component. If the frequency of the event is high within the landscape, it provides sites for early- and intermediate-successional species (Pickett, 1980; Veblen et al., 1980). Debris slides maintain a higher diversity of species which can sustain the ecological stability of the forest in spite of its geomorphic instability (Drury and Nisbet, 1971; Moss and Rosenfeld, 1978; Milne and Moss, 1988).

2.4 Bird Populations and Land Systems

2.4.1 Species and Community Organization

As with vegetation, diverse factors affect the structure of bird communities, these include weather, predation, food limitation in summer and/or winter, habitat (vegetation) structure, and interspecific interactions. Each bird species responds to its environment in a unique way, as determined by its evolutionary history and by a combination of different processes and factors that act on its populations. Each species population is potentially limited by one or more of these factors and the relative importance of these factors differ among species, such that the dynamics of each species are driven by a different combination of factors.

Two long-held hypotheses in ecology address the question of what shapes biogeographic patterns. One implicates biotic interactions, such as competition, as the main factors controlling these patterns (MacArthur, 1958); the other postulates abiotic factors, such as climate, are the primary forces shaping the biogeographic ranges of species (Andrewartha and Birch, 1954). In general, one or combinations of the following have been identified as forces that organize community structure: biological control, specifically individual and species interaction; and environmental controls including (i) food availability, (ii) structural features providing cover and nesting/feeding substrates, and (iii) weather variations (Holmes et al., 1986; Sieving and Willson, 1998).

Some factors take place on a local scale (e.g., vegetation structure, food abundance) while others operate over larger areas (e.g., some weather effects and conditions in areas where species winter). At the site level the distribution of an individual depends on those factors most important for survival; in other words, food and cover are reflected in many forms including microclimate and vegetation. These are controlled by biological and physical processes, primarily competition and resource availability. In a more general sense, bird pattern is related to habitat as described by the vegetation cover and at a larger scale by landforms at the meso-scale described in Bailey (1996).

Holmes et al. (1986) argue against the existence of a tightly organized community at any one spatial scale. Local coexistence of birds may be facilitated by differences in how populations are regulated. Such regulation could operate at any and all stages of the life cycle (Cox, 1985), or over one specific period, such as resource use patterns during the summer (MacArthur, 1958; Cody, 1974; Holmes et al., 1979) or survivorship over the winter (e.g., Fretwell, 1972). The importance of each factor varies from species to species, with each species being affected by a different combination of density-dependent processes such as competition and density-independent processes such as food resources, which may operate at different spatial and temporal scales.

2.4.2 Resource Availability

Much of the theory of community ecology rests on the premise that abundance and diversity of organisms are strongly influenced by resource abundance and quality. Many ecologists have argued that spatial and temporal differences in species density and diversity are largely determined by fluctuations in the abundance and quality of food (e.g., MacArthur, 1972; Pulliam, 1975; Brown et al., 1979), which can be considered as one of the main elements of stress (Pulliam and Dunning, 1987). MacArthur (1959) proposed that avian community structure, the number and diversity of birds in an area, reflects the availability of critical resources. Bird species breeding in temperate forests, especially neotropical migrants, were largely dependent on *Lepidoptera* larvae for food and this resource was characterized by periodic irruptions that provided abundant food. At Hubbard Brooks, *Lepidoptera* larvae vary markedly in abundance both temporally and spatially and account for some major fluctuations in bird populations. Long-term declines in many bird populations may be related to low densities of larval *Lepidoptera*, which result in poor reproductive success and low survival of birds (Holmes et al., 1986).

Much of the work on resource availability has focused on species in semi-arid environments, especially the pattern of ground-feeding species such as sparrows (Repasky and Schluter, 1994, 1996). Pulliam and Parker (1979) found a positive correlation between wintering-sparrow abundance and fall seed production where food availability and climate may represent a greater limiting stress; years of unusually low seed production limited local population density of sparrows.

2.4.3 Competition

Behavioral ecologists have considered the question of habitat selection, whereby individuals in a local population choose among the several habitats available to them. Most models of habitat selection assume that the availability of food, or other limiting resources, play a central role in habitat choice. On the other hand, community ecologists have addressed the question of species coexistence based on the assumption that whole populations of consumers are locally regulated by the availability of food or other limiting resources. Thus, both sets of theories are concerned with the relationship between resources and consumers, but behavioral ecologists emphasize the spatial scale over which individuals encounter and choose among available habitats, whereas community ecologists emphasize the spatial scale over which populations are regulated. Population regulation at the larger spatial scale determines the number of individuals that occupy a particular region, whereas events at the smaller scale determine how those individuals are distributed among available habitats within the region (Pulliam and Dunning, 1987).

Intraspecific Patterns

Fretwell and Lucas (1970) and Fretwell (1972) developed models to explain density and distribution of individuals along gradients of habitat quality. The 'ideal-free' distribution model proposes that the quality of preferred habitats declines as population density increases. Thus the less preferred habitats become equally attractive through the reproductive season, and individual fitness will be the same in preferred and less preferred habitats. The 'ideal-despotic' model proposes that there are differences in the resource holding potential of individuals, and subordinates are forced into less suitable habitats by territorial behaviour. Thus individual fitness is predicted to be higher in the preferred habitat than in a habitat of lower suitability (Huhta et al., 1998). More recently, Pulliam and Danielson (1991) proposed the term 'ideal-preemptive.' In this case, habitat selection includes a broader class of phenomena in which some individuals obtain resources by whatever means, not just despotism, which make those resources unavailable to other individuals (Holmes et al., 1996).

A critical prediction of the ideal-despotic/preemptive hypothesis, but not the ideal-free modal, is that individuals' fitness will differ among habitats (Fretwell, 1972; Sutherland and Parker, 1985; Pulliam and Danielson, 1991). These models predict the proportion of the population that will occupy each available habitat based on the assumption that all individuals choose habitats according to the expected fitness consequences of their choices. The consequences to any one individual depend on the habitat distribution of all other individuals and equilibrium distribution of individuals among habitats is reached when no individual can increase its own expected survival probability or reproductive success by changing habitats (Pulliam and Dunning, 1987). Differential fitness among habitats, in turn, is important to population dynamics and regulation on a landscape scale because it affects how different habitats might contribute to overall productivity, survival and subsequent recruitment of individuals into the available mix of habitats (Lomnicki, 1980; Bernstein et al., 1991; Sherry and Holmes, 1995). When reproductive output or survival differs among habitats, certain habitats may act as net sources where reproduction exceeds local mortality, while other habitats act as sinks where populations are maintained by net immigration (Pulliam, 1988). For bird populations, fitness differences among habitats that conform to the ideal-despotic/preemptive model have been reported for a variety of species, mostly raptors (e.g., Newton, 1986) and passerines (Holmes et al., 1996). Breeding populations of long-distance migratory species also experience fitness-related differences among habitats, e.g., in pairing success (Carey and Nolan, 1975; Probst and Hayes, 1987; Gibbs and Faaborg, 1990), fledging rates (Tye, 1992; Porneluzi et al., 1993) and site fidelity (Lanyon and Thompson, 1986; Payne and Payne, 1993; Holmes et al., 1996).

Interspecific Patterns

Direct interactions between species also account for changes in distribution and abundance of birds. Temperate birds are frequently habitat specialists and adjacent habitats are often occupied by closely related species. The morphological differences between species have only minor consequences on fitness in different habitats and species would be more widely distributed among habitats in the absence of congeners (Lack, 1944). For example, interspecific aggression by Least Flycatcher (*Empidonax minimus*) influenced the local distribution and density of American Redstart (*Setophaga ruticilla*) and similarly, specific habitat requirements combined with aggressive attacks by Red-eyed Vireo (*Vireo olivaceus*) influenced habitat use by Philadelphia Vireo (*Vireo philadelphicus*) (Holmes et al., 1986). Competition in ecological time must therefore be considered as one of the processes influencing the abundances of some bird species in temperate forest, at least on a local scale (James and Boecklen, 1984; Holmes et al., 1986).

In contrast, the foraging success hypothesis suggests that habitat distributions result from species differences in foraging success in different habitats (Schluter, 1982; Price, 1991; Repasky and Schluter, 1994). Habitat specialization might result from food alone if species are adapted to feeding conditions in alternate habitats (e.g., Smiley, 1978; Schluter, 1982). The trade-off in feeding ability between habitats must be large enough to restrict species' distributions. Each species should achieve its highest food intake rate in the habitat in which it normally occurs and the trade-off in foraging ability between habitats should be significant (Repasky and Schluter, 1996).

Repasky and Schluter (1996) argued that species' differences in feeding ability between habitats are generally small and unlikely to be responsible for species' distributions. The main factor restricting species' patterns is competition from ecologically similar species. With exploitative competition, competitors shape the foraging success of each other as they deplete food supplies. Habitat partitioning results if species deplete food supplies in such a way that each habitat becomes suitable for only one species (Pimm and Rosenzweig, 1981). Species could also be competing through interference, and the presence of one species in a habitat could be sufficient to exclude others from that habitat (e.g., Pimm and Rosenzweig, 1981; Rosenzweig and Abramsky, 1986). Some ecologists have challenged this view by suggesting that the relationship between community structure and resources is weak except during infrequent periods when resources are particularly scarce (Rotenberry and Wiens, 1980a; Wiens and Rotenberry, 1981). Wiens (1977) proposed ecological crunches occur periodically in the shrubsteppe environment and these have major impacts on bird populations.

The opposite pattern appears to exist for birds in the temperate deciduous forest. Food resources are chronically low for several to many successive years and may become superabundant only during relatively brief caterpillar irruptions. These irruptions seem to occur at variable and often long time intervals, but when they do occur nearly all species, including bark and ground foragers, actively glean caterpillars from foliage. At these times, bird diets would probably overlap greatly. Such abundant food probably leads to high reproductive success for many species, yet only some species show strong numerical responses (Holmes et al., 1986). In periods between outbreaks, food may frequently and regularly limit reproductive output of bird populations in temperate forest. The effects of predators, weather, and other mortality factors also contribute to a high variability in reproductive success. During such periods, competition (both interference and exploitative) plays a potentially important role. Birds respond differentially to tree species, vegetation structure and microhabitats which suggests resource partitioning (Holmes et al., 1986).

2.4.4 Habitat Partitioning

From the preceding discussion, it is apparent that there are several controlling factors of species distributions and it has been difficult to establish firm relationships between these processes at the site level scale. However, there is strong evidence to establish general relationships between wildlife and ecosystem components such as land units, or more generally, habitat. It is recognized that species and often groups of species are partitioned into niches that reflect the spatial pattern of environmental factors. At the scale of the land unit this includes the expression of habitat as a combination of vegetation and landform.

Habitat can be defined as the physical and biological environment, or more specifically the plant community in which an animal lives (Rabenold and Bromer, 1989; Morrison et al., 1992; Block and Brennan, 1993). As discussed above, different habitats require different physiological, morphological and behavioural specializations, and natural selection has produced general matches of plant and animal characters. Even subtle differences in adaptations for exploitation of a habitat could confer a critical advantage in efficiency. Similar species of animals needing the same limiting resources will segregate, because of competitive effects, into different habitats or different parts of a habitat (Block and Brennan, 1993). Consequently, avian community organization has been closely associated with habitat structure and in most cases, this has been investigated by examining the structure of the vegetation community.

For terrestrial birds, vegetation cover has an important effect on the distributions of species, especially at the local level (MacArthur and MacArthur, 1961; Karr, 1968; Holmes et al., 1979; Block and Brennan, 1993; Lloyd and Palmer, 1998). There has been a widely-held view that vegetation structure and habitat configuration ('physiognomy'; Whittaker, 1975) are more important to the determination of habitat occupancy patterns of birds than the particular plant taxonomic composition ('floristics') of the vegetation

(Rotenberry, 1985). A variety of studies have shown strong associations between physiognomy and patterns of species distributions and community structure (e.g., MacArthur and MacArthur, 1961; Holmes et al., 1979; Beedy, 1981; Verner and Larson, 1989). The results of these studies have led to the prediction that structurally similar habitats should support avifaunas with similar species richness, density, diversity and guild structure. However, other studies have not found strong correlations between vegetation structure and patterns of avian diversity (Tomoff, 1974; Willson, 1974; Roth, 1976). These studies recommend a deeper analysis of vegetation parameters such as species distribution or floristics that modify the composition of avian communities (Beedy 1981; Mills et al, 1991).

Physiognomy

Strong correlations have been recorded between Bird Species Diversity (BSD) and Foliage Height Diversity (FHD), and several authors have suggested that FHD is a good predictor of BSD (MacArthur and MacArthur, 1961; MacArthur et al., 1966; Karr, 1968). Holmes et al. (1979) suggested that FHD is an index to the presence and development of foraging areas from the ground to the top of the canopy. An area with a high FHD value, indicating the presence of foliage in a variety of vertical zones, would have a high BSD because it provides increased foraging opportunities for birds. One effect of the additional vegetation strata may be to provide an enlarged habitat space in which additional species can be accommodated through vertical segregation (MacArthur et al., 1962; Wiens, 1974a). It could also provide new substrates which support more food sources for birds (e.g., more foliage arthropods), and therefore more birds. Holmes et al. (1979) found that the understory provided a distinct foraging environment and that certain bird species were highly dependent on it. In closed-canopy forests, guilds contracted but were not eliminated when understory vegetation was lacking. The foliage profiles were nearly identical in the open-canopy forests, suggesting that these areas offered a similar vertical array of foraging substrates for birds.

Similarly, Beedy (1981) found FHD and BSD were both higher in open-canopy forests than in closed-canopy forests in the mixed conifer and red fir (*Abies magnifica*) zones of the central Sierra Nevada. With the exception of hummingbird species, all guilds were present in each transect. However, reductions in understory vegetation and forest clearings in closed-canopy forests caused pronounced decreases in three understory guilds as well as in the flycatchers. The open-canopy forest, with greater structural complexity, offered a greater variety of foraging opportunities for birds. These forests were a combination of foliage and bark, as well as understory vegetation and open air space. The greater availability of food permitted greater avian diversity, with more species of intermediate importance because there were simply more ways to subdivide the environment (Beedy, 1981).

Spatial partitioning can also be related to the dominant life-form of the vegetation community. For example, Huhta et al. (1998) found that Pied Flycatcher *(Ficedula hypoleuca)* favoured deciduous tree habitats which were more numerous in small- and medium-sized forest patches than in large ones. At the microhabitat level, the reproductive success of Pied Flycatchers was greater in deciduous tree territories than in pine-dominated territories because deciduous tree territories contained more food than the pine-dominated territories. Von Haartman (1971) found that deciduous forests supported more insects than conifer forests, and many workers have observed that deciduous or deciduous-conifer forests have greater bird species richness than do conifer forests alone (e.g., Winternitz, 1976; Beedy, 1981). Beedy (1981) found that patches or islands of black oak (*Quercus velutina*) within the mixed conifer forests added significantly to the vegetational variability on a horizontal plane, creating an edge effect and increasing foraging opportunities for birds.

Vegetation Volume

Some studies have found foliage volume accounts for a significant portion of the variation in bird density or species richness (e.g., Meents et al., 1983; Robinson and Holmes, 1984; Verner and Larson, 1989). Mills et al. (1991) proposed that breeding birds respond to critical resources as estimated by vegetation volume. Strong correlations between vegetation volume and breeding density suggest that bird density is proportional to available resources. Vegetation volume is an accurate estimator of plant biomass and, therefore, volume could be used to assess resources associated with biomass. If plants provide resources in proportion to their vegetation volume (by providing more insect prey, more nest sites, or more favorable daytime roosts, for instance), then bird density should be proportional to vegetation volume (Mills et al., 1991).

If the relationship between vegetation volume and bird density is resource-based, then fluctuations in resources should yield fluctuations in bird populations (Dunning and Brown, 1982) and regions subject to disturbance should have more variable bird populations than areas with more stable resource levels. Many North American habitats have relatively stable bird populations (Dunning, 1986), and Mills et al. (1991) suggested that resources will be relatively stable in these habitats. Other areas experience wide density fluctuations attributable to disturbance of vegetation (e.g., flooding, Dunning,

1986) and presumably resource levels. Vegetation volume may be a useful tool in predicting changes in bird populations resulting from such disturbance-caused changes in resources.

Floristics

Other studies have cast doubt upon the validity of the general relationship between vegetation structure and bird density (Tomoff, 1974; Willson, 1974, Roth, 1977; Franzreb and Ohmart, 1978). Willson (1974) found that different types of forests with similar foliage profiles did not support similar avian communities. Furthermore, she found that increases in the vertical layering or total volume of foliage did not alter species presence or the total avian biomass of guilds in any predictable manner. However, there were observed relationships with floristics, such as the densities of individual plant species. It has been concluded in several studies that floristics are more important determinants of bird community parameters than physiognomic (structural) measures (e.g., Kroodsma, 1982; Rice et al., 1983; 1984; Rotenberry, 1985). Specifically, individual bird species can be associated with individual plant species (e.g., Meents et al., 1982) and food sources such as fruit-bearing plants (Karr, 1971; Robinson and Holmes, 1984).

The differences between floristics and physiognomy can be attributed to differences in the relative geographic scale over which they were measured; the same species that appear to respond to the physical configuration of the environment at the continental level show little correlation with physiognomy at the regional level. Such observations led to the proposal that while birds may be differentiating between gross habitat types on the basis of physiognomy (i.e., occupying a general habitat type that is 'proper' in its structural configuration), further refinements of their distributions within the proper habitat type may occur with reference to plant taxonomic composition. Such a proposition reconciles the observations of large-scale or between-habitat type surveys that associate bird community composition and physiognomic factors (e.g., Willson, 1974; Cody, 1975; Rotenberry and Wiens, 1980a) with those of regional or within-habitat type surveys where the composition of bird communities appears more closely associated with floristics (e.g., Tomoff, 1974; Power, 1975; Wiens and Rotenberry, 1981). Mills et al. (1991) concluded that floristics and physiognomy are both important in determining avian community structure.

2.4.5 Vegetation Change and Avian Response

The emphasis of research on forest change in eastern North America has at the landscape scale been investigating the role of forest fragmentation on avian populations. There is a large body of work on this subject and a full investigation of this work is beyond the scope of this paper. In general, fragmentation of natural forest habitat can lead to a number of changes in wildlife populations including an increase in edge species (Yahner, 1988) and extinction rates (Terborgh, 1974; Wilcove et al., 1986), and increased predation and parasites. However, several areas of research related to heterogeneity of the internal forest pattern, created primarily by combinations of natural processes, are of particular relevance to the spatial heterogeneity of land units on the Niagara Escarpment. These include internal edge effects, gap dynamics and forest heterogeneity.

Edge Effect

In many landscapes, the pattern of habitat created by the structure and processes of the underlying topography and geology creates naturally occurring breaks in the vegetation cover. The physical boundary between two land units at these breaks is referred to as the 'edge'. The study of edge habitat constitutes a major field of research with a set of recognizable processes and structures known as the edge effect. In general, this has focused on anthropogenic or induced edges created by forest removal and disruption. Human modification creates sharp boundaries that may influence the movement and distribution of organisms (Restrepo and Gómez, 1998). Induced edges are often recent, abrupt, and exposed to the surrounding environment (Lopez de Casenave et al., 1998). In comparison there has been less examination of inherent or natural edges. Inherent edges are usually a long-term feature of the landscape. On the Escarpment, at least two types of natural edges occur: those created or maintained by stress, such as cliff faces, and those by disturbance, such as scar edges. There has been little research on the effect of natural forest edges on birds (e.g., Helle and Helle, 1982; Noss, 1991). Lopez de Casenave et al. (1998) noted older, natural edges in Argentina had different abiotic and structural conditions. They found that for natural edges, forest birds had different assemblages between forest interior and edge, with some species exclusive to each habitat such as bark insectivores in the forest interior. The pattern of abundance within guilds also differed between habitats. Bark insectivores and short-flight insect-hunters were more abundant in the interior, whereas long-flight insect-hunters, frugivores, terrestrial insectivores, and granivores were more abundant in the edge.

The investigation of edge effect constitutes some of the earliest attempts by ecologists to understand ecological processes at the landscape scale (e.g., Leopold, 1933; Lay, 1938; Sisk et al., 1997). Edge effect has been described as the maximum distance at which changes induced by edge creation are apparent within forest stands and the disturbed area (Harris, 1984; Lovejoy et al., 1986). Many edge areas report an increase in bird diversity (see Noss, 1991; Mills, 1995), and certain species reach their highest abundances at particular habitat edges (e.g., Whitcomb et al., 1981; Lynch and Whigham, 1984). Kilgo et al. (1997) found total species richness and abundance were greater in remnant woodlots with a defined field and forest edge. Species, more common near the edge, are often termed 'edge species'. Species that utilize both patch and matrix habitats are likely to be more abundant near edges, and therefore relatively common in small patches or land units with high edge-to-area ratios (Sisk et al., 1997).

In contrast, some species reach their lowest abundances at the edge. Those with densities lower near the edge are considered to be habitat-interior species (e.g., Brittingham and Temple, 1983; Wilcove et al., 1986). Small forest stands, isolated by open land, may be comprised entirely of edge habitat and edge-avoiding species may find little or no suitable habitat in patches where the influence of the edge reaches the centre of the patch (Sisk et al., 1997).

Edges may influence the behaviour of animals directly, through changes in microclimate and the distribution of suitable habitats (Gates and Gysel, 1978; Kroodsma, 1984a; Mills et al., 1991; Burke and Nol, 1998) and indirectly, through increasing the impact of parasites (Gates and Gysel, 1978; Wilcove, 1985; Freemark et al., 1995) and predators (Yahner and Scott, 1988; Paton, 1994; Haskell, 1995; Hannon and Cotterill, 1998), and limiting the resource base (Van Horn, 1990; Burke and Nol, 1998) and altering the configuration of territories (King et al., 1997a). When these factors are highly variable in space and time, it is unlikely that 'edge effects' will remain constant. Rather, effects will change over time and as a result edges become dynamic elements of the landscapes (Restrepo and Gómez, 1998). They will eventually close in as the vegetation fills disturbance openings (Ranney et al., 1981; Casenave et al., 1998). King et al. (1997b) argue that it is unlikely that birds in the northeast United States, in regions where disturbance has been historically uncommon, have had the opportunity to evolve edge avoidance behavior.

Gap Dynamics

As discussed earlier, forest gaps created by treefall are considered the dominant force initiating change within eastern forests and are considered as part of the static landscape. Small gaps increase local bird species diversity by providing a vegetation structure not found in undisturbed forest while still allowing forest specialists to maintain high numbers (Lent and Capen, 1995). Gaps created by treefall contribute to the creation of a habitat mosaic in many forests (e.g., Williamson, 1975; Whitmore, 1978; Runkle, 1981, 1982; Brokaw, 1985). Treefall gaps influence abundance and distribution of bird species by maintaining habitat heterogeneity and by affecting abundance and distribution patterns of food resources such as fruit and insects (Blake and Hoppes, 1986).

Studies have demonstrated differences in assemblages of birds captured in forest gaps and understory (Willson et al., 1982; Martin and Karr, 1986; Feinsinger et al., 1988). Results of these studies suggest birds might be attracted to gaps because of higher resource levels, specifically greater primary productivity associated with increased light levels (Hallë et al., 1978). In treefall gaps, species are able to recognize the potential of an improved foraging site or an area of increased food (Smith and Dallman, 1996). This could be the result of increased light penetration which produces warmer microclimates. The warmer microhabitat could benefit the thermoregulatory physiology of insects, increasing insect activity and abundance. The increased warmth also benefits a bird's energy budget especially during periods of colder temperatures during early season and cold mornings. Overall this allows an individual to maximize energy for the breeding effort and less for individual maintenance (Smith and Dallman, 1996). Forest gaps may also aid males in establishing and maintaining territorial boundaries. The edge of a recent gap can benefit males through increased visibility and song projection. Gap edges have also been found to represent territorial boundaries (Smith and Dallman, 1996).

Internal Heterogeneity

The dynamics of stress and disturbance in the landscape creates a heterogeneous forest. Often in continuous habitats, such as a forest, internal heterogeneity can occur due to frequent small-scale disturbances resulting in mosaics of recently disturbed patches and patches undisturbed for some time (Whittaker and Levin, 1977; White, 1979; Sousa, 1984; Pickett and White, 1985; Freemark and Merriam, 1986). Few studies have considered less obvious landscape heterogeneity such as found in a complex forest stand with a combination of several forest types includes old growth, early successional and plantation. Described as the 'forest buffer hypothesis', the functional size of a forest stand could be increased for area-sensitive species if the patch is surrounded by another forest type, regardless of the suitability of that type as habitat (Harris, 1984; Freemark and Collins, 1992). An example is an upland deciduous forest with adjacent coniferous plantations, as found in many areas of the central Escarpment, compared to forests with adjacent agricultural fields or developed land. If the edge is not as abrupt, some negative edge effects such as predation or light and wind penetration may be reduced, potentially allowing area-sensitive species to exist in relatively small stands (Kilgo et al., 1997).

There has been little research on this hypothesis at the stand level. Freemark and Collins (1992) reported that more area-sensitive species in forest fragments were found in an area of greater overall forest cover than in an area with less forest cover. Kilgo et al. (1997) compared bird communities in hardwood forests surrounded by agricultural habitat to those in hardwood forests surrounded by pine-forested habitat in South Carolina. They found that in hardwood forests surrounded by a pine buffer some species occurred in greater abundance including Red-eyed Vireo and Summer Tanager (*Piranga rubra*), both interior-edge neotropical migrants.

Sisk et al. (1997) found that surrounding landscape affected the edge species within oak woodland in California. Factors intrinsic to the patches were not driving the observed patterns of bird abundance, and matrix habitats influenced within-patch habitat quality, such as the vegetation structure of the surrounding landscape - in this case, chaparral or grassland. Patches surrounded by the same matrix habitat supported bird assemblages that were much more similar than patches surrounded by different habitats, both in species composition and in relative abundance.

For a particular species, extensive habitat may actually contain several habitat patches with functionally separate, local populations (e.g., Tomialijc et al., 1984; Wilcove, 1988). For example, the Ovenbird (*Seiurus aurocapillus*) within mature forest fragments surrounded by plantations or regenerating stands tends to exhibit low isolation and high connectivity and is not subjected to the same adverse effects to food supply (Sabine et al., 1996). It is less likely that edge effects, dessication of leaf litter, or sharp gradients in microclimate and microhabitat would occur in forest-dominated landscapes to the degree that is typical of woodlot fragments surrounded by agriculture. The higher connectivity of this landscape would benefit organisms with reduced dispersal capabilities, in particular litter-inhabiting arthropods, compared with highly fragmented landscapes where organisms need to disperse hundreds or thousands of metres to the next nearest patch. These results suggest that the negative effects of fragmentation might occur at a much larger fragment size in landscapes dominated by agriculture than in those dominated by forests (Sabine et al., 1996).

Landscape Heterogeneity and Metapopulations

At the landscape scale most of the attention has been placed on the response of forest bird diversity and abundance to habitat fragmentation. In this case, disturbance is the elimination of extensive forest cover leaving only a pattern of remnant forest habitats in agricultural (Freemark and Merriam, 1986) and urban landscapes (Friesen et al., 1995). Disturbance is external to the habitat and is often measured by changes to the shape, area and composition of the patch (e.g., McIntyre, 1995). In general, populations decline because areas of suitable habitat decrease; positive relationships have been found between patch size and species presence (Saunders, 1990) and abundance (Askins et al., 1990). Smaller patches have a greater edge to area ratio and consequently species from the external habitats may prey upon, parasitize or compete with the patch species (Paton, 1994; Schieck et al., 1995).

Flather and Sauer (1996) demonstrated the relationship between neotropical migrants and landscape structure. Species abundance was higher in landscapes with a greater cover of natural habitats compared to landscapes with high proportions of human-dominated land uses (i.e., agriculture and urban land). The relative abundance of neotropical migrants was lower in landscapes where diversity and edge were higher and where forest edges were more complex, average forest patch size was small and the distance among forested land was high. In an urbanizing landscape, diversity and abundance of neotropical migrants in small forested patches consistently decreased as the level of adjacent development increased, regardless of forest size. 4-ha woodlots without any nearby housing had on average a richer, more abundant neotropical community than did 25-ha urban woodlots (Friesen et al., 1995).

A number of models and theories have described the response and pattern of wildlife species to landscape fragmentation. Levins (1970) described these as 'metapopulations' for a 'population of populations'. Other names for these populations and models include 'core-satellite' or 'island-mainland' models (Boorman and Levitt, 1973), 'multipartite populations' (Den Boer, 1977) and 'winking patches' model (Wilson, 1980). Pulliam (1988) developed the 'source-sink' model of interaction among local populations, in which some patch populations act as sources of colonists for other patches that depend on these sources for persistence. The overall maintenance of regional populations often requires supplying individuals to patches where local extinctions have occurred (e.g., Merriam and Wegner, 1992; Villard et al., 1992). For example, Rivera-Milán (1997) noted the importance of xerophytic forest in Puerto Rico as a potential population source for Zenaida Doves (*Zenaida aurita*), whereas smaller and more fragmented forests may be population sinks in which annual reproduction is not enough to offset natural or human-induced mortality. Neotropical migrants, because of their huge global populations and high rates of natal and adult dispersal, keep recolonizing forest fragments in which their nesting success is extremely low. As a result, populations in fragmented forests can appear relatively stable even if their nesting success is far below levels necessary to compensate for adult mortality. These patches become population 'sinks' for these migrants (Brawn and Robinson, 1996; Robinson, 1998).

2.4.6 Slope Systems

Few studies have investigated the response of wildlife to disturbance from geomorphic form and processes, especially in slope systems. To gain an understanding of how wildlife will react to these systems it is necessary to consider avian response in other dynamic systems. In general, two broad disturbance scales can be recognized that affect species structure. These include small-scale, internal disturbances such as treefall gaps and self-contained disturbances such as landslides, or larger, external events such as hurricanes, fire or logging which can encompass many hectares (Burrows, 1990).

Micro-environment and Geomorphic Form

Despite the volumes of research on birds and habitat there has been little investigation relating wildlife pattern to landform pattern. There have been few attempts to develop a direct link between landforms and bird populations or community structure. For example, there is a strong association between birds and vegetation or resources as a function of the underlying geology, geomorphology and climate as manifested in the landform at intermediate- or meso-scales. Many studies have related birds to specific habitats and indirectly this can be related to specific landforms. Research in this area has focused on the relationship between birds and elevational gradients in mountainous environments. In the northeastern mountains of the United States, Able and Noon (1976) found that species differed between three major ecotones or vegetation zones and that habitat was the primary determinant of distributional patterns. Similarly, Mueller-Dombois et al. (1981) describe distinct boundaries between bird communities and elevational position for slopes on Mauna Loa, Hawaii. In this study, the pattern of bird populations was related to the distribution of major vegetation types. Vegetation structure exerted such a strong control on bird species' distribution that the distributional effect of competition was negligible (Huggett, 1995). In comparison, along a similar altitudinal gradient in the Peruvian Andes, Terborgh and Weske (1975) concluded that competition was a critical factor in the elevational pattern of bird communities in tropical mountains.

As mentioned, spatial distribution is most often associated with resource availability, but this can be overridden by topographical structures, by limiting or enhancing access to resources (Powell and Mitchell, 1998). For example, Reid and Weatherhead (1988) found that territories of Ipswich Sparrows (*Passerculus sandwichensis*) did not conform optimally to available resources but were influenced by local topography and unfavorable habitat. Territory boundaries set by topography limited the number of nest sites and the amount of food in a territory as well as affected mating patterns.

Geomorphic Processes

There are examples of vagile animals differentiating between undisturbed forest and patches resulting from anthropogenic disturbances (e.g., Johnston and Odum, 1956; Karr, 1968; May, 1982). When the disturbance is by logging, species dominance is dependent on frequency and extent of disturbance and the size, arrangement and boundary distinctness of habitat patches (Lent and Capen, 1995). White et al. (1996) found decreased diversity and abundance when mature pine forests were replaced with younger pine plantations. In comparison, Schieck et al. (1995) found that for old-growth species in montane forests of the northwest coast, richness and abundance were not related to human-generated patches. These forests typically experienced frequent disturbances by fires, wind, and disease, and wildlife species have evolved in contact with species from many forest types. For example, these differences have also been reported for natural disturbances, suggesting that although the grain of the disturbance mosaic is less coarse for relatively large, vagile consumers such as birds than for small consumers such as insects or intertidal animals, the mosaic could still be reflected in population and community patterns (Wiens, 1976; 1986; Karr and Freemark, 1985; Feinsinger et al., 1988). Birds respond directly to heterogeneity in physical conditions or they respond to disturbance-induced heterogeneity in the distribution of their food resources (e.g., Schemske and Brokaw, 1981; Willson et al., 1982; Karr and Freemark, 1985; Wiens, 1985b; Blake and Hoppes, 1986).

Major disturbances by strong wind events such as hurricanes and tornadoes can affect bird populations directly and indirectly. In the short term they can cause mortality of individuals associated with the high winds and rainfall. Indirectly, there is loss of food supplies or foraging substrates, loss of nests and nest or roost sites, increased vulnerability to predation, and microclimate changes (Wunderle, 1995). Birds respond by shifting their diet, foraging sites or habitats, and reproductive patterns. Jones et al. (2001) reported that Cerulean Warbler displayed a degree of plasticity in their habitat affinities following a significant disruption of forest canopy caused by a major ice storm in southeastern Ontario. Community changes can include increased numbers of canopy dwellers in the understory and the movement of fruit-eating birds into pre-existing gaps. It can also include the invasion by forest edge or shrubby second-growth species into the forest (Wunderle, 1995).

Increased stress can also lead to change by altering the vegetation structure or inducing higher levels of disturbance. Severe drought and windstorms in mature forests in Minnesota changed the internal structure of the forest from closed-canopy dominated by American elm *(Ulmus americana)*, black ash (*Fraxinus nigra*) and white birch (*Betula papyrifera*) to an open forest dominated by black ash and basswood (*Tilia americana*). The habitat now consisted of forest-edge habitat which was quite different from the continuous, mature forests of deciduous and pine trees that dominated the rest of the study area (Canterbury and Blockstein, 1997). Response by the bird species saw a drastic decline in Ovenbird, Veery (*Catharus fuscescens*) and Blackburnian Warbler (*Dendroica fusca*). Conversely, Mourning Warbler (*Oporornis philadelphia*), Song Sparrow (*Melospiza melodia*) and White-throated Sparrow (*Zonotrichia albicollis*) experienced major increases.

In general, when large areas of forest are disturbed and habitats become extensively fragmented, forest specialists tend to disappear and fugitive bird species become ecologically dominant. Fugitive or early successional species, such as Mourning Warbler and Song Sparrow, are those that prefer or require disturbed or early-successional habitats, which can be canopy openings embedded in a matrix of forest. This creates an ephemeral, constantly shifting patch structure and forest interior (Lent and Capen, 1995). Lent and Capen (1995) found larger gaps (0.7-1.6 ha) could attract a distinct group of breeding birds not found in the surrounding undisturbed forest. The disturbance alters the physical and biological conditions that may favour invasion by species other than those there previously, leading to differences in species composition between disturbed and undisturbed sites (e.g., Wiens, 1976; White and Pickett, 1985). Dominant species in long-lived 'mature phase' patches or undisturbed patches are expected to have life history traits and patterns of resource use different from those of populations dominating recently disturbed 'gap phase' patches (Feinsinger et al., 1988).

There have been few studies that have related bird communities to slope processes such as debris slides or blockfalls. Feinsinger et al. (1988) describe two levels of disturbance in tropical forests. These forests are mosaics of mature-phase patches, relatively small gap-phase patches created by falling trees and branches, and larger gap-phase patches created by disturbances such as landslides. Although a continuum of patch sizes exists, operationally the forest can be treated as a continuous canopy broken by disturbed patches of two size classes, moderate and large, with physical conditions in large gaps differing substantially from those of canopied forest and conditions in moderate sizes of gaps. All sizes of gaps eventually merge back into the surrounding forest as the canopy is reestablished.

Nectar-feeding birds (mainly hummingbirds) inhabiting the natural disturbance mosaic of the Costa Rican cloud forest responded to habitat heterogeneity in complex ways. Density of food (nectar) was highest in treefall gaps, and some characteristics such as species diversity reflected this enrichment. Characteristics that involved the collective foraging by the entire hummingbird assemblage (e.g., intensity of interspecific competition) suggest that species interactions in the forest are the least haphazard, those in treefall gaps more haphazard, and those in large gaps the most haphazard (Feinsinger et al., 1988).

Responses of consumers to disturbance mosaics may often be subtle and complex (Feinsinger et al., 1988). Disturbance in the cloud forests did not favour phenotypes more generalized than those existing in mature patches. This was true for consumers and producers. Plants with long flowers specialized for pollination by hummingbirds with long, curved bills were more frequent in large disturbances than in the forest. In contrast, anthropogenic second-growth communities ('tropical old fields') are characterized by phenotypes adapted for opportunistic use of resources. The largest natural disturbance gaps were rarely invaded by 'weed' species, available in the regional gene pool, and interactions in these gaps showed only faint resemblance to those in the fluctuating competitive environments that characterize nectar-feeding bird assemblages in large anthropogenic old fields. Disturbances did not disrupt the interactions between forest hummingbirds and their nectar resources severely enough for hummingbird 'weeds' to invade, even though they were abundant only a short flight away (Feinsinger et al., 1988).

2.5 Summary

Vegetation and avian systems were presented within a framework that examined the main controls of distribution and community organizational strategies. More specifically, the state of research on these components of slope systems was reviewed, with the focus on the role of geomorphic form and process on the vegetation and avian components. It has been emphasized that geomorphic form and process have been more successfully integrated with vegetation systems than with avian systems and has been most evident in the field of disturbance ecology.

The concepts of landscape and land unit were introduced, emphasizing the need to provide a more integrative approach to biophysical research. This can be achieved by adopting a process approach to system research and incorporating the ecological concepts of combining disturbance and stress with system equilibrium. Stress and disturbance can dictate the form or ecological structure of the land systems. Sources of change identified within the forest ecosystem have focused on gap dynamics from local disturbance that tend to increase the complexity of vegetation and wildlife interactions.

Consequently, landscapes that have a high degree of variability in the levels of stress and disturbance within various land units likely have a higher heterogeneity of species and habitat diversity. This heterogeneity will create a complex system with various combinations of biophysical components in various states of equilibrium. In the following chapter, the Niagara Escarpment is introduced, a landscape that exhibits a variety of land-shaping processes. A similar review of current research on the integration of geomorphic form and process and the vegetation and avian components will be presented to establish the gaps in this knowledge.

Chapter Three
The Niagara Escarpment and Research Sites

3.0 Introduction

To develop an understanding of the links between the biological and physical systems on the Niagara Escarpment, it is necessary to review the state of knowledge of these systems and to consider previous work that has attempted to integrate these to describe the Escarpment landscape system. A review of this material will also identify the current gaps in this work, including research directives and geographical areas that have not been represented in field studies.

The focus of biological work on the Escarpment has been the identification of the important life forms, their distribution and relation to habitat. The strongest work, within the biological sciences, that links vegetation to the geomorphic form has been the extensive work on cliff face ecology (e.g., Larson et al., 1988). Landform and processes have been considered in numerous studies but have not been linked to the biological system except for the work on geomorphic processes and vegetation dynamics (e.g., Moss and Rosenfeld, 1978; Moss and Nickling, 1980).

The first section of this chapter includes an introduction to the Niagara Escarpment as well as a review of relevant research on the combined biological and physical systems. The biological system will focus on the relationships of forest dynamics and the avian populations to the landforms, while the physical system encompasses the geological and geomorphic processes that shape these landforms. The slope systems of the Escarpment have been classified based on the shape and profile of the slope, the underlying bedrock geology, and the past and present geomorphic processes operating on the slope (Moss and Milne, 1998). The overlying vegetation communities and their processes are primarily a response to these physical processes. Several general slope types have been identified, and it is recognized that it is the combination of these found along the Escarpment that creates the complex slope systems.

3.1 Niagara Escarpment

The Niagara Escarpment of Southern Ontario is a dominant landscape feature extending for more than 700 km from the US border at the Niagara River to the tip of the Bruce Peninsula (Figure 3.1). It is an important feature of the landscape from both a natural and a human perspective. The geology of the Escarpment creates some of the most dramatic views that attract tourists and recreationalists, as well as providing an important source of aggregates used extensively in southern Ontario for brick manufacturing, building material and highway construction. This landscape is also an important natural area and is the site of many important biophysical features, including rare species such as Hart's tongue fern (*Pyllitis scolopendrium*) and Louisiana Waterthrush (*Seiurus motacilla*). In a broader picture, the lands of the Escarpment have many recognized Environmentally Sensitive Areas (ESAs) and Areas of Natural and Scientific Interest (ANSIs). The entire complex of the Escarpment lands has been recognized as an important corridor of landscapes and consequently has been protected through provincial government legislation.

The principal management plan for the Niagara Escarpment is the Niagara Escarpment Plan (NEP) which is administered by the Niagara Escarpment Commission (NEC), a government agency that is a component of the Ontario Ministry of Natural

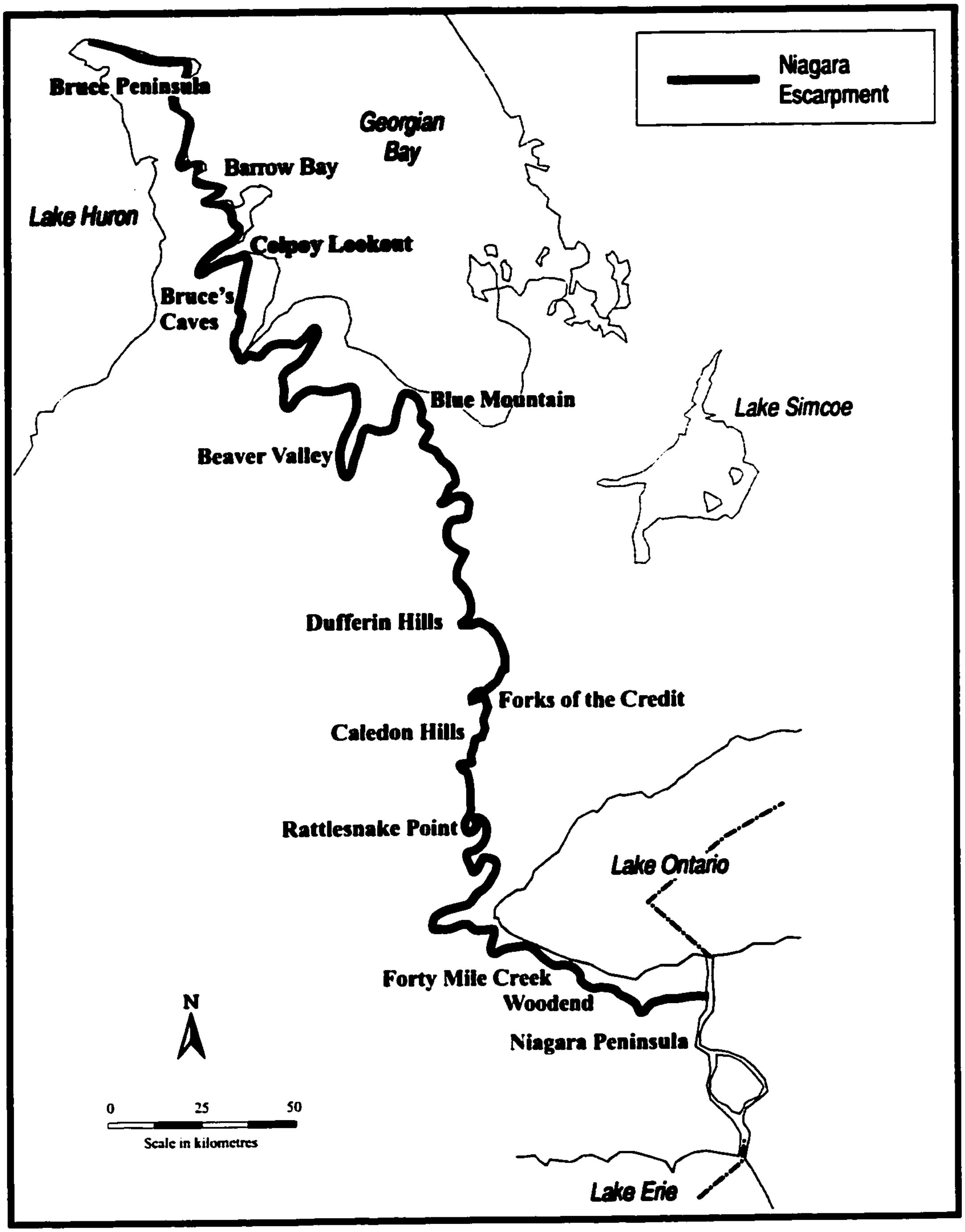


Figure 3.1 The Niagara Escarpment of Southern Ontario.

Resources. From the late 1950's, concerned citizen groups began to lobby for some form of preservation and controls on land use planning and development on the Escarpment. In 1973, the Niagara Escarpment Planning and Development Act was passed, establishing the NEC which published its Proposed Plan for the Niagara Escarpment in 1979 (NEC, 1979). The Niagara Escarpment Plan was approved in 1985 and subsequently revised as a result of further review initiated in 1990 by the Ontario Ministry of Environment and Energy (OMEE, 1994; Moss and Milne, 1998).

The plan represents a land use management strategy that provides for multiple-use of this landscape for activities including agriculture, aggregate extraction, tourism, and natural heritage. It also links a series of public lands from Tobermory to Niagara Falls, through a natural and protected corridor. The nature of this land use plan emphasizes the importance of combining stewardship of surrounding private land with multi-use public lands. In response to this arrangement, in 1990 the Niagara Escarpment was designated a World Biosphere Reserve by UNESCO (United Nations Cultural and Scientific Organization). The goal of this reserve is to promote and demonstrate a balance between people and nature and act as a working model for land managers and sustainable development (Milne et al., 1999).

3.2 Biophysical Components

The Niagara Escarpment consists of Ordovician and Silurian rocks formed from sediments in seas between 445 and 420 million years ago. This landscape has been shaped since at least 245 million years ago as the seas retreated and large drainage networks developed. Since then differential weathering of bedrock has created a cuesta which has been migrating primarily to the southwest over much of southern Ontario. The

Escarpment landscape has also been dramatically shaped by a series of glacial periods, most recently 23,000 to 12,000 years ago when the Escarpment was covered by 2-3 km of ice (Tovell, 1992). Landforms of the escarpment vary across the 700 km extent of this feature forming a continuum of identifiable slope systems consisting of combinations of large cliff faces, small and buried faces, rounded slopes and re-entrant valleys: the result of bedrock weathering (Fahey and Dagesse, 1984; Fahey and Lefebvre, 1988) and historical (Straw, 1966, 1968; Tinkler and Stenson, 1992) and present geomorphic processes (Hewitt and Hintz, 1998; Moss and Milne, 1998).

Research on the vegetation components of the Escarpment has been focused on specific species and habitats. Landforms of the Escarpment, such as the cliff faces and re-entrant stream valleys, will have specific influences on the vegetation pattern and consequently on habitats. For example, Larson and associates (e.g., Larson et al., 1989; Larson and Kelly, 1991; Kelly et al., 1994) have studied the pattern of old-growth eastern white cedar (*Thuja occidentalis*) forest communities on cliff faces and related talus slopes. They have shown that the physical and biological constraints of cliff faces, such as microclimate and soil layer, produce distinct changes within the ecosystem between the different components of the slope system. This creates distinct patterns of vegetation communities, and although there are no significant changes in life-form, there are significant shifts in species abundance (Larson et al., 1989).

On the Escarpment are some of the largest upland forest tracts in southern Ontario, and it is therefore an important regional source for forest-interior songbirds. In areas surrounding the Escarpment, there is increasing pressure from land use conflicts and consequently most of the remaining woodlands are small and isolated. Because of negative effects, nesting success and fecundity are reduced and populations of neotropical migrant forest birds in fragmented areas are thought to act as 'sinks' in which a species cannot sustain itself. These populations must be supplemented by immigrants from population 'sources' which produce a surplus of young birds (Pulliam and Danielson, 1991; Robinson et al., 1995; Wyatt et al., 1998).

Matheson and Larson (1998) found that cliff faces acted as inherent edges in the Escarpment landscape system which attracted a higher diversity of species than found in the adjacent forests. The complex of cliff face and talus slope possibly increased diversity because of the abrupt topography, protection from predators and high insolation, habitat qualities not available in adjacent forest. Their conclusion was that the Escarpment maintains relatively high species richness without the detrimental effects associated with edges.

3.3 Land Systems

There has been relatively little work completed that brings together the components of the Escarpment system, especially at the scale of the landscape system. This requires the integration of the biological and physical components and processes that comprise the Escarpment landscape. Integrated studies combining vegetation dynamics and geomorphic processes have been investigated by Moss and associates and summarized in Moss and Milne (1998). Vegetation patterns have been described as a response to a combination of landform controls and geomorphic processes. Local vegetation distributions are also associated with changes in site conditions such as soil moisture and slope aspect (Moss and Rosenfeld, 1978; Milne and Moss, 1988).

Moss and Rosenfeld (1978) examined the variations in vegetation processes within Forty Mile Creek, near Grimsby. The stream is a small re-entrant valley that flows over the Escarpment, cutting 100 m into the bedrock and creating northerly and southerly-facing slopes that are quite distinct in geomorphic processes and vegetation associations. Variations in forest cover between the two sides of the gorge are presented in Figure 3.2.

Mass-wasting processes within the gorge were placed into two groups on the basis of their magnitude and frequency of occurrence. The regular processes, which represent the normal or present regime, have promoted the development of more extensive plant communities and even-aged stands. In contrast, intermittent processes cause local catastrophic disruptions of forest communities along specific disturbance tracks. Sugar maple plays an important role in revegetation on the south-facing scars, but many other species are important at specific sites including black cherry (*Prunus serotina*), white cedar, red oak (*Quercus rubra*), eastern hemlock (*Tsuga canadensis*) and white birch. In contrast, eastern hemlock and white birch are more important in the cover of north-facing scars with some white ash (*Fraxinus americana*) and sugar maple. Succession on the active talus slopes is also quite different in nature with two distinct types of succession occurring. Near the mouth of the valley on the south-facing side, white cedar is the dominant species with some sugar maple and red oak. In comparison, on talus slopes on the same side but nearer the head of the valley, eastern hemlock with white ash and sugar maple form the tree canopy and various raspberry species (*Rubus* spp.) cover the ground.

The variance in mode and rate of slope development is apparent in the distribution of mass wasting types on the opposing slopes. Active talus accumulation is restricted to the south-facing slopes, except immediately below where the stream enters the valley and

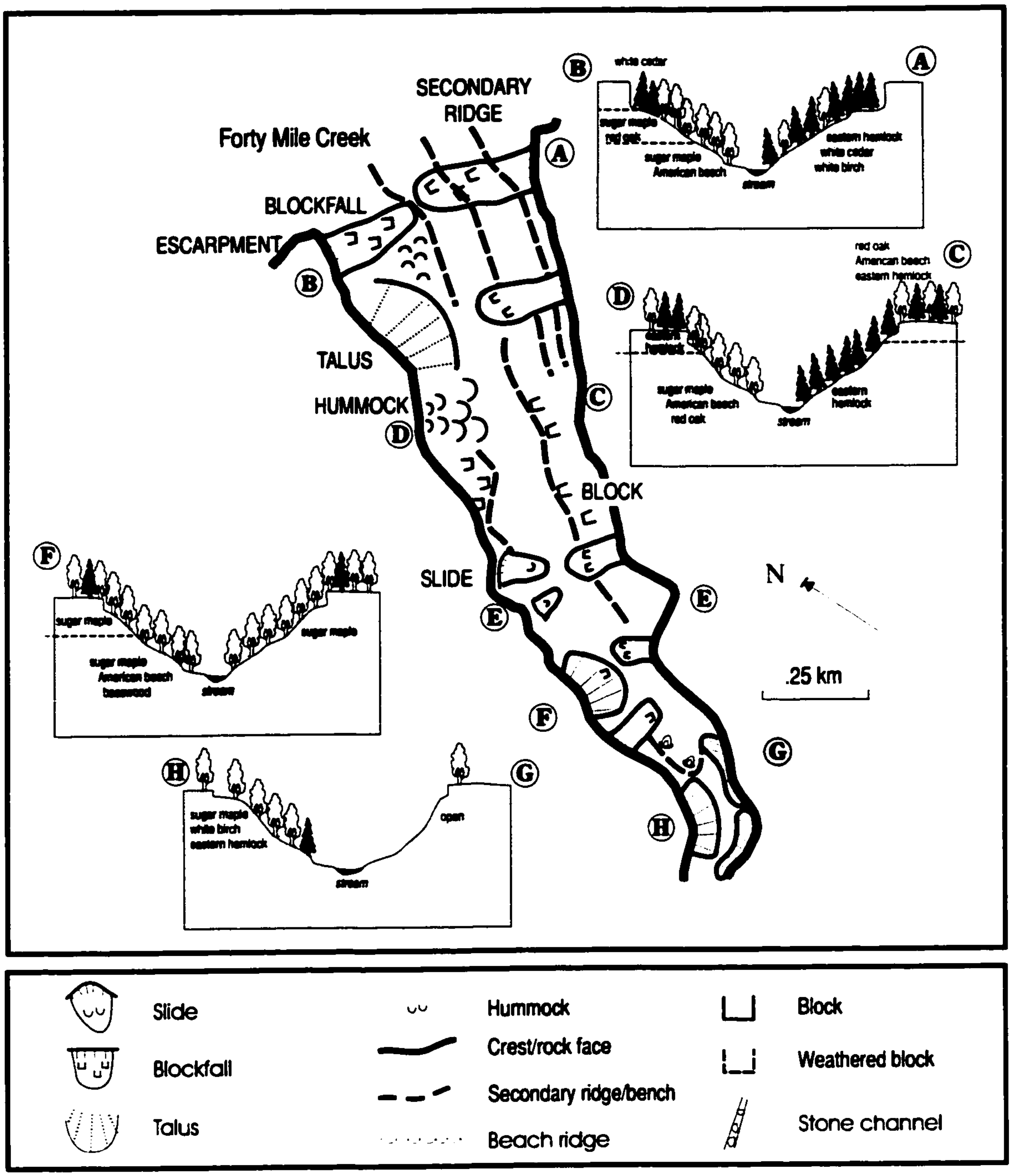


Figure 3.2 Vegetation-geomorphic relationships in a re-entrant valley, Forty Mile Creek, Niagara Peninsula . The four cross-valley transects show the variations in response of vegetation to slope processes (from Moss and Rosenfeld, 1978).

downcutting of the stream has produced unstable conditions on both sides of the valley. Rockfall debris is commonly associated with outcrops of the dolomite caprock on both sides of the gorge, although downwasting on the south-facing slope has exposed the subjacent shales in the scarp face, creating locally overhanging slopes and increased debris production. The most obvious difference between the slopes is the stability of the north-facing slopes where the main process is soil creep while the south-facing slopes are covered with hummocky solifluction-like terrain, with numerous scars or slumps.

In contrast, there is little difference over the valley in the magnitude and frequency of intermittent mass-wasting features. The largest features on the slopes occur at the same point within the valley and are the result of fluvial downcutting and oversteepening that increases the instability of the slope which leads to failure. At other points along the valley, debris avalanches appear to be more frequent on the north-facing slope, probably due to excessive accumulations of overburden. Rotational slips are localized within the shale areas of the south-facing slope, especially where overloading by talus accumulation has occurred (Moss and Rosenfeld, 1978).

At Barrow Bay and Hope Bay on the Bruce Peninsula, Moss and Nickling (1980) identified the relationships between landform and vegetation cover on Escarpment slopes. These slopes were sites of active talus accumulation and cliff faces. They identified five types of slopes based on slope angle and vegetation cover. On the steeper upper slopes (45°) there was little soil development and the slope was primarily exposed talus or had a cover of eastern white cedar. On upper slopes with lower angles (20° to 45°), there was little soil cover and the forest communities were dominated by white cedar with some white birch. On these slopes where the soil was thicker, between five and 10 cm, the forest cover was sugar maple, white ash and American elm. On the lower slope angles (<20°) the forest cover also varied depending on soil cover. When soil development was less than 5 cm, the vegetation component was primarily white birch with occasional white cedar, sugar maple and white ash. Where the soil thickness was five to 10 cm, the vegetation included yellow birch and maple (*Acer* spp.) with occasional white birch and white cedar.

Variations in vegetation cover were also related to the activity of the slope processes. Where the caprock had been removed by glacier ice and mass wasting, the remnant of the lower part of the dolomite was covered by a stable scree slope of small material (20 to 25 cm in diameter) that sustained a mature white birch forest cover. In contrast, where the caprock was intact, a large cliff face was exposed, and the dolomite was being actively undercut by the weathering and mass wasting of the weaker shale formation. Debris from the dolomite had formed a steep active scree slope at the base of the cliff. The relative instability of this slope segment was indicated by the freshness of the debris and the complete lack of soil and vegetation cover. Overall, the downslope vegetation sequences reflected increasing maturity from the upper slope to the lower. White birch retained its dominance throughout the profile and although the upper sections were covered by white cedar, subsequent replacement of these by deciduous species including sugar maple, ironwood (*Ostrya virginiana*) and American beech was common on the less active lower slopes (Moss and Nickling, 1980).

Milne and Moss (1988) investigated the response of vegetation to landslides at Blue Mountain near Collingwood in the north-central region of the Escarpment. A series of landslides was examined to determine the pattern of succession following disruption from the debris slides, including the species sequences and the rate of recovery.

At this site, four slope segments were identified that had corresponding vegetation. Some upper slopes had a lower angle (15-20°) and a rounded crest at the top of the Escarpment. The general form of the slope was convex. The steepest slope angles, ranging from 30° to 45°, were found on the upper-middle slopes. On the middle-lower slope, the slope profile was straight and there were moderate angles from 20° to 35°. The lower slope had the lowest slope angles, only reaching a maximum of 20°. This slope segment was typically concave.

On the lower slope, the main slope processes were creep and sheetwash. These processes occurred in the thicker deposits at the base and in the weathered shale at the crest. The forests on the deeper surface material were typically a sugar maple/basswood/red oak association. Vegetation change was initiated by small slumps, windfall and death of individual trees that created openings or gaps in the forest cover. In the larger gaps successional forests form temporary canopies. These forest patches were dominated by trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white cedar and white birch. These were gradually being replaced by basswood, sugar maple and ironwood, creating a patchwork pattern with stands ranging from 100 to 400 m^2 in size.

In the mid-slope section there were numerous small debris slides that originated along the lower bench of the slope. This slope unit had an irregular terrain and a series of steps which created a hummocky pattern. The mid-slope was the most active section of the slope with higher moisture levels. The vegetation cover was transitional and dominated by a high diversity of successional species, including white birch, white cedar, balsam poplar with balsam fir (*Abies balsamea*), white pine (*Pinus strobus*), and trembling aspen.

The upper slopes had better drainage and a greater concentration of carbonate materials. They were the sites of the largest slides although the frequency was not as great as on the mid-slope. Two distinct vegetation associations were identified; one was an open stand dominated by white birch and trembling aspen and the other a dense stand of white cedar with some balsam fir. The sapling layers indicated that individuals in both stands were being replaced by the same species.

These works culminated in a summary of general relationships of the geomorphic processes and vegetation dynamics (Moss and Milne, 1995). The following sections will review these findings followed by a description of the main slope types of the Escarpment and their related processes. This will provide a background for the ensuing discussion on the relationships between geomorphic processes and vegetation dynamics in this study.

3.4 Land-shaping Processes

Landforms of the Escarpment vary across the extent of this feature forming a continuum of identifiable slope systems consisting of combinations of large cliff faces, small and buried faces, rounded slopes and re-entrant valleys - the result of past and present land shaping processes. The present processes that shape these landforms are, in part, a response to geomorphic processes and controls that operate at longer time scales. The Escarpment has experienced periods of glaciation and post-glacial erosion by a range of shoreline, fluvial, periglacial and slope-forming processes. The result has been the creation of a variety of slope types from large dolostone scarp faces to rounded, more gradual, shale slopes (Moss and Milne, 1995).

Of importance to this study are the impacts of glacial action in the central Escarpment. The impact of glaciation on the structure of the Escarpment can be considered as a combination of depositional and erosional processes. The action of the glaciers deposited large layers of till and stratified drift which in places completely covered the Escarpment face. This deposition between the upper Escarpment and the surrounding lowlands has resulted in a smoothing of the slope gradient. The resultant landscape is typically a small outcrop of dolostone of several metres above a fairly low angle slope, such as found at Mono Mills where many sections have been completely covered by glacial material and few bedrock outcrops exist.

Along the Escarpment there are also extensive scarp faces that rise to large heights over the surrounding land. These slopes are characteristically dominated by a scarp with an upper talus slope created by rockfall. These faces were created by the movement of the glacial ice in a path parallel to the face, removing material along the face and leading to the development of over-steepened scarps and increased rock failure. This is evident along sections of the Escarpment in the Bighead Valley at Bayview Escarpment Provincial Nature Reserve and Bognor Marsh Management Area, at the Nottawasaga Bluffs, and in the south at Mount Nemo and Rattlesnake Point.

Large re-entrant valleys were created during glaciation as the ice followed the path of existing stream valleys. The action of the glacier widened these valleys, creating larger steep-sided valleys now occupied by small post-glacial streams (Straw, 1968). These features can be found throughout the length of the Escarpment and are especially large in the southern Georgian Bay area such as Beaver Valley. The result of this glacial action is the exposure of the scarp face and the deposition of drift in the valley. Re-entrant valleys are the sites of some of the most active slope processes, the result of continuing fluvial downcutting within these valleys (Moss and Rosenfeld, 1978).

The pattern of bedrock will also be one of the main controls of geomorphic form and process (Tovell, 1992). Variations in bedrock material changes significantly along the geographic extent of the Escarpment and in part is responsible for the main differences in landforms and slope systems in a later section. Differences between and within types of shales, sandstones and limestones lead to spatial variations in weathering and erosion rates, which creates complex patterns of landforms over short distances (Moss and Milne, 1995). Bedrock structure will also cause variation in groundwater drainage. Water flow is directed to the face of the slope or cliff depending on internal flow networks. Sites where these flows surface are often the initiation points of rapid mass movement. Local differences in bedrock layers and hydrology will create complex systems of geomorphic processes.

3.5 Slope processes and Vegetation Dynamics

Currently, there are a variety of geomorphic processes operating on the Escarpment that continue to modify the structure and profile of the slope systems. These processes are a function of chemical and physical environments operating over various temporal and spatial scales. They can be divided into those processes operating *in situ* or weathering, and those that involve movement of slope material including the erosion, transport and deposition of material usually downslope. This movement can be rapid and produce large mass movements such as debris slides, or it can be the slow, almost imperceptible movement of small particles by soil creep. Each of these processes will affect the vegetation associations and dynamics on the slope systems. Some of these relationships will be discussed in the following sections.

3.5.1 Weathering

Weathering is the *in situ* breakdown of material, including bedrock or blocks on the slope or face. This will be initiated by a number of processes but in general it is the mechanical or chemical breakdown of surface materials. The main chemical activity at the Escarpment is karst weathering where large exposures of limestone occur. The most important mechanical process is freeze-thaw activity because of the many fluctuations about the freezing point and an adequate supply of moisture to the exposed bedrock.

Karst

Dolostone bedrock of the Lockport, Amabel and Guelph formations is often fractured into blocks of various sizes and separated by large joints of varying width and depths. Water follows the flow through these joints and, through the chemical process of solution, transforms the calcite and dolomite material in the bedrock to a dissolved form (Tovell, 1992). This leads to a weakening of the scarp face and a freeing of large blocks of dolostone that become available for transport downslope. The joint pattern is widened primarily at the face of the scarp. Further back from the face, on flat plains or limestone pavement, the jointing is reduced (Figure 3.3). Depending on location this pattern can be quite extensive and important in the breakdown of the bedrock. It will eventually supply material for the talus slopes.

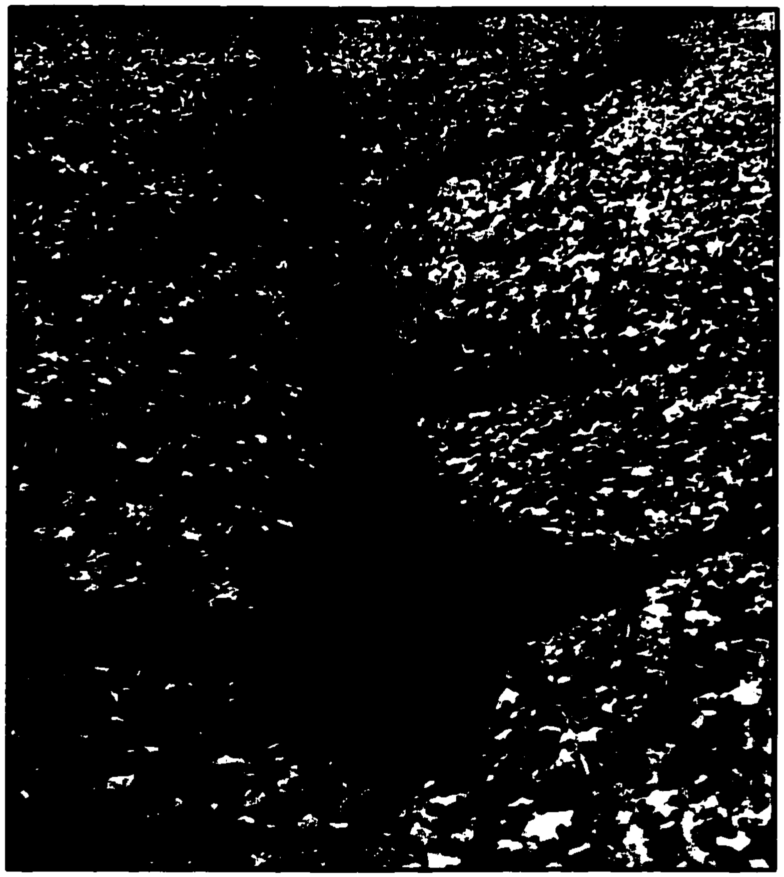


Figure 3.3 Joint patterns and karst weathering of dolostone, Woodend, Niagara Peninsula.

Freeze-Thaw

The breakdown of rock material can also take place by mechanical processes that do not produce a change in the composition of the material. The main process of mechanical weathering on the Escarpment is the removal of rock fragments by the force of ice expansion or freeze-thaw. When water is trapped within the structure of the rock and freezes, the expansion of the ice will increase the stress on the rock structure and lead to the dislodgement of rock fragments from the main rock face.

The bedrock of the Escarpment is susceptible to this process, especially certain shales (Fahey and Dagesse, 1984). Often these beds are found on the lower sections of the scarp face. This leads to greater weathering at the base of the slope, creating large overhangs of more resistant rock and unstable slope conditions. When material is exposed as on a rock face, the process is enhanced since water channelled along the face will accumulate in cracks and weaknesses. Periods of freezing and thawing will depend on the degree of exposure. It is the number of cycles to which material is exposed that affects the rate of disintegration; therefore sites that experience more variation in temperature will have the greatest breakdown of material (Fahey and Dagesse, 1984). Other factors that will increase the rate of weathering include the amount of moisture (eg. precipitation, dew, etc.) and exposure (eg. north vs. south). Therefore, exposed faces in favourable sites for freeze-thaw activity will tend to have a larger buildup of talus at the base of the slope (Moss and Rosenfeld, 1978).

3.5.2 Mass Wasting Processes

The movement of the material over the slope is referred to as mass wasting. This includes a number of processes that operate at varying temporal-spatial scales, but in general involve the erosion, movement and deposition of any slope material, usually in a downslope direction. Low energy processes which usually involve small particles include soil creep, sheetwash and rockfall. The larger high-energy events which can move large amounts of material are generally slides, where a mass of slope material including soil, rock and vegetation, or blockfalls, a large mass of bedrock, is released and moves downslope creating an unsorted jumble of material in the lower slope profile.

Soil Creep

On slopes that experience changes in temperature and moisture, there will be a gradual transfer of fine material from the upper reaches of the slope to the lower sections. The expansion and contraction of the ground surface, either by freezing and thawing or by wetting and drying, will cause a net movement of material in a downslope direction. This is a slow process that results in a gradual lowering of the slope gradient and shaping the slope into a convex-concave pattern. This process is typical in those locations without a resistant caprock and covered with till or weathered shales. These slopes can be observed over most of the mid-section of the Escarpment such as Hockley Valley and Blue Mountain.

On slopes where there has been little disturbance of the forest cover by high energy slope processes, the main process of tree replacement is by treefall. As trees fall downslope they create a micro-hummock or mound and pit topography (Cremeans and Kalisz, 1988; Schaetzl, et al., 1990; Norman et al., 1995). As the material moves downslope it collects in the depressions created by the treefall, eventually filling in the depressions and eroding the hummocks. Litter and deadwood also accumulate in this hollow, overall creating a favourable site for seed establishment (Moss and Milne, 1995).

The initiation of treefall and the resultant micro-topography could be related to several processes. First it could be from the age of the tree, so that as the tree grows older its ability to withstand the stress of a steep slope declines and its root system weakens causing eventual failure. Second, the movement of water overland is directed around the base of the tree. As it flows around the base, this action generates erosion at the downside of the base and reducing the soil support, or similarly it may erode at the base on the upside of the tree. In either case it decreases the strength of the tree to support itself on these steep slopes, which could lead to failure (Moss and Milne, 1995).

Rockfall

Rockfall occurs when rocks are detached from the cliff face through weathering. They fall to the base of the cliff where a slope of rock fragments or talus is created. As mentioned above, the frequency of the rockfall depends on weathering processes such as freeze-thaw and possibly heating and cooling. The shape and size of the talus depend on the structure and composition of the bedrock; this is then reflected in the talus found below the scarp face. The talus can range from very small rock fragments to large rocks several cubic metres in size and angular in shape (Figure 3.4). The size and shape of the talus determine the depositional pattern on the slope with the larger rocks travelling further downslope (Moss and Nickling, 1980).

On Escarpment slopes where rockfall predominates, there is often less vegetation cover indicating a more stressful, less stable environment. However, despite the occasional damage to tree stems, the overall effect appears to be increased stress from talus cover and limited nutrients rather than a disturbance regime. Immediately below the cliff face the talus is smaller as the larger material travels further downslope when it falls

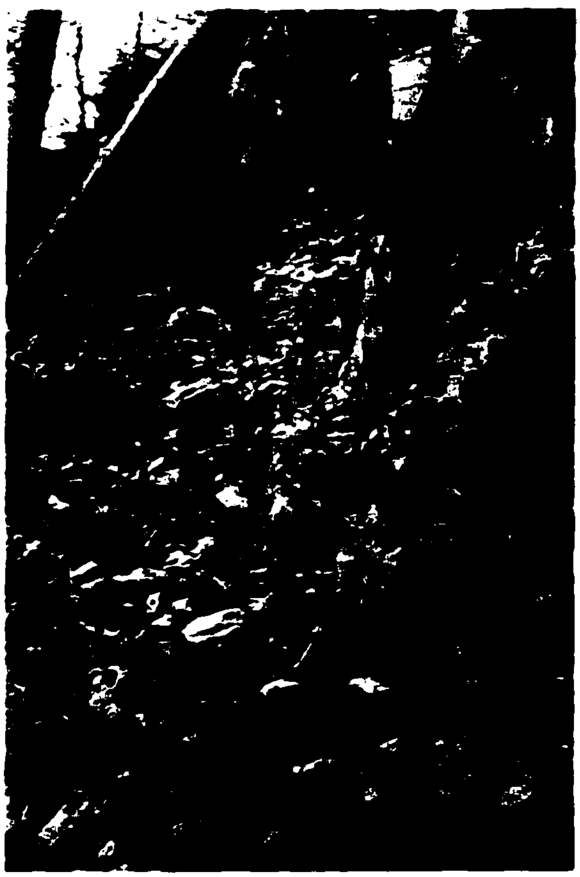


Figure 3.4 Talus at the base of a small cliff face, Glen Management Area, Bruce Peninsula.

Figure 3.5 Talus slope at Colpoy Lookout, Bruce Peninsula. Upper slope has low density of white cedar and white birch stems.

from the rock face (Moss and Nickling, 1980). Below the cliff face there is some establishment of trees such as white cedar and white birch (Figure 3.5). Where the talus is larger there is no vegetation (Moss and Milne, 1995).

Where talus dominates, a limited pattern of vegetation cycling takes place due to the stress of the rock accumulations. In the most active zone of the talus slopes, which is found on the upper slope, there is a distinct pattern of talus and forest created. As in many sections of the Escarpment, the jointing pattern of the caprock is not parallel to the cliff face. The general pattern of talus slopes and forest follows the joint pattern. Where the rock protrudes from the cliff face, the exposed face is prone to weathering and erosion, and an active talus slope is formed. On these sites there is little vegetation establishment, except sometimes at the immediate base of the cliff. In the recessed areas of the joints there is a smaller buildup of talus. Below these areas there is little talus, but in some cases there are large blocks indicating block failure. These large blocks usually have a greater cover of trees which are primarily white cedar. This pattern extends laterally across the slope where there is an extensive cliff face. As the face diminishes, the lateral pattern declines (Moss and Milne, 1995).

Blockfall

Bedrock on the Escarpment face can be weakened to the point where large blocks are released. They fall onto the talus slope and travel downslope coming to rest at some point of interception with trees or other rocks or where the slope angle decreases (Figure 3.6). Blockfalls are initiated where jointing and solutional weathering weaken the rock structure. It can also occur where undercutting or sapping removes the support below the upper caprock. Large blocks are detached and slide downslope. They often remove trees

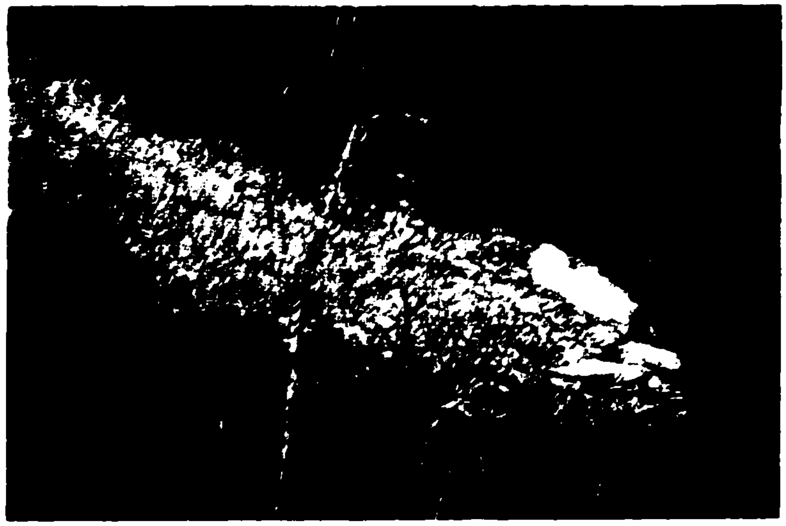


Figure 3.6 Block slide at Colpoy Lookout, Bruce Peninsula.

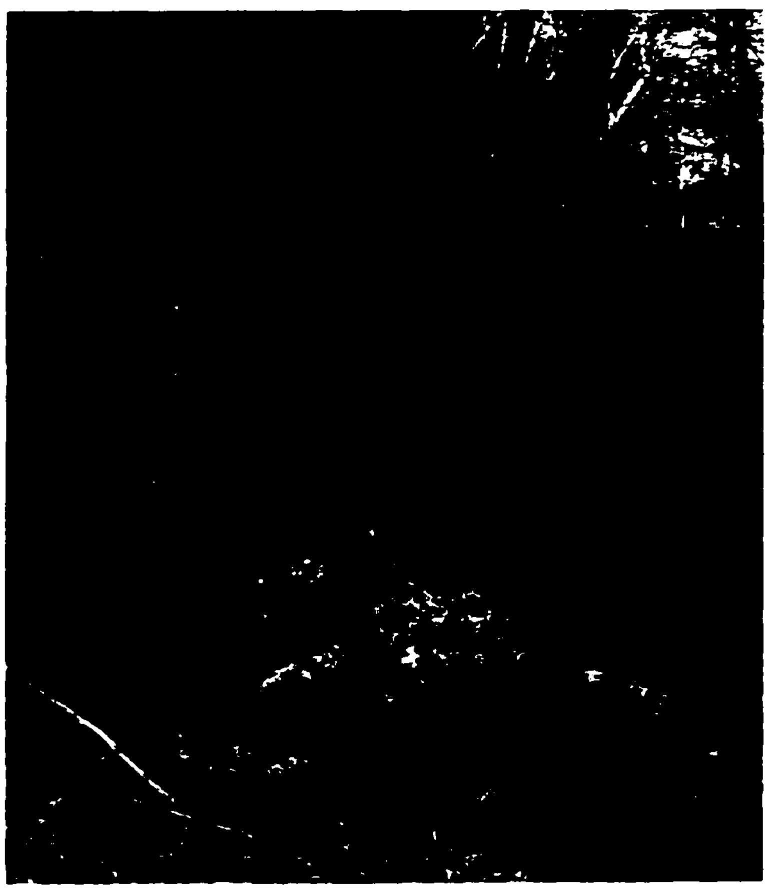


Figure 3.7 Toppled blocks and impact on tree stems, Bruce's Caves, Bruce Peninsula.

and other vegetation in their path. In other sections of the Escarpment, blocks have become free-standing as a result of karst and mechanical weathering and form small outliers from the cliff face. In some cases the basal support is removed by weathering and the block collapses on its support and topples downslope. The block can remain intact or break apart and be spread across the slope, adding to the pattern of talus. These blocks are not as destructive as blockfalls since there is no freefall and consequently little momentum.

Many of the occurrences of blockfall on the Escarpment are likely relics from past environments although a few recent events have been documented (Moss and Milne, 1995). When recent blockfalls occur the results are similar to small debris slides. Vegetation is damaged or destroyed in the path of the block which opens up the forest cover and promotes revegetation. Unlike debris slides, a blockfall does not add as much debris to the base of the disturbance; therefore this will not be a preferred site for seedling establishment, although there will be some debris pushed to the base by the block. Alternatively, the block will likely not scar the surface to the same extent as a slide, nor alter the upper slope to the same extent as a debris slide. Where the blocks formed the main cover of the slope, vegetation establishment appeared to favour sites on top of the blocks. Many stems were observed to be rooted on the flat surfaces of these large blocks. This could be from a combination of the presence of a rooting substrate and a more competitive microclimate (Moss and Milne, 1995).

Toppling was common on sites where there was only a small cliff face and extensive weathering at the base of the rock face. Tree stems play an important role in toppling, often acting as a barrier to downslope movement (Figure 3.7). Large blocks are released from the face and tumble downslope hitting mature stems and damaging the trees. In some instances the trees act as a barrier to downslope movement trapping the block at different points along the slope profile. The tree stops the movement of the material for an indefinite period of time. Eventually, the tree dies and, depending on the extent of damage by the block, the time frame may be only several years after failure or the normal life expectancy of the tree (100+ years). If the tree does not remain as a snag and falls downslope, the block will be released and will continue its movement downslope. This creates a dynamic state in which blockfall is initiated across the slope and there is movement, then it is temporarily stopped only to be released later. This may happen repeatedly across the slope or the block will come to rest and be incorporated into the matrix of the talus slope (Moss and Milne, 1995).

Debris Slides

In some cases entire sections of the slope become mobile, moving downslope as a mass of unconsolidated material including, rock, soil, clays and vegetation. These slides leave a large portion of the slope bare, usually in the upper- and mid-sections of the resultant scar, and often expose the bedrock. The slide material is deposited at the base of the slope in a large mound or debris lobe (Figure 3.8). The initiation of a slide is a function of a number of factors including the slope material, slope angle and the moisture regime. When the stability or the strength of the slope is reduced and/or the stress on the slope is increased, a threshold is reached and failure takes place. Some factors that can lead to failure include an increase in overburden on the slope, the removal of lateral support, and by external forces acting on the slope such as earthquakes.

Figure 3.8 Large debris slide at Forks of the Credit Provincial Park. The debris lobe is evident at the lower left corner where it meets the Credit River.

Figure 3.9 Upper section of debris slide in stratified drift.

Slides occur frequently on segments of the slope that are composed of fine, unconsolidated material such as in the clays of the shale slopes at Blue Mountain. Specifically, slides are initiated at breaks in the slopes where water flow is directed to the surface. This occurs commonly where there are layers of more resistant dolostone in the slope profile. The water table will be perched and a seep often occurs at this point. Slides are also initiated in coarse material composed primarily of sands and gravels. In some places, ice-contact deposits of stratified drift are common on the upper slopes (e.g., Glen Haffy and Forks of the Credit Provincial Parks). As water flows through this material, the fines are removed leading to irregular slumping, especially when the basal support is removed (Figure 3.9) (Tovell, 1992).

Smaller variations of this type of slide are common along the whole Escarpment. Slumps or small slides will occur where a small amount of material and a few trees move downslope several metres. They are less destructive than a debris slide; usually the material remains intact and the trees rooted in the material survive the movement. Alternatively, if the slope is composed primarily of clay, larger and deeper movements or slips can occur. The movement of material is rotational. The material slides out at the base and fans out downslope.

Regeneration of the forest on the scars of slides will follow many pathways depending on site specific circumstances. The pattern of vegetation recovery is typical of succession in hardwood forests in which a complex of uneven-aged stands exists, representing different stages in recovery. Various species co-exist spatially by occupying gaps created by periodic disturbances such as mass movements. The patchwork pattern on Blue Mountain is the result of the existence of multiple successions in which the recovery to a closed canopy will be representative of the frequency and magnitude of the disturbance as well as the species present and their successional strategies. The recovery forest often includes a broad mixture of species with very few dominants. For example, the sapling layer at a scar site at Blue Mountain included white cedar, white birch, sugar maple, ironwood and balsam fir, while the seedling layer was composed of white cedar, balsam poplar, balsam fir, white pine, white ash and sugar maple. Shrubs were also an important component of the scar vegetation, dominated by several species of dogwood (*Cornus* spp.), willow (*Salix* spp.), honeysuckle (*Caprifoliaceae* spp.), buffaloberry (*Sheperdia canadensis*), and mountain maple (*Acer spicatum*) (Milne and Moss, 1988).

At the study site on Blue Mountain, there were only a few scars where revegetation showed any relationship to the surrounding vegetation. Of the sites that recovered to a closed canopy, regeneration began adjacent to the surrounding vegetation, extending onto the scar surface. In these stands, the tree layer was dominated by successional species. On the drier slope the tree layer was primarily balsam poplar and large-toothed aspen (*Populus grandidentata*), with white birch and sugar maple present in the sapling layer. It is likely that the shift here is towards a cover dominated by a mix of hardwoods and softwoods. At a wetter site, on a structural bench and perched water table, the cover was dominated by white birch, balsam poplar and white cedar in all strata of the stand. Shrubs also formed a dense cover, with dogwood, honeysuckle and willow species especially common. The direction of recovery of this site is toward the white birch and trembling aspen stand type typical of the middle section of the slopes (Milne and Moss, 1988). The main sites of regeneration on a typical scar at Blue Mountain are presented in Figure 3.10. Vegetation successfully establishes on structural benches,

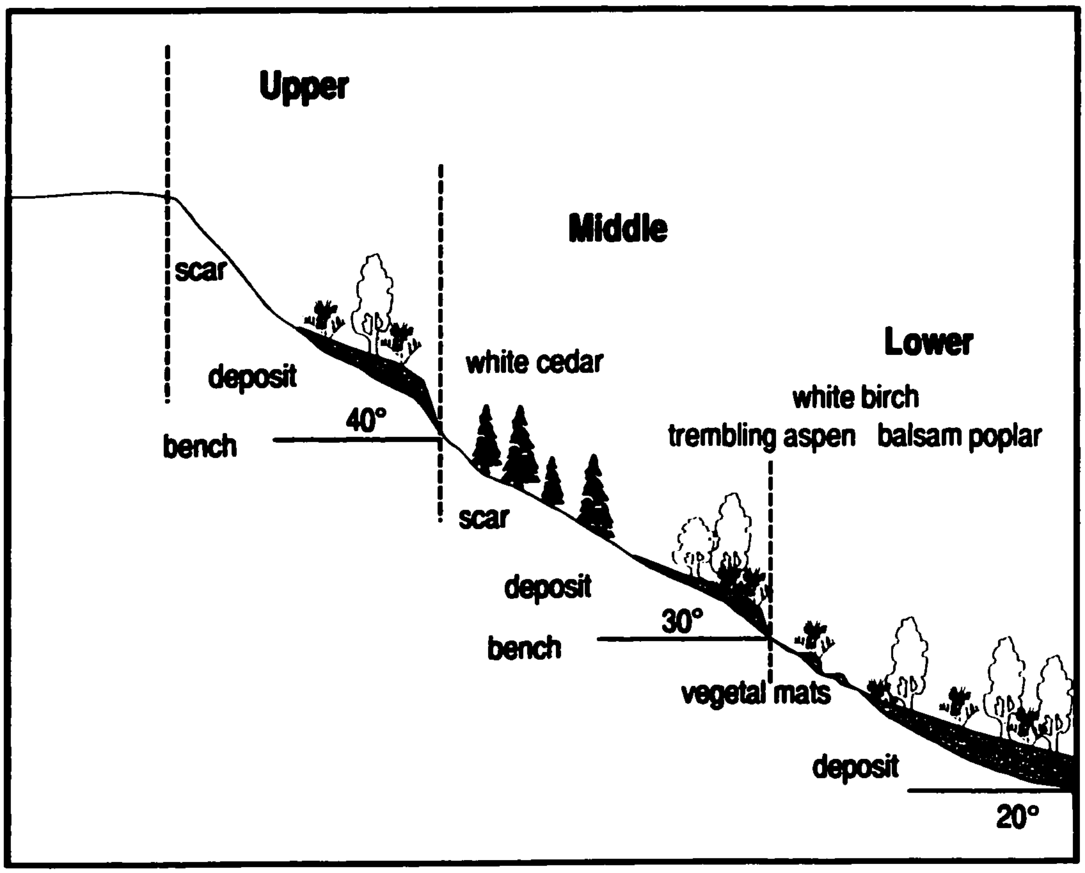


Figure 3.10 Spatial pattern of vegetation regeneration on a debris slide scar, Blue Mountain, Georgian Bay (from Milne and Moss, 1988).

exposed upper slopes and on debris lobes at the base of the scar.

At the upper level of these slopes, the dominant tree cover is white cedar, reaching ages of up to 50 years which is older than most of the trees nearer the base. The combination of periodic disruption farther downslope as material is redistributed from the benches and the sides of the scar and higher environmental stress at the site for other colonizing species may account for this pattern. For the sites where a closed canopy of white birch, balsam poplar and trembling aspen was achieved, the minimum age of these stands is 40 years. This time period should be considered as a minimum recovery period, for many of the scars recovery is quite long (Milne and Moss, 1988).

In summary, these observations indicate that the overall effect of the land-shaping processes on the Escarpment is to create vegetation patterns and patches, that vary in species spatially on the slopes and temporally as many groups of similar species exist at different life stages. The model, presented in Figure 3.11, attempts to capture this variation in processes temporally and spatially and displays the different successional and end forests that exist within the slope system of Blue Mountain.

Different processes operate at different levels. Slope processes, such as creep, solifluction and wind-throw disrupt the vegetation, causing single tree replacement. The gaps that are created by those processes are quickly filled in as saplings replace fallen trees in the canopy. However, revegetation on slides varies from very slow in most instances to rapid in some areas of deposition of materials. Dynamic equilibrium is therefore maintained in the landscape by a combination of biophysical processes acting over varying time scales. These can be expressed as a low energy equilibrium that refers to a gradual

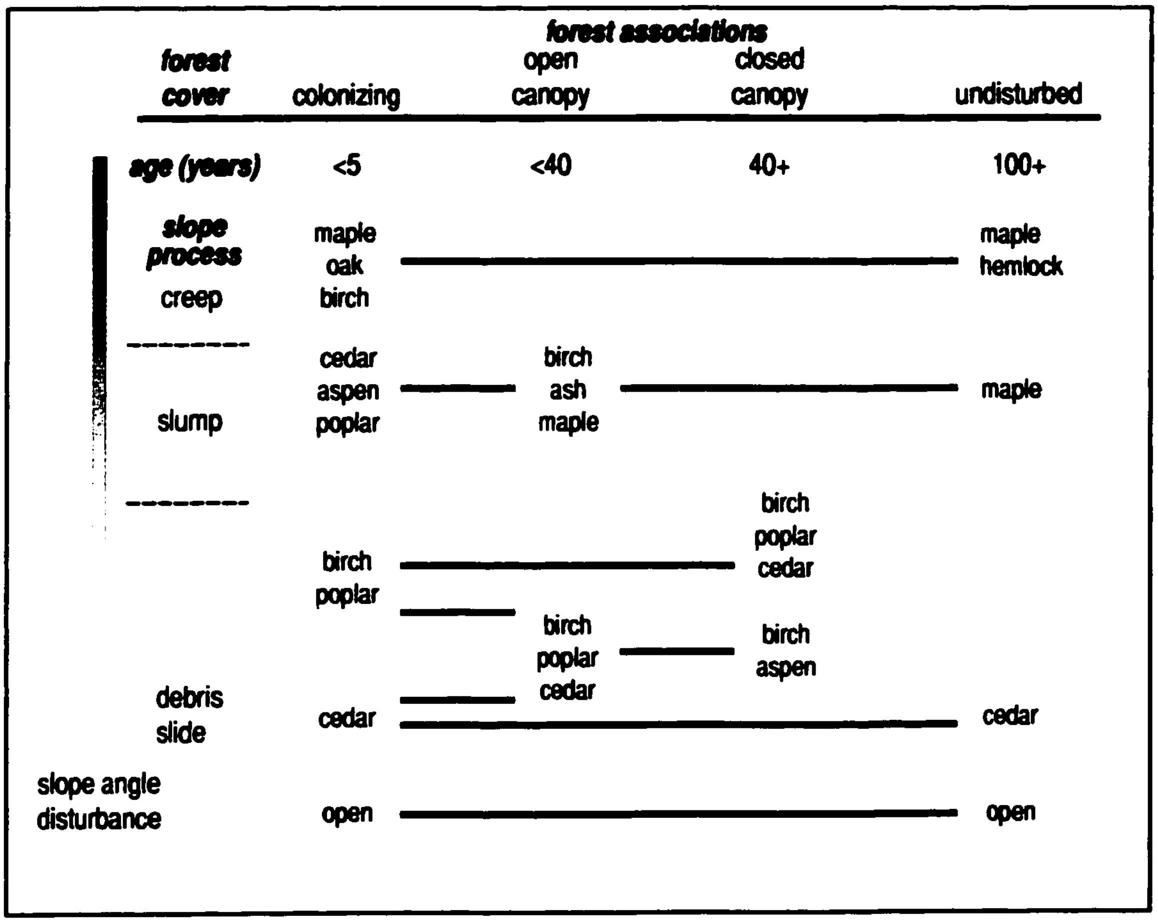


Figure 3.11 Model of slope system at Blue Mountain showing the successional pathways of forest cover following disturbance (from Moss and Milne, 1998).

species replacement by events of a small magnitude, and high energy equilibrium in which rapid mass movement initiates new vegetational communities (Milne and Moss, 1988).

3.6 Slope Form and Process

From this work, three general slope types have been identified for the Escarpment slope systems (Moss and Milne, 1995). These three slopes are presented in Figure 3.12. The types distinguished were between extensive bluffs with large scarp faces, buried slopes with a small scarp of several metres, and rounded slopes of shale and till with no evidence of caprock or a buried layer that often is exposed midway on the slope. These general types are found across the length of the Escarpment, with no one type restricted to a specific region, although in most cases one type will dominate a site. In some cases, the three forms often exist as a continuum gradually or abruptly shifting from one to the other across the slope. The following sections provide a description of the general form of the slopes and the dominant land-shaping processes.

3.6.1 Type A Slope

Form

This slope type is dominated by massive walls of rock that extend large heights above the slopes. The prominent feature of the cliff face slope type is the extensive scarp of resistant caprock of either the Guelph, Amabel or Lockport formations of dolostone and limestone (Figure 3.13). As depicted in Figure 3.12, this face can rise 25 m or more above the talus slope and is typically found over many of the northern and southern areas of the Escarpment. It typically has an upper bedrock or limestone plain that extends back from the rim of the scarp face, usually with some jointing in the bedrock.

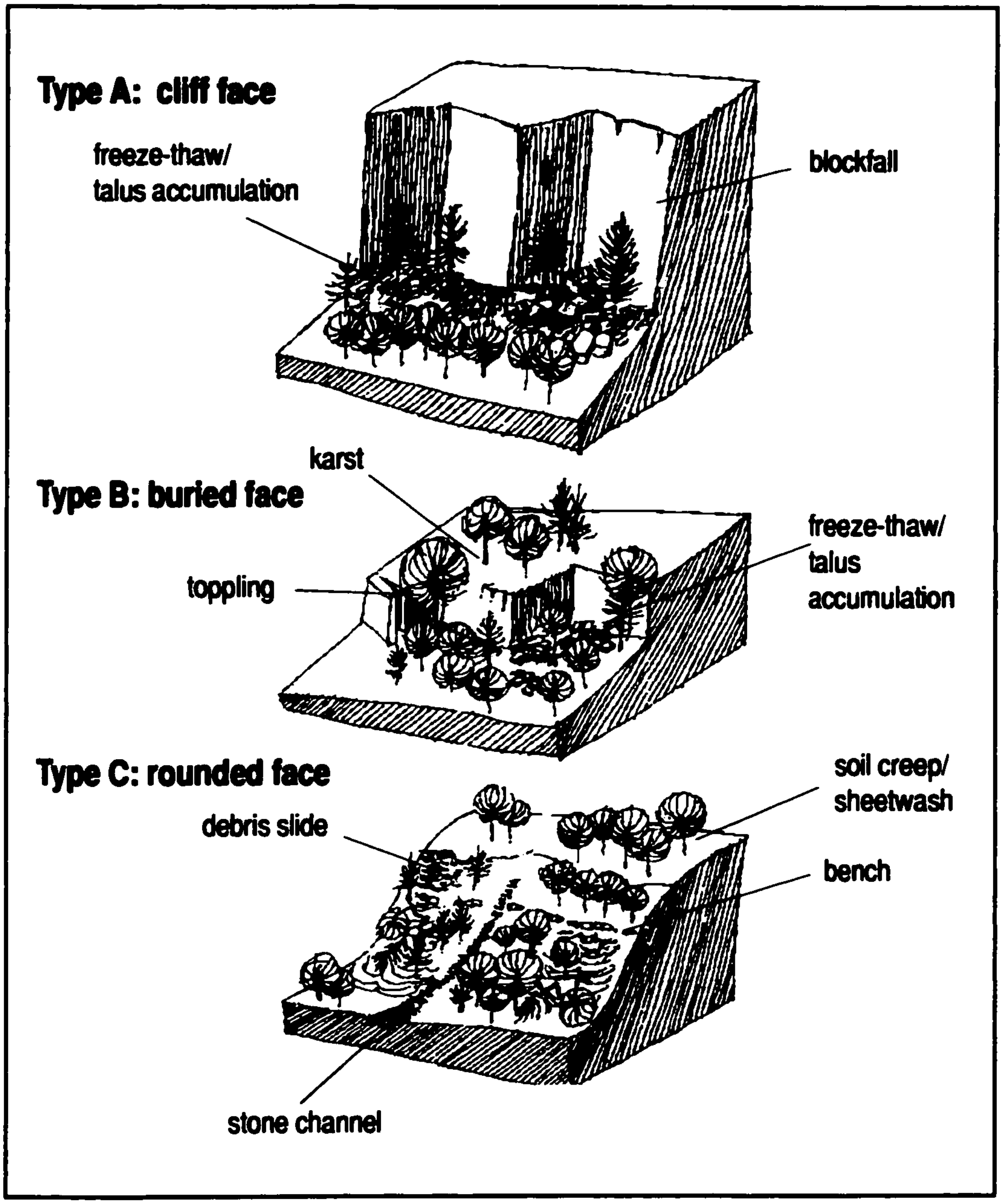


Figure 3.12 The major slope types of the Niagara Escarpment (from Moss and Milne, 1998).

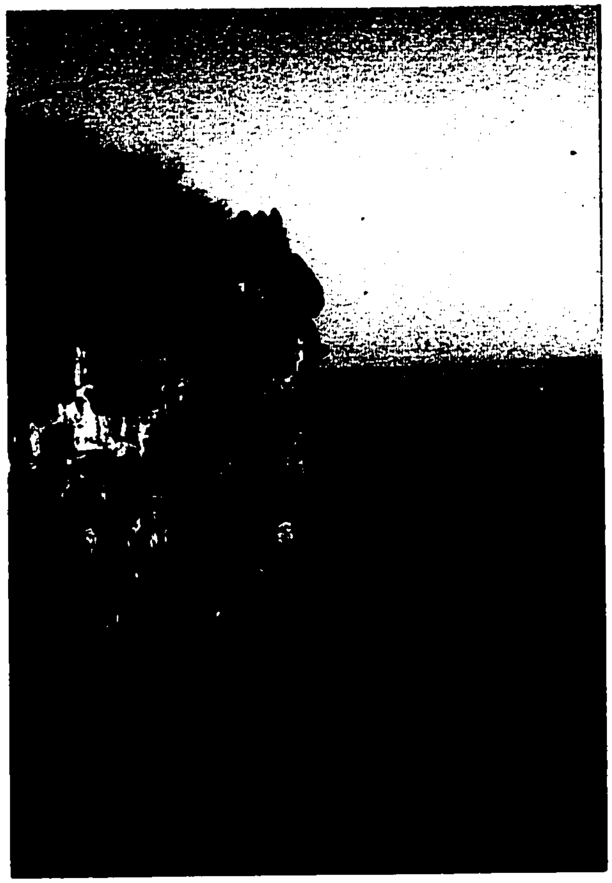


Figure 3.13 Slope type A - Cliff face at Rattlesnake Point, Halton Hills.

Figure 3.14 Slope type B - Small cliff face at Griersville, Beaver Valley.

Immediately below the scarp face is usually an upper section of slope with extensive talus deposits. This slope section can be open rock and free of vegetation, or covered with shrub or forest communities. The talus will range in size from several centimetres to large blocks. Some of this material is almost plate-like and creates a very deep unstable surface of exposed rock. Below the talus slope is often a secondary, lower slope that is usually a mixture of bedrock, regolith, and glacial material - till, soils and weathered clays. These slopes are gentler and gradually grade down to the dominant slope of the region.

Processes

The main processes operating on this slope include weathering of the scarp face and the bedrock plain and the transport and deposition of material on the slope. There is karst or solutional weathering as water drains over and through the bedrock plain and cliff face. As the rock dissolves, lines of weakness develop which loosen rock pieces. Similarly, as water freezes and thaws in cracks in the exposed bedrock, rock pieces are released by the cliff face and are added to the talus slope by the process of rockfall. Many of the talus slopes are created by rockfall from the exposed cliff faces.

Alternatively, when undercutting of the caprock occurs and the lower layers of bedrock are removed, then large sections of the cliff face can be weakened sufficiently for block failures. This has occurred over many of the cliff faces, and the mid- and lower-slope sections below many of these cliff faces have a ridge of large rocks. There are also patterns on the slopes where a ridge of blocks extends upslope to the cliff face. This pattern often corresponds to recessions in the face along joint patterns. The blocks collapse from the cliff face and are transported downslope. Some of these blocks are from recent events, but more commonly many of these blocks were deposited during earlier glacial and post-glacial periods, especially where wave action attacked the cliff face.

3.6.2 Type B Slope

Form

Large sections of the Escarpment have slopes that are typically controlled by a scarp with a short face, often only several metres in height (Figure 3.14). These slopes also have a flat to undulating bedrock plain extending back from the face, usually with a heavily jointed rim. The scarp is short and not as exposed as the larger faces of Type A, and there is a lesser accumulation of talus below the scarp face (Figure 3.12).

The slope below the scarp is usually a combination of large boulders, weathered material and shallow soils. In some instances there are large blocks several metres in diameter, as described for Type A. However, the pattern of these blocks appears to be more irregularly spaced over the slope. Their position could be related to movement of these blocks during peri-glacial environments (Straw, 1966), or these blocks are added to the slope by toppling, mainly by rolling from the scarp face downslope until their path is blocked by trees, other blocks, or the base of the slope.

Processes

Karst weathering is dominant in many areas of these slopes. Large blocks are separated from the main face as solutional weathering widens the joints between blocks. These blocks are then exposed on both sides and water is channeled to their base, which weakens the support blocks. Eventually they topple over and fall downslope. Large blocks are almost embedded on the slope, which suggests an earlier period of more intensive weathering and erosion and post-glacial breakdown *in situ*. The buildup of slope material is from the continual feed from freeze-thaw processes on the exposed rock faces. There are often well-developed talus slopes below these faces.

3.6.3 Type C Slope

Form

Where the resistant caprock has been buried or is not present, the slope profile will be a combination of convex ridge, straight slope and concave base (Figure 3.12). This is common on the Escarpment, especially where there are extensive layers of bedrock consisting of shale or thick deposits of till or stratified drift deposited over the bedrock. Type C slopes are often complexes of slopes that have been heavily dissected from post-glacial fluvial erosion. Slopes will join at the bottom of a stream channel which connects with another series of slopes emptying into a bigger channel.

The top of the slope is typically rounded, and can achieve steep slopes in the upper reaches, up to 40 to 45°. Some shale slopes have carbonate beds. These beds of carbonates will form structural benches which become sites of material buildup and slope failure. These beds can be fairly thin or up to a metre at Silver Creek and Forks of the Credit Provincial Park. The bench directs water to the slope surface and forms perched water tables. At certain locations, water will surface on the slope at seeps, weakening the surface material which can lead to debris slides.

Processes

These slopes are a function of several processes. The convex-concave pattern is typically created by soil creep leading to a gradual rounding of the slopes (Figure 3.15). This is enhanced by water flowing over the surface of the steeper slopes and moving small quantities of material by sheetwash. The slope surface can also develop a very hummocky

Figure 3.15 Slope type C - Convex slopes at Blue Mountain.

relief with small undulations in the surface, up to a metre plus, characterized by mounds of material and depressions. This pattern of micro-hummocks is related to treefall: as a tree falls over either from natural death or external disturbances, such as wind or blockfall, it usually falls downslope throwing debris, soil and rock, and leaving a hollow where its roots once were located.

3.7 Escarpment Slope System Units

The Escarpment has been divided into nine slope system units based on the three general slope types. The slope system units were determined based on the specific slope complexes which included the immediate upper rim and lower slope and geographic location on the Escarpment. This classification provided a more specific classification of Escarpment land systems compared to earlier work (OMNR, 1976; NEC, 1991), and identified nine regions along the entire length of the mainland Ontario portion of the Escarpment. The location of each of these units is presented in Figure 3.16. Escarpment regions are broad areas of similar classifications based on the slope complexes, which include the upper rim, cliff and slope components as well as a broader classification based on geographic position along the Escarpment. The slope system units are comparable in scale to the land type association of the United States classification system (ECOMAP, 1993) or the community series of the Ecological Land Classification (ELC) program in Ontario (Lee et al., 1998). These units are recognizable at a scale of 1:250,000.

3.8 Summary

This chapter has presented an overview of the current knowledge of slope systems on the Niagara Escarpment focusing on the complexity of relationships between

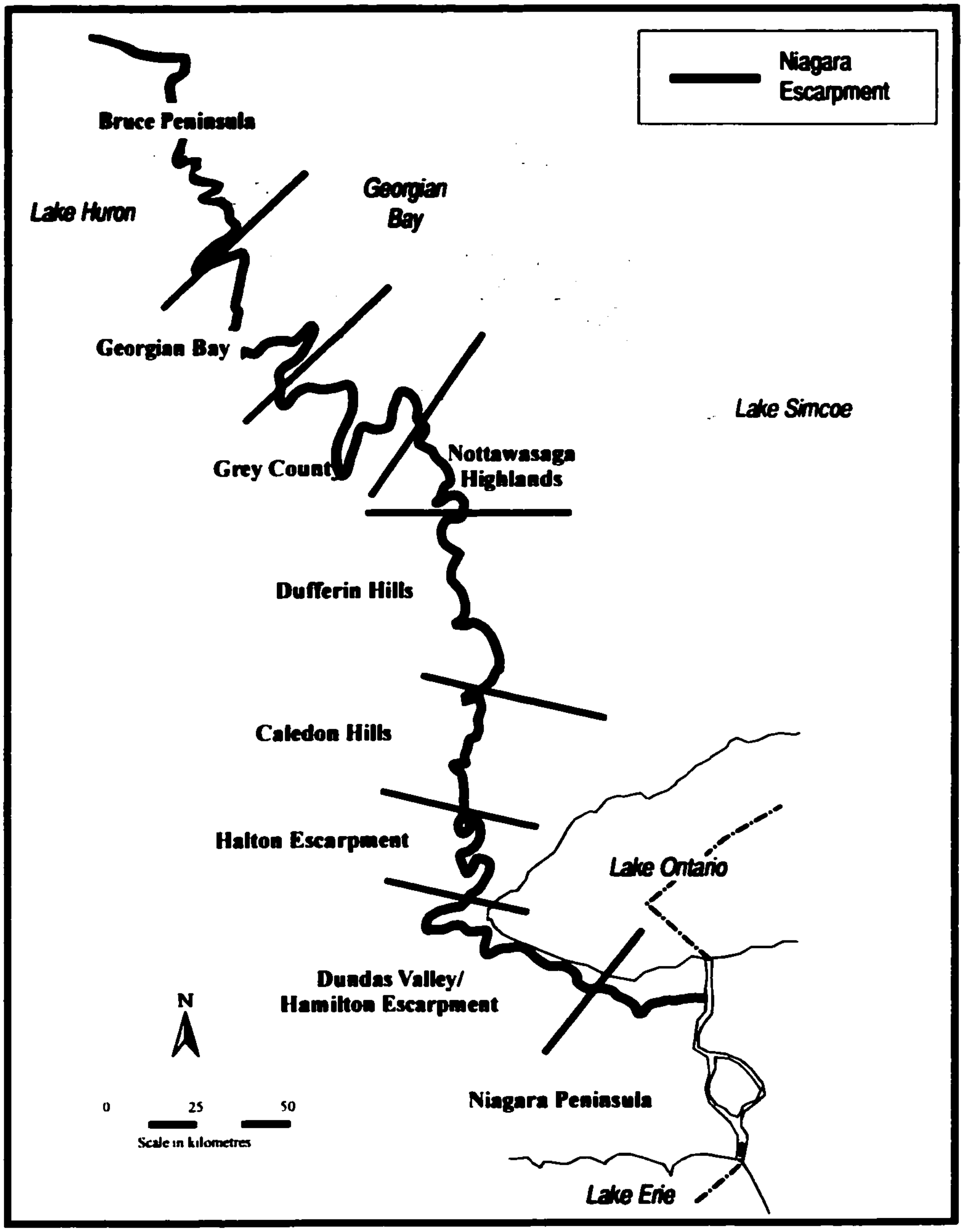


Figure 3.16 Subdivision of the Escarpment into nine slope unit systems (from Moss and Milne, 1998).

geomorphic processes and vegetation communities. A set of general slope types was reviewed that described the general results of past and present actions shaping the Escarpment. It is apparent from this overview that there are gaps in the knowledge and areas for expansion and addition to the present knowledge of the Escarpment slope systems. First, a number of representative areas have been investigated in some detail, but the focus has been on the more dramatic features of the Escarpment systems, the large cliff faces (Moss and Nickling, 1980; Larson et al., 1988), deep re-entrant valleys (Moss and Rosenfeld, 1978) and the highly active, steep slopes of the Queenston shale at Blue Mountain (Milne and Moss, 1988). Aside from descriptive work, there has not been a detailed analysis of the regions of the Escarpment where there are combinations of small cliff faces and rolling slopes of glacial origin as found in the central region of the Escarpment. Secondly, these studies have provided a strong foundation of knowledge of the biophysical interactions occurring on the immediate slope component, but there is less information on how the vegetation responds to processes operating above and below the slope segment within the larger Escarpment land system. Finally, it is also notable that there have been few attempts to understand the response of the avian component, or wildlife in general, to geomorphic form and process (Matheson and Larson, 1998). One reason for this could be the complexity in bringing together related information from a set of biophysical systems. In the following chapter, a framework is established that will combine data collection and analysis to provide a stronger integration of this material.

Chapter Four
Methods

4.0 Introduction

This chapter provides a description of the methods used to complete the objectives of this study, including an overview of the rationale and description of the field and statistical techniques. The chapter will also present a description of the research sites and the rationale for the selection of this study region and the specific research sites.

It is apparent from the previous chapters that the biophysical relationships within Escarpment landscapes are complex and a research strategy for the thesis objectives will require combining a series of steps to establish an integrated understanding of these sets of relationships. In considering this strategy, it was determined that two directions of enquiry could be followed. First, a landscape system model could be developed by building from a series of detailed field analyses of each of the system components to construct the general model. This approach would require either a large number of researchers, a long research period or a history of past research. The second approach would be to complete a more descriptive overview of the landscapes that provides general relationships and serves to target important areas or subjects in subsequent work. It was decided to combine these two approaches by studying a region of the Escarpment with a complexity of landscape units to provide an overview of the general relationships between several landscapes at a scale appropriate for planning issues. This was combined with a detailed analysis of the biophysical components at a number of selected sites to provide a stronger interpretation of the interrelationship between the geomorphic, vegetation and avian components. One of the reasons for this approach is that the central region of the

Escarpment, like many areas in southern Ontario, is under increasing pressure from land use and urbanization, and there is an urgent need for ecological information at this level. This approach also provides a baseline of geoecological information of the land systems, which will provide direction for subsequent research on specific areas, processes or species.

A flowchart has been provided to guide the reader through the steps of this study (Figure 4.1). This flowchart includes the main procedures outlined in Chapters four through six including site selection, field data collection, statistical data analysis and concluding with the development of the biophysical models and land units. In the first step, research sites were selected in the central region of the Niagara Escarpment that were representative of upland, face and valley Escarpment land units. The second step was the collection of field data. The field work was divided into three components, the data collection of geomorphic, vegetation and avian components. Due to limitations of time and resources for the collection of long-term process and dynamics information, several techniques were employed to provide an estimate of the importance of geomorphic processes and of vegetation change. Landform characteristics such as slope angle and aspect, were combined with descriptive measures of geomorphic and human processes, based on levels of disturbance and stress. Forest dynamics were considered as a combination of forest composition, and structural components such as the density of stems, the ratio of coniferous to deciduous trees and other similar indices. These variables provided relevant habitat characteristics as well as the pattern of change in forest cover or the functional aspect of the forest. The avian component was obtained from a long-term collection of seasonal data on bird populations.

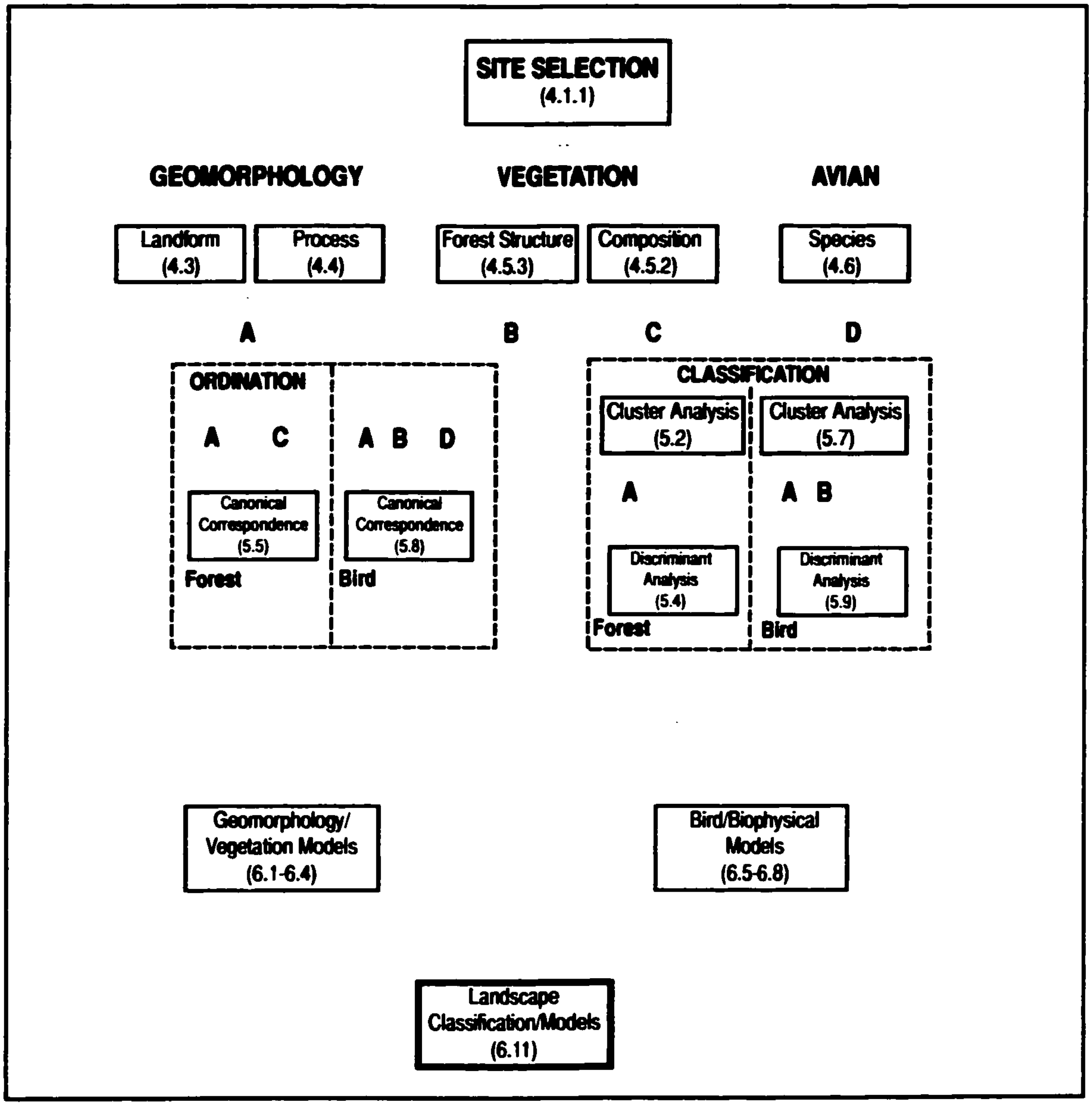


Figure 4.1. Flowchart of the sequence of data collection and analyses leading to the development of landscape classification units and biophysical models. Various combinations of the biophysical components, identified by characters A-D, were used to complete the classification analyses. The numbers in brackets refer to the section in the text where each step is described.

In steps three and four several multivariate statistical procedures were completed to identify associations between the biological and physical systems. In step three the vegetation and bird populations were classified by cluster analysis using TWINSPAN (Hill, 1979). The biological data was then compared to the physical and habitat data through two procedures in step four. An ordination of the species with the biophysical variables, was completed by Canonical Correspondence analysis using CANOCO, version 4 (Ter Braak, 1998). To provide a second independent analysis, a Discriminant Analysis (SPSS, 1999) was completed combining the classified groups with the biophysical variables.

In step five the results of the statistical analyses were combined to produce a set of biophysical models that identify the relationships between landscape processes and the biological associations. As well a set of land units was created based on the results of the cluster analysis. In step six this information is further interpreted to develop a landscape model that relates the landscape form and processes to the landscape units. These are homogeneous landscape elements that represent areas with similar biophysical characteristics and are controlled by similar biophysical processes. These units are arranged in a descriptive model to identify the links within the biophysical components and between other land units.

4.1 Research Site

The research area for this study extends approximately 100 km along the Niagara Escarpment from Mono Cliffs Provincial Park located north of Orangeville, south to Speyside near Georgetown (Figure 4.2). The study area is located in the central portion of the Niagara Escarpment, an area distinguished by its rolling hills and buried cliffs. This

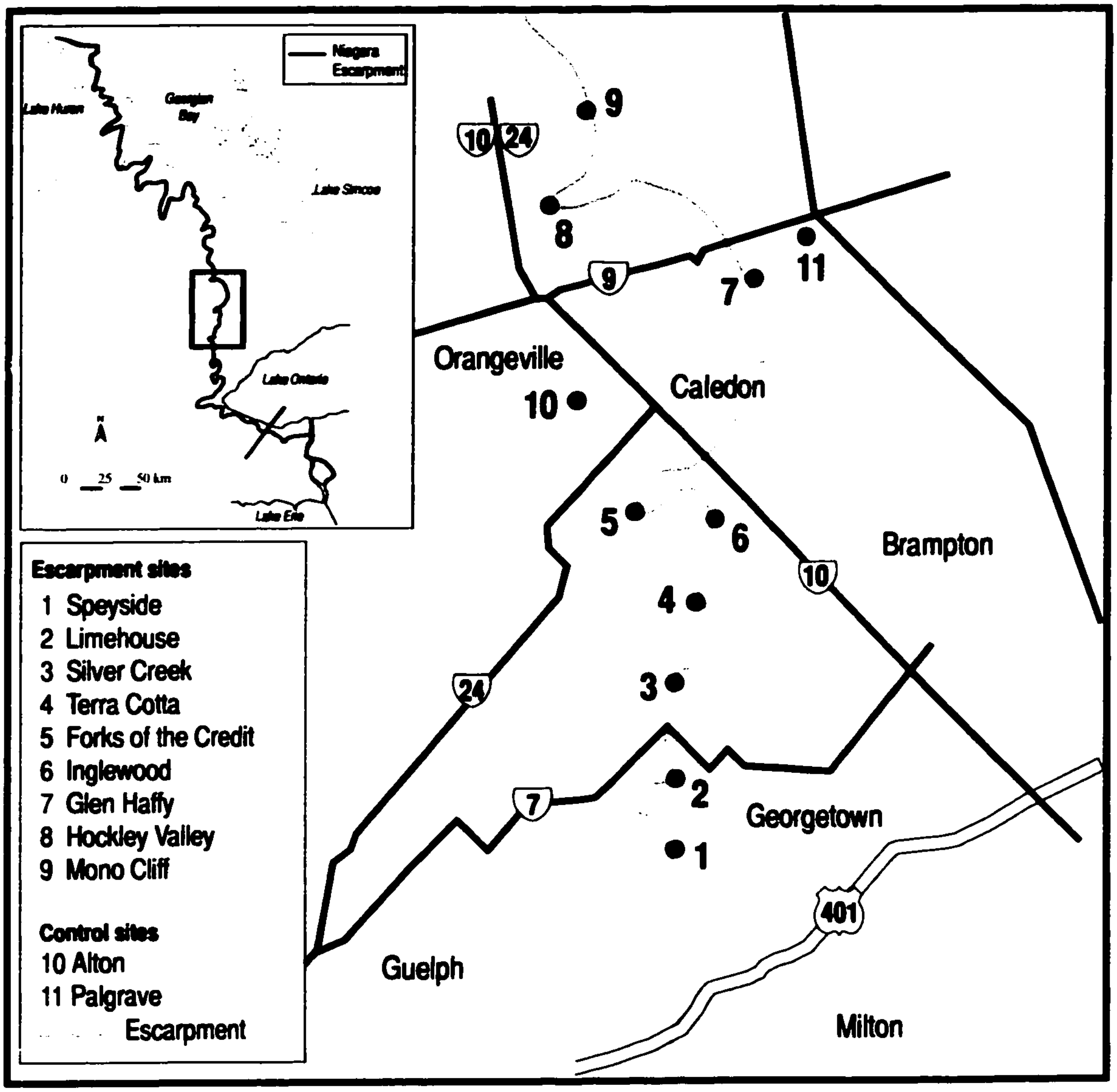


Figure 4.2 Research area and eleven study sites.

region crosses two of the slope system units identified in Figure 3.16. The northern section of the study area is found within the Dufferin Hills unit. There are four study sites, sites 6-9 found in this unit, including Mono Cliffs, Hockley, Glen Haffy, and Forks of the Credit (Table 4.1, Figure 4.2). This area also includes the two control sites at Alton and Palgrave (sites 10 and 11), which are located on deep glacial deposits near the Escarpment. These sites were added to allow for a comparison with land units not located on the Escarpment but which include combinations of land units and land use similar to the Escarpment lands. Alton is located to the west, above the Escarpment along the Credit River, while Palgrave is found to the east of the Escarpment, on a northern lobe of the Oak Ridges moraine. In this unit, the face is predominantly buried by glacial deposits, a complex mantle of glacial and fluvio-glacial deposits which include tills and extensive sand and gravel deposits (OMNR, 1976). Drainage over the Escarpment produces extensive stream valleys that cut deeply through the glacial material, creating slope systems that are almost exclusively type C or rounded slopes, as described in Figure 3.11.

There are several sites where cliff faces are exposed. At Mono Cliffs Provincial Park (site 9), three dolomite-capped outliers are cut off from the Escarpment. A major complex of meltwater channels lies between the Escarpment face and the western end of the Oak Ridges Moraine. This meltwater river system was responsible both for the sand and gravel deposits along the base of the Escarpment and for cutting into the tills which mantled the Escarpment, thereby exposing the cliff face in certain areas (OMNR, 1976).

The southern region begins at the Forks of the Credit Provincial Park and includes all sites south of there, including Inglewood, Terra Cotta, Silver Creek, Limehouse, and Speyside (sites 1-5, Figure 4.2). This section is known as the Caledon Hills region

Table 4.1 Distribution of transects for Escarpment and control land units.

Escarpment Units	Upland Plateau	Slope	Valley
Forks of the Credit		✔	✔
Glen Haffy		✔✔	
Hockley Valley	✔	✔	✔
Inglewood	✔		
Limehouse	✔✔	✔	✔
Mono Cliffs	✔	✔	✔
Silver Creek	✔✔	✔	✔
Speyside	✔✔		
Terra Cotta	✔		
Alton		✔	✔✔
Palgrave	✔✔✔		✔

✔ research transect

(Moss and Milne, 1998) and is a transition region between the rolling hills, or Type C slopes, of the northern Dufferin Hills region and the steep cliff faces, or Type A slopes, of the Halton Escarpment region to the south. In this area are some moderate Type B cliff faces, such as at Silver Creek, and combinations of small, buried vertical faces and rounded slopes, Type C, which dominate the Forks of the Credit Provincial Park (Moss and Milne, 1995).

Unlike the Dufferin Hills region, where large deposits of till cover the bedrock, the southern region has many areas without a deep cover of till, creating an extensive upper plateau to the Escarpment with shallow soils, exposed bedrock, and poor drainage. Several valleys dissect the Escarpment at sites such as Limehouse. These valleys have a different shape than those in the north; they are smaller and not as sharply or deeply incised. The lower elevation and smaller drainage basins, relative to those in the north, lessen the effect of river erosion in the valleys, thereby preserving rather broad "U"-shaped stream valleys (OMNR, 1976).

4.1.1 Rationale for Site Selection

Planning units within the NEP are classified as either natural, protected, rural, urban, recreation, or resource extraction. All of the study sites, except the two not on the Escarpment, are located within Escarpment natural or protected areas, designations which indicate the Escarpment features and associated stream valleys, wetlands, and forests are in a relatively natural state (NEC, 1991). An effort was made to locate sites in forests where human disturbance is minimal. However, this region of southern Ontario has been heavily impacted through agriculture, forestry, resource extraction, and to a lesser but growing extent, through recreation, and it was impossible to locate pristine sites. A number of sites are near trails such as the Bruce Trail, which is used for hiking and in some cases for biking. In general, it was difficult to find a site without some form of human impact. Also most sites are relatively close to areas of land clearance, primarily agriculture, although there are areas with encroaching urban development (e.g., Forks of the Credit). Consequently, it was decided that the low-level impact of human use and land cover alteration would be considered as a component of ecosystem processes. This included sites where recreational activity takes place, as well as instances where plantations have replaced the natural forest cover.

This region of the Escarpment was chosen for several reasons. First, this area offers a variety of land units that are relatively close in geographical distance. Within the study site there are rounded slopes, cliff faces and limestone plains, representing many of the slope types consistently found along the Escarpment. Limiting the distance between sites reduced the potential differences in bird and plant species due to geographical variations. As mentioned, the Escarpment extends 700 km from the Bruce Peninsula to the Niagara Peninsula, a distance great enough to introduce latitudinal variation in species distribution. The Ontario Breeding Bird Atlas reveals that species such as Yellow-bellied Flycatcher (*Empidonax flaviventris*) are restricted to the Bruce Peninsula region; similarly southern species such as Louisiana Waterthrush are located only near the Niagara Peninsula, along the southern section (Cadman et al., 1987).

Secondly, the biophysical system of this area of the Escarpment has not been intensely investigated. There have been detailed surveys of biophysical relationships on the Bruce Peninsula at Barrow Bay (Moss and Nickling, 1980) and Blue Mountain (Milne and Moss, 1988), and on the Niagara Peninsula near Grimsby (Moss and Rosenfeld, 1978), but other than a preliminary overview by Moss and Milne (1995), there have not been any detailed studies of this nature, in this region. An analysis of the biophysical processes of a section of the Escarpment that includes B and C type slopes will improve the understanding of the Escarpment slope system model.

4.1.2 Escarpment Units

A set of one or more land units was identified at each study site, representing units that combine to form the Escarpment slope system. These units include (a) upland plateaus including rims or ridges, (b) faces, and (c) valleys, and will be referred to as Escarpment land units. They represent relatively homogeneous areas with similar general geomorphic and geologic characteristics. The distribution of research transects for each of these units at each study site is presented in Table 4.1 and described in the following sections.

Upland/Rim Transects

In total, 13 transects, which are described in the following section, were established on the upland and rim land units. Of these, nine transects are located on limestone plains and till deposits usually on top of the Escarpment and extending back from the cliff face or slope ridge at least several hundred metres (see Table 4.1). An additional four transects fall into this category at the control sites. Where there is little surface material, a limestone plain dominates with poor drainage and small seasonal ponds are present. These units are a common component of the Escarpment ecosystem in the southern region. A rolling topography, with moderate slopes and small stream valleys, develops in the northern section where the surface material is deeper.

Large cliff faces do not form continuous ridges in the study region, as found on other sections of the Escarpment such as in the Bruce and Niagara regions. Few sites in the area have extensive cliff faces exposed (e.g., Mono Cliff and Silver Creek) and therefore only a few transects are located on this slope type. There are also locations where the ridge of a steep slope forms a distinctive rim, such as at Limehouse. This does not create as distinct a habitat as on large cliffs. Of the 13 transects, three are located along the edge of a cliff or slope crest, and the transect at Glen Haffy is a combination of crest and slope.

Face Transects

There are several types of Escarpment faces found in the study area. Most have an extensive cover of glacial till and exposed layers of shale and clay. On these faces, the slopes are predominantly rounded and are the most active areas of geomorphic processes ranging from small slumps, 10 m^2 in size, to 500 m^2 landslide scars, such as at Silver Creek. In most cases, these sites are more likely to be found where there has been major downcutting by fluvial processes. At Mono Cliffs, where weathering is extensive on the cliff faces, there is a continual addition of talus to the slope which creates open rock slopes with little substrate for vegetation establishment. In all there are eight transects on the slope units. Seven are on the Escarpment face while the eighth is at Alton, on a slope that grades between the upland and adjacent floodplain.

Valley Transect

Many stream channels and re-entrant valleys flow over the Escarpment, creating steep valleys with fast-flowing streams. Typically there is little floodplain, with only small deposits of boulders and gravel on small point bars occasionally reworked especially during spring runoff. At other sites, poorer drainage and lower gradients create slow-moving streams and areas of pooled water. There are six transects including the control sites located along drainage channels (see Table 4.1). Forks of the Credit and Hockley Valley are sites of high-energy streams, while the rest are lower energy. Two sites, at Alton and Palgrave, are located in poorly drained bottomlands.

4.2 Sampling Strategy

A sampling structure was established to provide an objective collection of the biophysical information for the selected Escarpment land units (Figure 4.3). Within the 11 study sites, in most cases several land units were identified that included combinations of upland, face and valley. Within each study site, one to four transects were established within a specific land unit depending on the variation in land units and accessibility at the site. For example, at Inglewood there was only one transect since the site was on private land and the only area with relatively undisturbed forest cover was along the bedrock plain. By comparison, at Silver Creek, where there has been limited land clearance and there are large tracts of forest on public land, four transects were established on the upland plain, rim, face and stream valley. In all, a total of 29 transects were located across the 11 sites. Each transect was divided into a series of stops, usually with four to a transect (Figure 4.3). These stops were the centre for the data collection, including bird, vegetation, and geomorphic characteristics which are described in detail in the following sections. These separate observations could then be averaged to establish an average or more general characteristic for the land units within each research site (Milne and Moss, 1988; Matheson and Larson, 1998). The total lengths of each transect was approximately 500 m but in a few cases there were only three stops because of the limited size of the land unit in which the transect was located. Transect stops was approximately 150 m apart to reduce duplication between the bird records. A number of stops were added at the Speyside, Mono Cliff and Terra Cotta sites (Figure 4.2) to improve the level of information on the forest and geomorphic characteristics.

4.2.1 Variables Rationale

To establish the foundation of the relationships between geomorphology, vegetation and wildlife, it is useful to identify a hierarchy of relationships among the components to assist in structuring the research design. Typically, a number of environmental variables (e.g., slope, aspect, soil texture) simultaneously contribute to a smaller number of major factors (such as moisture or soil fertility), and likewise the distribution of numerous plant and animal species may be determined by these few

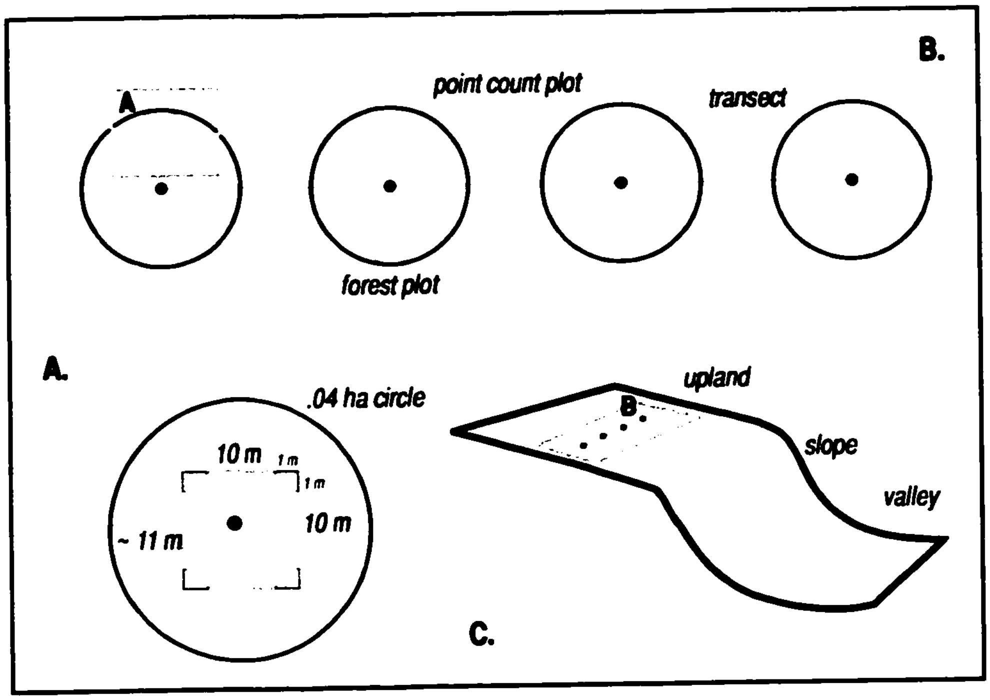


Figure 4.3 Details of survey plots and research transects. A. Close-up of forest plot including tree, sapling and seedling layers. B. Research transect with avian point counts and forest plots. C. Landscape positions of Escarpment land unit transects.

dominant factors. In other words, there often exists a relatively simple set of major factors (or gradients) which effectively summarizes the totality of environmental factors and largely determines species distributions (McGarigal et al., 2000). In this study, the foundation will be the landform-vegetation cover; this system produces the habitat upon which wildlife is dependent. In general, wildlife distributions are dependent on the availability of habitat, food, cover, etc. as well as other species. In some cases, wildlife can be an important control on the structure of the land; however, at the landscape scale, landform is often the dominant control of habitat and, consequently, of wildlife (Bailey, 1996).

In studies that combine vegetation communities and the physical environment, both vegetation and environmental variables have been used to explain patterns of the other component. In many studies, vegetation has been used as an indicator of a site's ability to provide an environment for growth. An example is the site index, defined as an average height of individual dominant trees in the stand at a specified age (Waring and Running, 1998). It is favoured by many forest scientists as a direct and easy method for evaluating site productivity (e.g., McLeod and Running, 1988). However, this measure is limited because it assumes that height growth has not been influenced by stand density or stand history, a situation difficult to confirm (Iverson et al., 1997). The limitation of this approach has been noted by Parker (1982), since it is only applicable in regions where the investigation includes intimate knowledge of plant ecological relationships. Parker recommended that physical parameters be included in the analysis where possible if the final use of the index is to examine plant species or vegetation distributions, since the use of indicator species or composite extremes engenders circularity.

The description or classification of the physical, or more specifically geomorphic, component should include a strategy incorporating the biophysical components of the landscape, including vegetation and wildlife. Consequently, variables that influence or even control the pattern of vegetation and habitat are important. As introduced in Chapter Two, vegetation distribution patterns are a response to the spatial variability of environmental components including water, light, heat and nutrient availability (Parker, 1982; Bazzaz, 1996) or, in general, to the pattern of the micro-environment and geomorphic processes. At the landscape scale, these are controlled by landform pattern and structure. A number of indices have been developed that focus on physical parameters to explain the distribution of vegetation patterns.

4.3 Landform Parameters and Microclimate Environment

For studies at the scale of the landscape, it is convenient to employ inferential techniques, since they can be employed over broader land areas. Inferential techniques are based on topographic/edaphic conditions and have been employed to characterize environmental control patterns for measurements of site-level variables while circumventing the difficulties of direct monitoring of characteristics such as moisture levels (Parker, 1982). Many studies that have established the micro-environment of slope systems have utilized topographic variables to indirectly measure moisture and temperature controls. A number of authors have employed inferential techniques, based on measurable slope or soil characteristics, which can be modified to provide an index along which individual sites may be ordered. This can range from ordering of topographic positions (e.g., draw/cove, north-facing slope, south-facing slope, ridgetop) to complex scalar indices which combine a series of variables to yield a single measure of site conditions (Parker et al., 1992; Iverson et al., 1997).

Slope angle, aspect, and position have been combined in various ways to relate to vegetation patterns (e.g., Host et al., 1987; Lloyd et al., 1994). Fralish (1994) found a strong relationship between stand basal area and slope angle, aspect, slope position, and effective soil depth for forests in southern Illinois. This association was related mostly to the amount of water in the soil-water reservoir. Some of the best research in environments similar to the Niagara Escarpment is from the Appalachian region of the United States (e.g., Hack and Goodlett, 1960; Ware et al., 1992; McNab, 1993). Iverson et al. (1997) developed an integrated moisture index consisting of four factors based on topographic and edaphic characteristics. These included hillshade (related to landscape position and aspect), curvature (slope shape), flow accumulation (slope position) as well as a measure of the total water-holding capacity of the slope material. Parker (1982) introduced the Topographic Relative Moisture Index (TRMI) to quantify relative available moisture as dictated by topographic features. It is a scalar index determined by summing assigned values for topographic position, aspect, slope configuration, and steepness.

Table 4.2 presents a summary of these studies, which identifies the landform characteristics that were the focus of measurement and the inferred environmental variables. This table also includes the terminology used in the specific paper and the form of measurement. From the literature it was apparent that the common factors used in developing general biophysical relationships in slope systems are usually some combination of slope angle, slope aspect, site position, landscape position and in some cases, elevation. Other variables can include specific measures of the soil environment

Table 4.2 A comparison of landform and slope variables from recent literature. The table includes variants of terminology applied to the characteristics, the application of the variable as well as a description of the measurement characteristics, including the type of data and related indexes.

Landform Characteristic	Alternative Terms	Related Variable	Measurement	Data Type*	Index	Authors
Slope Angle	angle	stand basal area	degrees,	ordinal (11)	none	Fralish et al. (1991)
	steepness	available moisture	degrees,	ordinal ()	Topographic Relative Moisture Index (TRMI)	Parker (1982)
	average maximum slope gradient	forest ecological types	percentage	continuous	none	Odom and McNab, 2000
Slope Aspect	hillshade	forest composition	?	?	Integrated Moisture Index (IMI)	Iverson et al. (1997)
	aspect	stand basal area	degree azimuth	ordinal (8)	none	Fralish et al. (1991)
	aspect	forest ecological types	degree azimuth	ratio	none	Odom and McNab (2000)
	aspect	available moisture	degree azimuth	ordinal (20)	TRMI	Parker (1982), Cowell and Gallien (1997)
Site Position	slope configuration	available moisture	classification, concave - convex	nominal (5)	TRMI	Parker (1982)
	terrain shape	forest ecological types	index	ratio	terrain shape index	Odom and McNab (2000)
	curvature	forest composition	classification, convex - concave	nominal (3)	IMI	Iverson et al. (1997)

Landscape Position	flow accumulation	forest composition	?	?	IMI	Iverson et al (1997)
	slope position	stand basal area	classification, ridge - terrace	nominal (10)	none	Fralish et al. (1991)
	topographic position	vegetation distribution	classification, floodplain - flat upland	nominal (5)	none	Cowell (1991), Cowell and Gallien (1997)
	landform position	forest ecological types	classification, ridge - cove	nominal (3)	landform index	Odom and McNab (2000)
	topographic position	available moisture	classification, ridge - valley	nominal (5)	TRMI	Parker (1982)
	slope position	species distribution	classification, ridge - lower slope	nominal (3)	Solar Radiation Stress (SRS)	Rochow (1972), Nigh et al. (1985)
	slope declivity	soil moisture/vegetation	classifcation, nose - cove	nominal (3)	none	Hack and Goodlett (1960)
Elevation	elevation	forest ecological types	metres	ratio	none	Odom and McNab, 2000
Disturbance	disturbance	forest communities	descriptive	?	none	Hack and Goodlett (1960)
	land use	forest communities	classification farmed - unfarmed	nominal (2)	none	Cowell and Gallien (1997)
	disturbance	species distribution	classification, grazing - logging - fire	nominal (3)	none	Nigh et al. (1985)

* if nominal or ordinal data, number in brackets represents the number of categories or ranks

such as soil depth, or disturbance regimes. For this study, it was decided to employ the first five characteristics. Differences in elevation were minimal in this study and not relevant to the focus of the paper. Detailed analyses, such as soil characteristics were also ruled out, because the nature of the Escarpment slope system creates complex soil and surface material layers that vary considerably over short distances (Milne, 1982). Soil variables could be considered for more intensive, site level studies, but this was beyond the scope of this paper. Similarly, the role of geological controls is recognized as an important control in Escarpment land systems. Characteristics such as the pattern of bedrock stratigraphy, the direction of groundwater flow and the rates of bedrock weathering will all influence the vegetation communities and wildlife habitats at individual sites. For this study, it was decided that many of these controls can be inferred by the topographic measures identified earlier and that the landform reflects the long-term response to the geological environment. These could also be determined in site level studies.

The five landform parameters, slope angle and aspect, site and landscape position, and slope type, were combined with qualitative measures of natural and human disturbance. This combination of variables provides coverage of the micro-environment, geomorphic processes and the general landform.

4.3.1 Slope Angle

The angle (ANGLE, the bolded titles refer to codes used in the statistical analysis) of the slope was measured at each stop along the transect using an abney clinometer. Several measurements were made at each stop to ensure that the average slope was determined. An average angle was recorded for each stop, which was then averaged with the angles for all the stops to determine the general slope angle. The angle was then scaled into indices of steepness that were divided into increments of 3° starting at 0°, as described in Parker (1982). These categories are presented under *Slope Angle* in Table 4.3. Parker used a scalar index to infer the effect of various slope parameters on the hydrology of the site. Therefore lower slopes would score higher since more moisture would likely be captured and less runoff would occur on these slopes. Parker (1982) used these scores as part of a comprehensive index, as mentioned earlier, the TRMI. In this study, each variable is considered separately but the scoring system has been retained to provide a ranking for the ordinal data used in the interpretation of vegetation and bird association patterns.

4.3.2 Slope Aspect

At each stop a measurement of the cardinal direction of the slope face or aspect (AZIMUTH) was determined using a compass. As with slope angle, the average of the aspect was established by taking a number of readings at each stop. From these measurements an average azimuth was determined for each transect. The azimuth for the transect was then divided into twenty categories, following the scale identified by Parker (1982). The divisions of these categories are presented as *Slope Aspect* in Table 4.3. These divisions indirectly measure the effect of aspect on micro-environmental processes such as the moisture level and evaporative effect of exposure to sunlight. The categories equally divide sites between dry SSW-facing slopes of high solar radiation incidence to wetter sites on NNE-facing slopes (Parker, 1982). This pattern of categories, which is slightly skewed from N-S, alleviates the problem of studies (e.g., Frank and Lee, 1966) which assign similar values to E-W-facing aspects (Nigh et al., 1985). Site water stress is

Table 4.3 Land system variables and division of rank and assigned scores

Landscape Position:		***Slope Type***:		***Slope Angle*** (degree):	
valley bottom	5	slope type A	1	< 3.0	10
lower slope/valley	4	slope type B	2	3.0 to 5.9	9
slope	3	slope type C	3	6.0 to 8.9	8
ridge/rim	2	other	4	9.0 to 11.9	7
upland	1			12.0 to 14.9	6
				15.0 to 17.9	5
Site Position:				18.0 to 20.9	4
concave slope	4			21.0 to 23.9	3
straight slope	3			24.0 to 26.9	2
convex slope	2			27.0 to 29.9	1
plain	1			> 30.0	0
Aspect (degrees azimuth):					
19 - 26	20	81 - 89; 316 - 324	13	144 - 152; 253 - 261	6
27 - 35; 10 - 18	19	90 - 98; 307 - 315	12	153 - 161; 244 - 252	5
36 - 44; 1 - 9	18	99 - 107; 298 - 306	11	162 - 170; 235 - 243	4
45 - 53; 352 - 360	17	108 - 116; 289 - 297	10	171 - 179; 226 - 234	3
54 - 62; 352 - 360	16	117 - 125; 280 - 288	9	180 - 188; 217 - 225	2
63 - 71; 334 - 342	15	126 - 134; 217 - 279	8	189 - 197; 208 - 216	1
72 - 80; 325 - 333	14	135 - 143; 262 - 270	7	198 - 207	0

Natural Disturbance:		***Human Disturbance***:	
no noticeable material movement/creep	1	no evidence	1
treefall/sheetwash	2	foot path	2
small cliff/slumps/rockfall/seeps	3	trails/grazing/small plantings	3
blockfall/slides/fluvial action	4	non-managed plantation	4
permanent scar/talus/cliff face	5	selective logging/manage woodlot/plantation	5

generally higher on W-facing aspects because of the higher air temperatures associated with direct afternoon insolation (Geiger, 1965).

4.3.3 Site Position

Slope position (SITEPOS) is the shape of the slope at the stop. This is different from the overall shape of the landform, which is identified as the landscape shape and is discussed in the next section. Various authors have divided the slope position into shape units which range from convex or water-dispersing slopes to concave or water-collecting slopes. Parker (1982) divided the slope configurations into the following categories: (a) concave; (b) concave/straight; (c) straight; (d) convex/straight; and (e) convex. A terrain shape index (TSI) has been employed to characterize slope shape in the Southern and Central Appalachians (McNab, 1993; Ford et al., 2000; Odom and McNab, 2000). The TSI quantifies plot surface shape as a continuous variable, but in general the slope ranges from convex to concave shape. Nigh et al. (1985) recognized the importance of site and landscape position on soil moisture. Lower slopes, those more likely to experience concavity, are typically more mesic than upper slopes because they experience more shading, receive sub-surface drainage and runoff, and are the sites of cold air drainage.

In this study the shape of the slope was visually determined at each stop by observing the general shape of the land in all directions - upslope, downslope and cross slope - from the centre of the stop. The slope shape was then identified as either (a) plain or flat surface, with a slope less than 3°; (b) a rounded, convex slope; (c) straight slope; or (d) inwardly rounded, concave slope. These were assigned to categories with the convex sites ranked the lowest to recognize the negative impact on moisture conditions. These categories are presented under the title *Site Position* in Table 4.3.

4.3.4 Landscape Position

Landscape position (LANDPOS) is a measure of the location of the stop with respect to the pattern of landform. In larger slope systems, landform components can be divided into five land units: an upper plain; the crest of the slope or the rim of the cliff face which could also be described as the convex portion of the slope; the slope itself, mainly the straight section of the slope; the base of the slope or the concave section of the slope, which in the Escarpment landscape usually includes a small stream channel with restricted or no floodplain; and finally expanded, extensive floodplains and river channels. Parker (1982) divided the slope into five components that were focused only on the slope and did not include the upland beyond the ridge/rim. The categories of topographic position included valley bottom, lower slope, middle slope, upper slope, and ridge top. Cowell (1993) recognized topographic position as floodplain, lower slope, mid-slope, upper slope, or flat upland; these were included in the analysis as nominal variables. McNab (1992) developed a field method for quantifying mesoscale landform described as the Landform Index (LFI). LFI characterizes the plot location or landform type as an indicator of exposure to solar radiation, wind, and other biological and meteorological factors. The index is based on landscape features that confine the view of the horizon and is measured as the average vertical gradient to the topographic horizon (Odom and McNab, 2000). From this work, three landform types were identified: ridge, slope and cove. Cove is a term often used in conjunction with landforms of the Appalachian Mountains and refers to a smooth-floored, somewhat oval valley sheltered by hills or mountains. These three landform types are comparable, at a larger scale, to the landforms that occur within the Escarpment.

For many sites within the study area, slope segments of the face were relatively short and not easily separated into more than three segments; it was decided to use a condensed version of Parker (1982) and Cowell (1993), similar to the measurement employed by McNab (1992). Three slope segments were identified: the convex or cliff rim, the straight slope segment, and the valley bottom or convex segment. However, to accommodate the extended landscapes beyond the immediate Escarpment rim, several other categories were added - upland and valley - representing those sites away from the ridge and valley at the base of the slope or nestled within a V-shaped valley as found in high-energy streams flowing over the Escarpment. Landscape position was determined at each stop and a general classification was developed for each transect. These units were also ranked from upper to lower units to include the moisture factors as described in the last section. The categories are presented under *Landscape Position* in Table 4.3.

4.3.5 Slope Type

Transects were also classified by slope type (LANDUNIT). This was completed to provide a comparison between the slope types and landform characteristics and land-shaping processes. This classification is based on previous terminology introduced in Moss and Milne (1995) as described in section 3.5. All transects recorded within one study site were considered as part of the same slope type. For example, the upland, slope and river valley at Hockley Valley are all considered as members of slope type C unit. The categories and corresponding land unit types are presented as *Slope Type* in Table 4.3.

4.4 Geomorphic Processes and Disturbance Measures

Site-specific studies on the Escarpment illustrate the spatial and temporal relationships between forest dynamics and geomorphic processes (Moss and Rosenfeld, 1978; Moss and Nickling, 1980; Milne and Moss, 1988). These authors identified the importance of geomorphic processes in promoting local succession which serves to regenerate the forest system. However, within these studies the role of human disturbance to the forest cover was not considered. Much of the work on Escarpment ecosystem processes has focused on natural land cover in less disturbed sections of the Niagara Escarpment Plan, with the exception of work on the impact of rock-climbing (Kelly, 1996) and larger-scale land use practices (e.g., Milne and Moss, 1996).

Qualitative measures of natural and human disturbance are introduced in this study. The human disturbance measure is not meant to capture all levels of disturbance existing within the realm of the Niagara Escarpment Plan. There are obvious, major disruptions to land and vegetation cover, such as housing developments and quarries, not considered within the scope of this work. The intent is to consider the impact of humans on the natural systems within the natural and protected areas of the Escarpment. Specifically, the focus is on change to vegetation cover in public lands, impacts such as plantations and trails, land clearance and abandonment, or natural regeneration.

4.4.1 Human Disturbance

Compared to the previous variables, it is much more difficult to establish a detailed measurement of disturbance at each stop, especially a measure that can be completed within a similar time frame as the previous variables. Several authors have attempted rudimentary assessments of disturbance but these are limited to identifying nominal categories without ranking the disturbance level (e.g., Nigh et al., 1985; Cowell and Gallien, 1997) (see Table 4.2). More recently, Canterbury et al. (2000) have developed a qualitative ranking of disturbance levels in southeastern pine forests. They identified five levels of disturbance by forestry operations ranging from no disturbance to foot trails, selective logging and recent clearcuts.

In this study, a measure of human activity (HDISTLEV) was determined at each stop based on the extent to which natural vegetation cover has been disrupted. This included current processes as well as evidence of previous impacts such as forest removal and subsequent establishment of pine plantations, and was based on the present vegetation cover - previous changes were not determined beyond the current cover. The categories are listed in Table 4.3 under the heading *Human Disturbance*. The first level had no obvious impacts or little evidence of any impact. Level two included low-level disturbances such as the presence of a foot-trail system, in most cases the Bruce Trail, which usually has low to moderate levels of foot traffic. Level three included disturbances such as a larger trail system which allowed vehicular traffic (e.g., bikes, all terrain vehicles), or evidence of selective logging. The fourth level included forest clearance and subsequent replacement, by units such as abandoned fields, successional forests or older plantations that were naturally regenerating. Finally, the fifth level included sites with large tracts of monocultures, such as managed plantations or crops.

4.4.2 Natural Disturbance and Stress

Within the scope of this project, it was impossible to conduct a long-term study that would establish the details of the magnitude of geomorphic processes (NDISTLEV) acting on these slopes. It was, however, possible to qualitatively assess the extent and magnitude of disturbance of these processes and assign a relative importance to each transect. As with human disturbance, an assessment of physical processes was completed at each site based on visual evidence or a qualitative measure of current and historical environments. A scale was developed to measure the impact of the processes at the site. Five categories typical of geomorphic environments found on the Escarpment were identified, ranging from soil creep and sheetwash to landslides and blockfall. These categories represent, at a minimum, different land-shaping processes that dominate the site. However, they can also be a measure of increasing magnitude of disturbance or stress as well as, in some cases, the spatial extent of the impact. These divisions also represent a range from low- to high-energy events. The five categories are described under *Natural Disturbance* in Table 4.3. The first category has the least amount of disruption to the ground cover, soil structure and vegetative cover. This includes sites on plains that experience limited waterflow over the soil surface or soil creep. Category two includes areas where there is more extensive sheetwash and soil creep; there is obvious movement of material across the land surface as would be found on steep slopes with little groundcover. It also includes sites with frequent treefall and related material movement, as well as sites with seasonal ponding such that species preferring wet conditions are prevalent and there is a build-up of sediment in the depressions. The third level includes small areas of tree blowdowns greater than single treefall. This category also includes small debris slides (10 m^2) which pull away from the slope surface and in the process knock down a small number of trees to expose the underlying till or bedrock surface. The fourth level includes sites that have experienced disruption from high flood events where the channel material has been reworked or deposition of gravel and boulders has taken place. It also includes sites of large landslides, but specifically those where there is evidence of regeneration, high resiliency sites and cliff sites with a moderate amount of talus deposition. Finally, the fifth level includes sites with cliff faces or exposed bedrock, slopes with a large build-up of talus, or sites with extensive blockfall or debris slides where the scar surface is a stressful environment and regeneration is limited.

4.5 Vegetation Analyses

There are two purposes of research for the vegetation cover: to establish the nature of the forest ecosystems of the different Escarpment units; and to determine the forest characteristics relevant to avian habitat. To achieve this requires information on both the composition and physical structure of the vegetation cover. Compositional measures include the basal area, density and frequency of all trees, saplings, and shrub species. Structural measures include measures of canopy cover, ground cover, snags, and ratios of deciduous to coniferous cover. This information was obtained from measurements at plots located within the point-count stops of the bird observations (Figure 4.3c). In total, 127 plots were established and measured.

4.5.1 Vegetation Plots

Since one of the main objectives of this work was to compare forest patterns to distribution of avian populations, the vegetation plots were designed to provide information relevant to avian habitat. As such, this analysis followed procedures developed for determining breeding bird habitat as described in James and Shugart (1970). This methodology has been employed extensively to detect the habitat relationships of bird populations (e.g., Mehlhop and Lynch, 1986; Goguen and Mathews, 1998; Wiebe and Martin, 1998).

A forest plot was established at each stop along the 29 transects. This plot was a .04 hectare circular plot (11.3m in radius, Figure 4.3), a plot size used in forest composition research (e.g., Nigh et al., 1985; Fralish et al., 1991; Cowell and Gallien, 1997). The plot was located, to the left or right of the transect at a distance of either 5, 10, 15 or 20 metres depending on a random selection of distance. If there were obvious signs of recent human disturbance, such as trails or logging, the plot was located beyond this disturbance. To obtain measures of the lower strata of the forest, smaller plots, 10 x 10 m squares, were established within the perimeter of the larger circle. Situated at the corners within this square were four smaller squares, 1 x 1 m in area (Figure 4.3c). These smaller plots were used to measure percent ground cover and the frequency and density of tree and shrub seedlings.

4.5.2 Forest Composition

Each species was identified within the dominant forest strata including tree, sapling and seedling and measured for size to provide an estimate of changes in vegetation dominance over time. From this data, importance values were determined for each species to provide a relative measure of their role within the forest communities. These values were based on measures of abundance, density and frequency of species.

Trees, Saplings, and Seedlings

All stems within the .04 ha plot were identified by species and measured for diameter at breast height (dbh). Trees were distinguished from smaller saplings as stems greater than 4 cm. The tree stems were divided into older stems, greater than 10 cm, and younger stems, those between 4 and 10 cm dbh. Often, 10 cm dbh is used as an identifier of dominant forest communities (e.g., Fralish et al., 1991; Ware et al., 1992; Cowell and Gallien 1997; Odom and McNab, 2000).

Saplings were identified by species and as stems smaller than 4 cm dbh, but greater than 1.5 m in height (Ware et al., 1992). Only the sapling stems found within the 10 x 10 m plot were counted. Other measurements within the 10 x 10 square included ground cover and the presence of all herbaceous species, tree seedlings and shrubs. To provide a more detailed measurement of the youngest component of the forest system, species composition and density of seedlings were identified within the 1 x 1 m plots.

Importance Values

The species data from each stop were converted to importance values, which allowed for a standardized comparison between species and transects. Importance values are often a combination of density, basal area and frequency and calculated as the sum of the relative values for a species for each of those parameters (Greig-Smith, 1964; Mueller-Dombois and Ellenberg, 1974). However, any one of the three parameters can be used depending on which the investigator considers most important (Whittaker, 1975). Recent studies investigating large-scale patterns of forest composition have created importance values that combine density and dominance or basal area (Cowell and Gallien, 1997; Odom and McNab, 2000). For this study, an importance value based on two parameters, dominance and density, was calculated for each transect. Since there were only three to five stops on any one transect, it was decided that there were not enough samples to adequately represent frequency and its inclusion would tend to dampen the results. However, when the transects were later placed in groups, identified by the cluster analysis, importance values were recalculated to reflect the contribution of each species to the forest association groups. In this calculation, frequency was included to provide a better measure of the importance of each species.

Importance values were calculated based on the following equations (Greig-Smith, 1964). Stem density was calculated as the number of individual stems of each species recorded in the .04 hectares plots. Therefore, total stem density can be expressed as:

$$SDt = sd_{s1} + sd_{s2} \ldots sd_{sn}$$

where SDt is the total species density and sd is the density of each species. It follows that the relative density for each species can be considered as the percentage of each species density to total stem density and can be expressed in the following equation:

$$\text{Relative Density} = \frac{sd_s}{SD_t}$$

The second measure was forest cover. Cover is indirectly measured as the dbh of the species and the total cover would be the total of all dbhs recorded for all species within all plots on the transect. Total cover is expressed as:

$$Ct = c_{s1} + c_{s2} \ldots c_{sn}$$

where Ct is the total cover and c_s is the dbh for a specific species. Relative cover can be determined by calculating the percentage of a species cover to the total cover of all species at the stop.

$$\text{Relative Cover} = \frac{c_s}{C_t}$$

In the first assessment, relative cover and relative density were summed and recalculated to provide composite species importance values as a score out of 200 for each species (Ware et al., 1992; Cowell and Gallien, 1997; Odom and McNab, 2000).

$$\text{Importance value} = \text{relative density} + \text{relative cover}$$

In the assessment of the combined forest association groups, importance values were recalculated as the summation of three measures: density, cover, and frequency (Greig-Smith, 1964).

Importance value = relative density + relative cover + relative frequency

Relative frequency can be determined for each species as a measure of the frequency or the number of plots in which the species was recorded. The frequency for each species was summed and recalculated as a total out of 100 to obtain the relative frequency. Total frequency is measured as the number of recorded events for each species.

$$Ft = f_{s1} + f_{s2} \ldots f_{sn}$$

where Ft is the total frequency and f_s is the frequency of each species. Relative frequency can be expressed as the percentage of a species frequency to a total frequency for all species recorded over the transect.

$$\text{Relative Frequency} = \frac{fs}{Ft}$$

4.5.3 Forest Structure

A number of measures of the physical nature of the forest or vegetation structure were developed as important habitat variables as well as biological indicators of landform units. Structural indicators of forest cover are more easily obtained at the scale of the land units and for studies at the planning scale than detailed compositional measurements. These structural characteristics were also considered as possible indicators of disturbance and geomorphic activity. Some of these variables could be applied directly from the field data such as the percent of canopy cover (CANCOVER, the bolded titles refer to codes used in the statistical analyses), ground cover (GRCOVER), the density of snags (SNAGS), and density of older and younger stems (OLDSTEM and YOUNGSTEM). Other variables required standardization measures including age ratio (AGE RATIO), multiple stem density and cover (MULTINUM and MULTIBAS), and the percentage of deciduous cover to coniferous cover for both old and young stems (OLDDEC and YOUNGDEC).

Age Ratio

The forest cover was divided into two age classes: younger stems between 4 and 10 cm dbh and older stems greater than 10 cm dbh. This is a typical division of tree age structure (e.g., Fralish et al., 1991; Ware et al., 1992; Cowell and Gallien, 1997; Odom and McNab, 2000). Age ratio (AGERATIO) was developed based on the number of stems greater than 10 cm divided by the total number of stems greater than 4 cm, in other words the total number of trees.

$$\text{Age Ratio} = \frac{\#\,\text{stems} > 10\text{ cm}}{\#\,\text{stems} > 4\text{cm}}$$

This ratio can be used as a preliminary measure of forest dynamics; if there is a high ratio, the forest is older and has likely achieved some level of equilibrium.

Deciduous/Coniferous Ratio

Often wildlife species' presence/absence is a function of the type of vegetation cover. General distinctions have been made between the importance of deciduous or coniferous cover for bird populations (Mills et al., 1991). A ratio of deciduous to coniferous forest was determined by dividing the sum of the deciduous stems by the total number of stems for the plot. A ratio was calculated for both age classes.

$$\text{Old Deciduous ratio (OLDDEC)} = \frac{\#\,\text{deciduous stems}(>10\text{ cm})}{\text{total }\#\,\text{stems}}$$

and

$$\text{Young Deciduous ratio (NEWDEC)} = \frac{\text{\# young deciduous stems (>4 and <10 cm)}}{\text{total \# young stems}}$$

Snags

A large number of wildlife species in eastern deciduous forests require large snags (SNAGS) or wildlife trees for a variety of functions, perching, foraging, nesting, roosting and denning and are an essential component of an undisturbed forest system (MadDonald, 1992; Keddy and Drummond, 1995). All upright dead trees or snags greater than 4 cm were recorded within each plot. The snag was determined to be upright if it was at an angle roughly 45° or greater to the forest floor. Density was determined as the number of snags within the plot.

Ground Cover and Canopy Cover

Within each of the 1 x 1 m squares, a measure of the percent of ground covered by vegetation lower than .5 m was completed. The average of ground cover (GRCOVER) was determined for each plot. Similarly, a measure of the extent that the canopy covered the understory was estimated visually within the 10 x 10 m squares. Canopy cover (CANCOVER) was estimated as a percentage of canopy.

Multistems

A distinction was made between single and multiple stems for measurement. Tree stems were identified in the field as either a single or multiple stem. A multistem was identified as two or more stems originating from near the base of the tree trunk. To be consistent this was interpreted as any stems originating from the same base or obvious root system. It is proposed that forests with a higher number of multiple stems may be more indicative of disturbance from geomorphic processes, wildlife or humans. Impacts from browsing, debris slides, rock impacts and similar processes will disrupt the main stem and could promote the growth of multiple shoots. This was calculated as the density of multistems (MULTINUM) as well as a measure of the total dbh of all the stems (MULTIBAS).

A ratio of multistems to single stems was determined by dividing the number of multistems by the total number of trees. In this case each grouping of stems was considered one tree.

$$\text{Multistem ratio (MULTINUM)} = \frac{\text{\# multiple stems}}{\text{total all stems}}$$

Multiple stems were also evaluated by the dominance in the forest cover. By calculating the dominance total a stronger representation of the forest cover occurred. Each multiple-stem trunk was measured and the total number divided by the dominance for the entire transect.

$$\text{Multibasal ratio (MULTIBAS)} = \frac{\text{cover of multiple stems}}{\text{total cover all stems}}$$

4.6 Avian Richness and Abundance

To develop an understanding of the avian component of these systems, a record of the species utilizing each of the land units or habitats was required. This included use of the site for nesting, feeding, territorial protection and so on. Given the scope of the project, this was best accomplished with a general description of the species that utilize the site; therefore it was decided to focus on those species using the site during the breeding season, a time when birds are most active both visually and vocally. It is also the time when a higher diversity of species, including many neotropical and short-distance migrants, occupy the forest, and when the bird populations are more stable compared to periods such as fall and spring when migration introduces larger abundances and diversity to the forest system on a very irregular basis. Breeding birds are also important from a conservation perspective; the long-term decline in their population levels has generated considerable concern for understanding and managing population trends and habitat to reduce or reverse these declines (e.g., Rappole, 1996; Askins, 2000).

4.6.1 Point Count Census

Point count censuses were conducted following standard procedures (e.g., Verner, 1985; Ralph et al., 1993). In general, it involved an observer identifying the species and recording all birds observed within a circular plot during a set time period (Bond, 1957; Edwards et al., 1981). This method was determined to provide the best analysis for this type of study for a number of reasons. It allows the observer enough time without human disruption to determine species use of the land unit, for instance their foraging or nesting behaviour, but at the same time a number of stops can be sampled within one period, the early morning, thus eliminating possible differences in data if transects at one site were sampled over several days. The territorial or spot-mapping method was considered as an alternative, especially to obtain detailed information of species use in land units that had a high spatial variability of habitats such as the talus slopes. However, it was decided that it would require too much time to complete for the scope of this study and it was more applicable to studies of a limited number of relatively small tracts of habitat (Edwards et al., 1981). The transect technique was also considered unsuitable for this study, as stationary observers spend more time searching for birds and there is less impact on bird activity leading to better estimates of density (Reynolds et al., 1980; Anderson and Ohmart, 1981).

Dawson (1981) warns of using the transect technique in rugged terrain since the time required to move along the transect will affect the results and since more observation time may be spent at sites with more difficult terrain. It also increases the observer's concern for personal safety and decreases focus on accurately detecting and recording distances to birds. Only a portion of the study sites were on flat surfaces and along established paths. Therefore, it was decided the circular plot technique would provide a better census of the slope transects. Finally, the point-count technique was most similar to the protocol of the Forest Bird Monitoring Program and it was decided to obtain data that could be compared in future studies.

There are several approaches to the point count method: the undefined count or the fixed area count. It was decided to use the fixed count at a distance of 50 m. The undefined count, which is a record of all birds identified at the stop regardless of their distance, would cause an overlap of species recorded within different habitats related to the slope systems as well as between stops. Since many of the sites had several transects located within the area and were often established parallel to each other along the slope, this increased the chance of a species being recorded in the count from a different land unit. This strategy would be effective in more homogenous habitats. The fixed area allows for a stronger delineation between transects and assigning a habitat to specific species. This does not suggest that species do not move between sites; movement does occur and when possible this is recorded in the data. This added to the understanding of species' use of these heterogeneous landscape systems.

4.6.2 Survey Times

The data set includes records of bird populations for four breeding seasons, from 1996 - 1999. The 29 transects were sampled at least once every four to six weeks, starting in spring from late May to August. This time period covered the end of spring migration and the few late migrants were distinguished from breeders. The period at the end of July and early August preceded the beginning of fall migration but there was some evidence of pre-migration flocking and dispersal of young birds.

Surveys were conducted between the hours of 5:00 and 10:00 am. Research has shown that the first two hours following sunrise are the most active for vocalisation and that it gradually declines as the morning progresses (Robbins, 1981a). Variations between sites were minimized to ensure similar data sets. It was important to complete the survey of all transects of the entire site during one visit; as several sites had four transacts this required approximately four hours to complete, and consequently not all transects could be surveyed at the peak vocal times. Therefore, the order in which the transects were sampled was varied between visits to ensure that all transects were sampled during the peak hours a similar number of times. Surveys were only conducted during periods with similar weather conditions, which preferably included clear skies and low wind conditions (Robbins, 1981b).

At each stop all species and their relative abundances, populations relative to one another, were recorded for a duration of 12 minutes (Scott and Ramsey, 1981). This length of time was considered sufficient to obtain a representative sample; shorter sample periods have been criticized (Anderson and Ohmart, 1981). Scott and Ramsey (1981) estimated that about 80% of species recorded in a 32-minute survey were detected within the first 10 to 12 min. This included 10 minutes of undisturbed observation in which the researcher remained still at a count point. Several additional minutes were added at the beginning of the count period to allow for the birds to settle down from the disturbance of walking along the transect. However, any species that were flushed or silenced by movement of the researcher as the stop was approached were included in the record (Hutto et al., 1986). Any species observed by sight or sound within a 50 m radius of the point were recorded. Using auditory signals to obtain population estimates has several advantages. Birds are disturbed less and relatively few observers can cover a substantial area to obtain a large number of observations rather inexpensively even when the density of a species is low (Bull, 1981). Notes were also taken on behaviour and breeding evidence such as defending territory, foraging, and nest-building.

The plots were established 150 metres apart to avoid overlap between stops. However, bird movement can circumvent this strategy. Whenever a bird was observed moving between stops, it was recorded as the same species to accurately estimate relative bird abundance (McGarigal and McComb, 1992). Visits were made by two observers for the entire sample period. Each observer's effort was distributed relatively equally among all sample points to avoid systematic observer bias in the comparison of different sites and land units. When possible both observers completed a single transect. This allowed for a better determination of the movement of the individuals between sample stops and reduced the possibility of double-counting an individual.

4.6.3 Importance Values

A data set was developed based on importance values for each species at each of the 29 transects. As with the vegetation data, importance values were determined by the combined observations for all species at each stop along a transect, so the importance value was based on the number of individuals combined for all observations for all stops along each of the 29 transects. In this case, the importance value is a combined measure of the relative scores of density and frequency. Abundance is measured as the average number of individuals for each species recorded over the study period at each stop.

$$At = a_{s1} + a_{s2} + \dots a_{sn}$$

An average abundance was calculated based on the number of visits to the site which could range from six to ten visits (e.g., Goguen and Mathews, 1998). The average abundance for each species was then summed and recalculated as a percent of 100 to obtain a relative score for each species, as described earlier for the forest association groups. However, unlike the vegetation importance values, only two measures were used to calculate the IV for bird species: abundance and frequency. There was not a comparable measure for basal area or cover.

Relative Density = Density species/summation of species x100

Similarly, a relative frequency for each species was calculated by determining the number of visits in which the species was observed and the raw score of number of records out of the total visits. The frequency for each species was summed and recalculated as a total out of 100 to obtain the relative frequency.

RelF = Frequency species/summation of all frequencies x100

Finally, the relative frequency and relative density were summed and recalculated as a score out of 100 for each species.

Importance Value = Relative Density + Relative Frequency

4.7 Data Assessment

Following the establishment of species and environment data sets several statistical analyses were completed to provide a better understanding of the patterns and relationships between different components of the data sets. Specifically, these assessments developed a better understanding of the relationships between the vegetation and biophysical processes that influence forest dynamics; the relationships between the avian component and the biophysical processes; and classification of land units to emphasize the variation in these biophysical components. The analyses included cluster analysis of the data sets of vegetation and avian species. This grouped the transects based on similarities between the sample characteristics, such as species importance values. This analysis aided in establishing functional groups representative of Escarpment units, related to combinations of geomorphic and vegetational characteristics. Secondly, the biotic data were compared to the environmental data, and in the case of the avian populations, to the combination of geomorphic and vegetation characteristics, to discern relationships or controlling factors in these populations.

Several approaches were applied to explore the various interrelationship. These analyses included ordination and discriminant analyses comparing all species independently to their correlation to environmental variables. In the discriminant analysis a comparison was completed between the combined scores of each classification group, to compare between group variance. It was also important to complete a correlation analysis of the vegetation species to landform characteristics to establish the controls in the distribution and development of species associations. This included completing an ordination analysis of the vegetation and bird data with environmental variables. Finally, the groupings of specific vegetation and bird associations were compared to landform and biophysical characteristics respectively to establish an overall pattern of control or relationship along environmental and resource management gradients.

There are two basic conceptual models for analyzing species by sampling-unit matrices. One model is that in which sampling-units are arranged into hierarchical groups or community types, and is known as classification. The other conceptual model is that in which sites and/or species can be arranged along environmental gradients, and is known as ordination (Palmer, 1993). Classifications are often produced by clustering techniques while ordination can be achieved by a set of techniques related to factor analysis such as Principal Component Analysis (PCA), Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA). These are all forms of gradient analysis in which species distribution is related to gradients, often environmental factors or controls. PCA and DCA are forms of indirect gradient analysis. In this form, environmental gradients are not studied directly but are inferred from species composition data. In comparison, CCA is a direct gradient analysis technique and represents a special case of multivariate regression. Species composition is directly and immediately related to measured environmental variables (Palmer, 1993). Many authors combine classification and ordination techniques to explore and discern complex relationships between biological and environmental data (e.g., Whitehead et al., 1992; Myklestad and Birks, 1993).

4.7.1 Cluster Analysis

It was decided to apply cluster analysis (CA) in an attempt to organize the large collection of species data and sample sites into more meaningful combinations. The basic aim of cluster analysis is to find the 'natural groupings', if any, of a set of individuals. It allocates a set of individuals to mutually exclusive groups so that individuals within a group are similar to each another while individuals in different groups are dissimilar. Many authors use the term 'cluster analysis' synonymously with 'classification' - this denotes grouping techniques where categories are determined from the data as opposed to the assignment of individuals to a pre-established set of categories, which is related to discriminant analysis as discussed in the next section (McGarigal et al., 2000).

One goal of this work was to develop a set of land units that reflect variations in ecosystem components. If there were recognizable collections of species, such as guilds or functional groups (e.g. based on habitat disturbance, Canterbury et al., 2000) used in avian ecology that represented different land units, this would aid in developing this classification. CA can be used to gain insight into the organization of ecological systems by depicting how readily entities can be partitioned into discrete, discontinuous classes. Further, CA can facilitate the management of ecological systems by establishing groups of entities (e.g. species, habitats, etc.) with similar ecological relationships, and hopefully similar responses to management activities (McGarigal et al., 2000). Wildlife managers often require tools for managing large numbers of species simultaneously. If groups of species exhibit a similar distribution along environmental gradients, then it may be possible to aggregate species into groups for purposes of management (McGarigal et al., 2000).

The cluster analysis was completed using Two-Way Indicator Species Analysis (TWINSPAN) (Hill, 1979). This is a Polythetic Divisive Hierarchical Clustering (PDHC) technique, one of the most popular for use with samples-by-species data (Gauch, 1982). PDHC techniques successively divide a single cluster into a hierarchy of smaller and smaller clusters (McGarigal et al., 2000). TWINSPAN is most appropriate whenever a dual ordination of rows and columns in the data matrix is meaningful. This method differs from most clustering techniques since the data are first ordinated by reciprocal averaging. Those species that characterize the reciprocal averaging axis extremes are emphasized in order to polarize the samples, and the samples are divided into two clusters by breaking the ordination axis near its middle. The sample division is refined by a reclassification using species with maximum value for indicating the poles of the ordination axis. This procedure is repeated to produce a hierarchy of clusters, until each cluster has no more than a chosen minimum of number of members. A corresponding species clustering is produced, and the sample and species hierarchical clusterings are used together to produce an arranged data matrix (Gauch, 1982; McGarigal et al., 2000).

Some suggest that PDHC techniques are preferable to Polythetic Agglomerative Hierarchical Clustering (PAHC) techniques for the analysis of community ecology data (Gauch and Whittaker, 1981; Gauch, 1982). Agglomerative techniques begin by examining small distances between similar entities. In community data, these small distances are likely to be a reflection of noise more than anything else, and these initial groupings will constrain the ultimate cluster hierarchy because there are no provisions for reclassifying an entity that is poorly classified during an early stage in the clustering. Divisive techniques, however, begin by examining overall major gradients in the data; all available information is used to make the critical topmost divisions. In this manner, noise among entities does not seriously influence the upper level of the hierarchy (McGarigal et al., 2000).

4.7.2 Analysis of Biological and Physical Relationships

Following the classification of the vegetation and avian species, these species were then compared to the environmental data sets to determine if relationships existed between the vegetation and landform variables and between the birds and the combination of landforms and vegetation structural characteristics. The first comparisons were performed separately completing an analysis of variance (ANOVA) between the environmental parameters and the vegetation and avian species. The avian species were also compared to the vegetation structural characteristics. Following the ANOVA, the classification groups of bird and vegetation species were compared to the environmental variable through a Discriminant Analysis. Discriminant analysis (DA) refers to objectively discriminating among pre-specified, well-defined groups of sampling entities based on a suite of characteristics. This differs from ordination, which attempts to organize a single group of entities along a gradient of maximum variation, and cluster analysis (CA) which attempts to organize entities into classes or groups. CA often serves as a precursor to DA when prespecified groups do not exist. Artificial groups are created in CA, and ecological differences among the newly created groups are described using DA. The result is an organization of the species groups along continuous gradients (McGarigal et al., 2000). This approach aids in identifying factors that could explain differences between groups of variables, for example, identifying ecological or environmental factors that best explain the differences in the distribution patterns of the plants and wildlife. Both the ANOVA and DA were completed using SPSS Base 10.0 (SPSS, 1999).

4.7.3 Ordination Analysis

Following the classification of the vegetation and avian species into general groups, and subsequent discriminant analysis, the vegetation and bird data were compared to environmental data to determine if relationships existed between the vegetation species and landform variables and between the birds and the combination of landforms and vegetation characteristics. This is achieved by using ordination techniques which organize entities along a continuum and extracting dominant gradients of variation. This assists in identifying factors that could identify ecological or environmental factors that best explain the differences in the distribution patterns of the plants and wildlife.

To determine these relationships, a Canonical Correspondence Analysis (CCA) was performed using CANOCO version 4 (ter Braak, 1998). CCA is preferred over other ordination techniques such as Principal Component Analysis (PCA) or Detrended Correspondence Analysis. These techniques require performing secondary analyses to determine the relationship of pattern and environmental controls. CANOCO directly ordinates the first set of variables on axes that are combinations of the second set of variables. This method is particularly applicable when the first set of variables consists of species scores (e.g. abundances) and the second set consists of environmental variables (e.g. habitat characteristics). CCA is a hybrid of ordination and multiple regression. One of the major advantages of CCA, over other ordination techniques such as DCA, is that the axes are linear combinations of the independent variables that explain the most variance in the dependent variables. This gives an immediate understanding of what the axes mean and how the independent variables are related to the distribution of the dependent variables (McGarigal et al., 2000).

4.8 Summary

In this chapter, descriptions have been provided for the techniques and methodologies of the field surveys that were completed to obtain data on the characteristics of the land, vegetation and bird systems. This chapter also included the rationale for the selection of the methods in each case, followed by a presentation of the development of secondary parameters from the raw data, such as importance values, to improve the quality of the data and to allow for easier comparisons between data. Finally, an overview of the analysis of this data, including cluster and discriminant analysis, was presented. These methods assisted in developing patterns in the large data sets that were generated in this study.

Interpretation of this type of data requires both a qualitative and quantitative assessment. As described above, methods such as cluster analysis and importance values help to place a quantitative or relative value to the data. However, there is also a need to interpret the data from an experiential viewpoint. When dealing with natural systems, especially the biotic component, observational behaviour will add to the understanding of the system. In the following chapter, the results are presented in several sections which begin with a description of the sites, from the details of the data sets as well as from field observations. In the second section, the results of the interpretation the importance values and the statistical tests will be presented.

Chapter Five
Biophysical Classification and Ordination

5.0 Introduction

To better understand the relationships between the biological and physical systems, the second phase of the analysis requires subjecting the data to several procedures in an attempt to increase the understanding of the patterns introduced in the preceding chapter. This involves two general approaches to data interpretation typically employed in the ecological sciences: classification and ordination. The classification method will be employed to determine similarities within the main land units and to identify patterns in the distribution of tree and bird species related to the position within the land system and related processes. Relationships between biological components and the physical environment can also be investigated by employing analyses broadly described as ordination. In this chapter the species data is compared to the results of the geomorphic form and process as well as bird species to vegetation structural components.

Classifications of the vegetation and avian data sets were completed using TWINSPAN (Hill, 1979). The resulting clusters will be described with a brief description of the composition and, in the case of vegetation, the patterns of structure and change or dynamics within the forest. Also included is a descriptive comparison between groups for environmental variables; this includes landform and geomorphic variables for the vegetation component and the combination of physical and vegetation structural variables for the avian groups.

In the second section of this chapter, the results of the discriminant and ordination analyses are presented. The discriminant analysis considers variance between the groups identified in the vegetation and bird cluster analyses to the biophysical variables. Similarly, the results of the ordination analysis using CANOCO, version 4 (ter Braak, 1998), a form of CCA, will examine relationships between species and environmental variables. The chapter will conclude with a comparison of the cluster analysis of the vegetation and avian populations and recommend combinations of groups to create a land classification for this study area. To complement the statistical analyses, a qualitative assessment of each site has been provided in Appendix A. This includes an overview of the results of the geomorphic components, the vegetation species and structural characteristics as well as the avian species. This additional section provides a description of the field data as well as anecdotal observations of the biophysical landscape.

5.1 Vegetation Analysis

A wide variety of tree species was recorded throughout the sites, a total of 42 species altogether. This included species typical for southern Ontario such as sugar maple and American beech, as well as some with a more typically northern presence such as white spruce and tamarack found in the lowland swamp at Alton. There was also one Carolinean-associated species, blue beech (*Carpinus caroliniana*), found at Silver Creek Conservation Area. The tree cover also included several species that were introduced in plantations. The dominant species at these sites were white pine and red pine (*Pinus resinosa*) with some small stands of jack pine (*Pinus banksiana*) and green ash (*Fraxinus pennsylvanica*). The species ranged from early successional, old field species, including hawthorn spp. and apple (*Malus sylvestris*) to those of mature deciduous and mixed forests, such as American beech and eastern hemlock. There were also a number of shrub species which could be considered small trees, because they met the criteria of 4 cm dbh.

These included mountain maple, alternate-leaved dogwood (*Cornus alternifolia*), gray dogwood and European buckthorn (*Rhamnus cathartica*).

The most common species in terms of presence was white ash occurring in 93% of the transects. Other common species included sugar maple (79%) and American elm (72.5%). Species common in approximately 50% of the records included basswood (62%), white birch (58%), eastern white cedar (51%), black cherry, (51%), ironwood (48%) and eastern hemlock (41%). Less common species, found in approximately 25% of the sites, included balsam fir, (17%), balsam poplar, (17%), trembling aspen, (27.5%), yellow birch, (34.5%), and white pine (27.5%). A large group of species was found in less than 15% of the transects; these included apple, (13%), silver maple (*Acer saccharinum*), (13%), and alternate-leaved dogwood. Relative values for frequency are presented in Table 5.1 along with the values for relative density, relative cover and total importance values.

Similar trends are exhibited in values for dominance or cover (measured as dbh) for some species. Sugar maple is by far the most dominant tree with respect to cover; total value of sugar maple accounts for 35% of all the trees measured. The closest tree to this value is white ash with 10%. Other trees with high scores included eastern white cedar (8.9%) and white pine (7%). A group of species with moderate scores for cover included American elm, eastern hemlock, red pine, silver maple, white birch, basswood and balsam fir.

Density was also similar for common species, with sugar maple having the greatest density (32). As well, white ash had a value of 11.5 and white cedar had 10. The next

Table 5.1 Common forest species importance value scores for relative density, frequency, cover and combined importance values for all three variables.

Tree Species	Relative Density	Relative Frequency	Relative Cover	Total Importance Value
sugar maple	32.24	8.01	34.55	74.80
white ash	11.52	9.41	10.09	31.02
eastern white cedar	9.94	5.23	8.9	24.07
American elm	5.8	7.32	4.05	17.17
white birch	3.59	5.92	4.12	13.64
white pine	5.4	2.79	6.91	15.10
basswood	2.46	6.27	2.3	11.03
eastern hemlock	2.58	4.18	3.2	9.96
black cherry	1.96	5.23	1.67	8.86
ironwood	2.41	4.88	1.7	8.98
American beech	0.87	3.83	1.28	5.98
yellow birch	1.57	3.48	1.25	6.30
silver maple	1.93	1.39	3.29	6.61
black ash	1.08	3.48	1.04	5.61
red pine	2.53	0.70	3.55	6.78
balsam fir	3.34	1.74	2.09	7.17
red maple	1.80	1.62	1.50	5.04

level included American elm (6), white pine (5.5), white birch (3.5), balsam fir (3.5), basswood (2.5), eastern hemlock (2.5), red pine (2.5), and ironwood (2.5).

Overall the species with the greatest importance value is sugar maple (75), followed by white ash and eastern white cedar. This is followed by a group with lower values including American elm (17), white pine (15), white birch (13.5), and basswood (11). Less common trees include eastern hemlock (10), ironwood (9), black cherry (9), balsam fir (7), red pine (7), silver maple (6.5), yellow birch (6.5), American beech (6) and black ash (5.5).

5.2 Classification of Vegetation Communities

A cluster analysis was completed for the 29 transects using TWINSPAN (Hill, 1979). The results of this analysis are presented in the form of a dendrogram diagram in Figure 5.1. The major divisions of the sites have been identified on the left side of the chart. In the first division, the two main groups identify the sites altered by human disturbance (land clearance and plantations). Group I comprises two groups - those that include the larger plantations (Group F) and those that are found at the Limehouse site which include a number of transitional forests (Group E). Group II is broader, including most of the transects, especially those on the upland and slope sites with natural forest cover and those that occur in low-lying areas and are associated with water including the transects located on floodplains and in re-entrant valleys. The other main division at the second level separates the upland and slope sites (Groups A-C) from the valley sites (Group D).

At the third division, upland and slope sites are separated into two groups, separating those that experience greater natural disturbance (Group C) from those that are

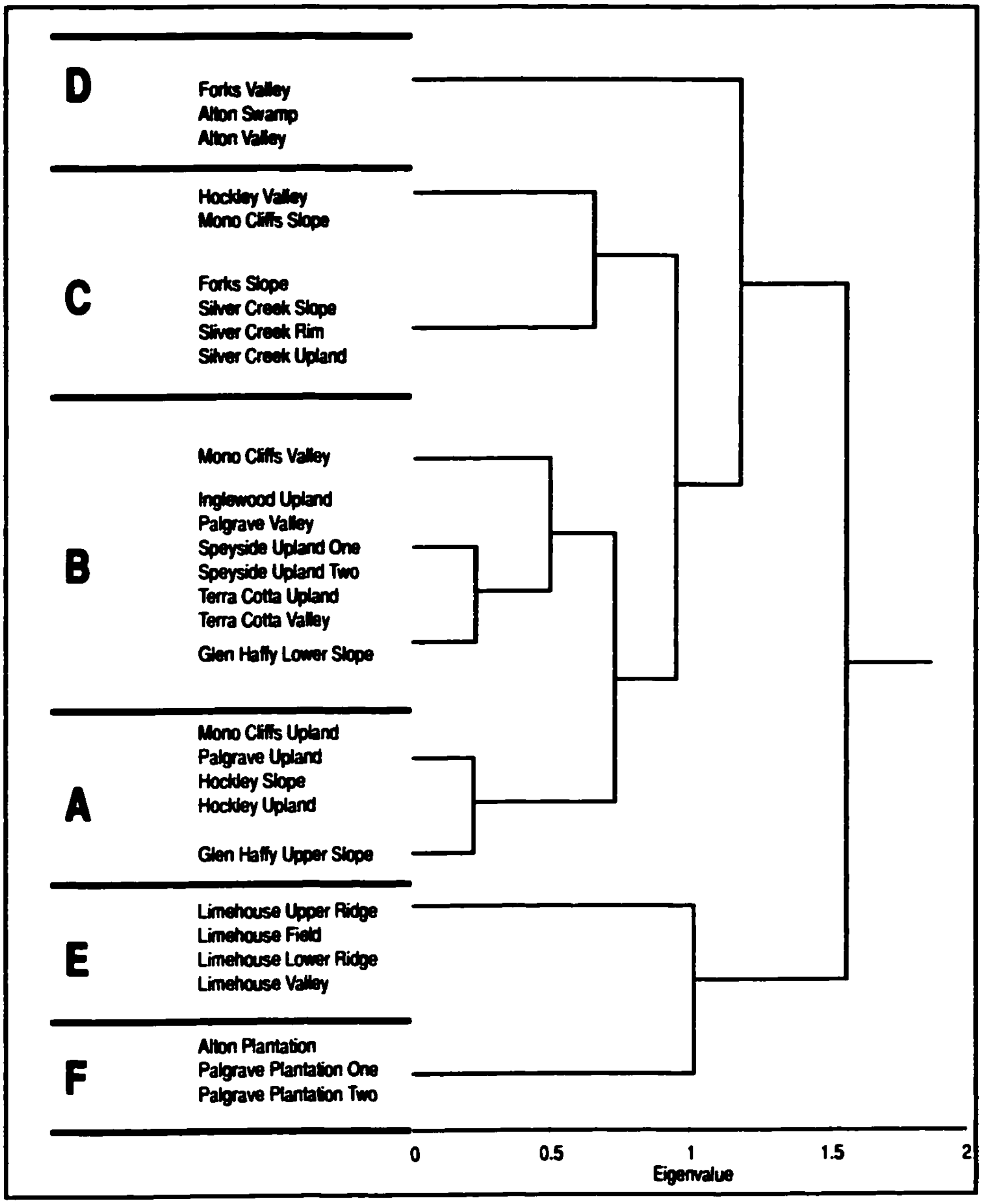


Figure 5.1 Dendrogram illustrating the results of a TWINSPAN analysis of the forest populations occurring at the twenty-nine sites. Similarity between forest associations increases from right to left.

more stable (Groups A, B). At the fourth level, several further divisions create a number of small groups. For this study it was decided to only consider the separation of the larger group (A, B) into sites found on poorly drained uplands, Group B, and those on deep glacial deposits, Group A, to compare the differences between these groups.

Section 5.3 will present descriptions of these six forest community groups. The importance values of each species for these groups are presented in Table 5.2. These values were based on an accumulative total of density, frequency and cover for all of the sites found on the transects within each group. This description covers the composition, structure and dynamics of the forest groups, including dominant forest cover as well as dominant canopy layers. This will be combined with a qualitative description of the dynamics of forest associations and the structure and functions of these groups, such as successional or equilibrium conditions, based on the description of vegetation data in Appendix A.

To add to these group descriptions, the results of the ANOVAs (SPSS, 1999) on the relationships between species and vegetation structural characteristics and physical variables will be included to provide a measure of the important similarities and differences between the groups.

5.2.1 Analysis of Variance

Vegetation Structural Characteristics

Differences in vegetation structure indicators were compared between forest association groups (A-F). An ANOVA was performed between the six groups for each of these vegetation structure characteristics (Table 5.3). Several of these indicators were significant at .01; these included the deciduous/coniferous ratios for older stems

Table 5.2 Dominant and sub-dominant tree species for each of the forest association groups identified by the TWINSPAN classification. The numbers refer to the species Importance Values calculated as a score out of a total of 300. These values have been calculated as a combined total for each association group.

DOMINANT TREE SPECIES		FOREST ASSOCIATION GROUPS					
		GROUP I				GROUP II	
		A	B	C	D	E	F
DECIDUOUS	sugar maple	175	103	92	-	52	-
	white ash	41	33	29	18	53	22
CONIFEROUS	white pine	-	1	-	-	54	84
	red pine	-	-	-	-	-	82
	eastern white cedar	-	15	37	89	17	3
SUB-DOMINANT TREE SPECIES							
DECIDUOUS	American beech	26	3	2	-	2	-
	yellow birch	2	12	4	-	-	-
Disturbance/Gap	basswood	17	11	22	4	2	-
	ironwood	4	9	29	-	2	-
	white birch	5	15	19	27	7	-
	balsam poplar	-	1	8	7	-	-
	black cherry	4	5	6	2	9	35
Riparian	American elm	2	16	13	38	25	-
	black ash	-	5	3	21	-	-
	silver maple	-	17	-	-	-	-
	red maple	-	14	-	-	-	-
Field	apple	-	1	-	-	31	-
	downy hawthorn	-	-	-	-	25	-
CONIFEROUS	eastern hemlock	15	17	1	-	2	-
	balsam fir	-	1	2	37	-	35
	jack pine	-	-	-	-	-	15

Table 5.3 ANOVA of vegetation structural variables for vegetation association groups identified in the TWINSPAN classification.

Vegetation Structural Characteristic		Sum of Squares	df	Mean Square	F	Sig.
OLDRATIO	Between Groups	2194.941	5	438.988	1.741	.165
	Within Groups	5800.187	23	252.182		
	Total	7995.127	28			
OLDDEC	Between Groups	18193.255	5	3638.651	11.124	.000
	Within Groups	7523.374	23	327.103		
	Total	25716.629	28			
YOUNGDEC	Between Groups	4459.523	5	891.905	2.924	.035
	Within Groups	7015.650	23	305.028		
	Total	11475.172	28			
MULTINUM	Between Groups	553.709	5	110.742	5.614	.002
	Within Groups	453.714	23	19.727		
	Total	1007.423	28			
MULTIBAS	Between Groups	1787.846	5	357.569	5.805	.001
	Within Groups	1416.660	23	61.594		
	Total	3204.506	28			
SNAGS	Between Groups	122.175	5	24.435	.987	.447
	Within Groups	569.621	23	24.766		
	Total	691.795	28			
OLDSTEM	Between Groups	803.578	5	160.716	1.692	.176
	Within Groups	2184.202	23	94.965		
	Total	2987.779	28			
NEWSTEM	Between Groups	1515.323	5	303.065	1.857	.141
	Within Groups	3754.124	23	163.223		
	Total	5269.447	28			
SAPLING	Between Groups	463.612	5	92.722	.603	.698
	Within Groups	3534.516	23	153.675		
	Total	3998.127	28			
GRCOVER	Between Groups	7353.473	5	1470.695	5.815	.001
	Within Groups	5817.192	23	252.921		
	Total	13170.665	28			
CANCOVER	Between Groups	3375.986	5	675.197	2.074	.106
	Within Groups	7487.690	23	325.552		
	Total	10863.676	28			

(OLDDEC), and both measures of multistems, MULTINUM and MULTIBAS. Groundcover was also significant at this level. The only other significant variable was the YOUNGDEC variable at the .05 level. These results are indicated in Table 5.4. Patterns of these characteristics for each group are discussed in the next section.

Physical Parameters

The results of the ANOVA for the five vegetation groups and the seven landform and geomorphic variables are presented in Table 5.5. Landscape position (LANDPOS) and human disturbance (HDISTLEV) were significant at the .01 significance level. Also important but less significant at the .05 level were natural disturbance (NDISTLEV) and land unit (LANDUNIT). Landscape position showed the greatest variation between Group D and the rest of the groups. This was confirmed by running a Berfonnini test which showed a significant variance between Group D and the rest. This was due to the fact that almost all members of this group are found in the valleys.

Both forms of disturbance were important, especially human impacts. The greatest human disturbance was measured in Group E and, to a lesser extent, in Group C. Group E included the plantation sites while C had smaller levels of disturbance including selective logging, trails and small plantations. Natural disturbance had a less significant score; the variability was mainly in Groups B and D. Group B had the larger number of face sites such as Mono Cliff and Silver Creek. Group D had disturbance from fluvial processes reworking the stream channel during high flow events. These results are presented in Table 5.6.

Table 5.4 Forest association group characteristics of forest composition, structure and dynamics. The forest groups are based on the TWINSPAN classification. Forest structure variables that had significant variance between groups are identified by the asterisk(s). The values for the ratios (old/young, old dec, and young dec) and cover (ground and canopy) are expressed as percentages. The values for the multi stems (multistem and multibas), snags and stems (old stem, new stem and sapling) are averages of the observed totals. Forest composition and dynamics are based on the dominance of species in each forest layer.

Forest Group	Forest Composition and Dynamics			Forest Structure Characteristics										
	Canopy	Understory	Sapling	old/ young	old dec**	young dec*	multi num**	multi bas**	snags	old stem	new stem	sapling	ground cover**	canopy cover
Group A	sugar maple white ash - American beech	sugar maple American beech - white ash	sugar maple	76.4	94.3	97.9	3.5	6.9	2.7	17.5	7.0	18.8	26.7	81.8
Group B	sugar maple white ash - American elm	sugar maple white ash - silver maple	sugar maple - white ash mountain maple - yellow birch	59.6	85.7	84.2	11.6	22.3	7.4	28.5	23.3	19.8	31.8	80.6
Group C	sugar maple white cedar - white ash	sugar maple ironwood - basswood - white ash	sugar maple ironwood	57.3	85.0	90.0	12.6	20.7	7.95	22.7	17.8	12.0	44.0	76.1
Group D	white cedar American elm - white birch	balsam fir - white cedar - American elm	balsam fir white cedar - American elm	35.2	58.8	61.1	11.4	23.5	7.7	26.7	25.9	13.5	81.9	47.7
Group E	white pine - white ash - sugar maple	white ash - sugar maple apple - downy hawthorn	white ash - sugar maple apple - black cherry	47.8	70.4	87.8	14.4	24.5	6.6	20.9	30.1	18.6	47.4	67.7
Group F	white pine - red pine balsam fir	black cherry balsam fir - white ash	black cherry balsam fir - white ash	69.1	6.7	59.9	1.83	2.4	9.7	35.2	16.5	25.2	29.0	61.0

** significant variance between groups at .01
* significant variance between groups at .05

Table 5.5 ANOVA of physical parameters for the vegetation association groups identified by the TWINSPAN classification.

Land Characteristics		Sum of Squares	df	Mean Square	F	Sig.
ANGLE	Between Groups	47.177	5	9.435	1.398	.262
	Within Groups	155.248	23	6.750		
	Total	202.425	28			
AZIMUTH	Between Groups	304.310	5	60.862	3.246	.023
	Within Groups	431.213	23	18.748		
	Total	735.524	28			
LANDPOS	Between Groups	25.347	5	5.069	3.255	.023
	Within Groups	35.825	23	1.558		
	Total	61.172	28			
LANDUNIT	Between Groups	13.028	5	2.606	4.343	.006
	Within Groups	13.800	23	.600		
	Total	26.828	28			
NDISTLEV	Between Groups	22.694	5	4.539	3.995	.009
	Within Groups	26.133	23	1.136		
	Total	48.828	28			
HDISTLEV	Between Groups	37.559	5	7.512	13.089	.000
	Within Groups	13.200	23	.574		
	Total	50.759	28			
SITEPOS	Between Groups	9.177	5	1.835	3.027	.030
	Within Groups	13.944	23	.606		
	Total	23.120	28			
HDISLEV2	Between Groups	1.295	5	.259	10.066	.000
	Within Groups	.592	23	2.574E-02		
	Total	1.888	28			

Table 5.6 Characteristics of the physical variables for the forest association groups identified by the TWINSPAN classification. Physical parameters that have been identified as showing variance between groups are identified by the asterisk(s). An explanation of each variable follows the descriptions in chapter four. The values for disturbance are averages of the combined scores.

Forest Groups	Canopy	Land Unit**	Angle	Azimuth*	Landscape Position*	Site Position*	Natural Disturbance**	Human Disturbance**
Group A	sugar maple white ash - American beech	C	6-26	E-NE	upland/ slope	convex- concave	1.80	1.60
Group B	sugar maple white ash - American elm	B	flat- 10-15	E-SE-W	upland/ valley	plain- concave	2.00	2.25
Group C	sugar maple white cedar - white ash	A-C	flat 20-26	E-SW	slope	plain- slope	4.00	1.17
Group D	white cedar American elm - white birch	other	flat	none	valley	plain	2.67	1.00
Group E	white pine - white ash - sugar maple	B	flat 9-16	NE	upland/ ridge	plain- convex	2.00	3.50
Group F	white pine - red pine balsam fir	other	5-13	NE-SW	upland	slope- concave	1.33	4.67

** significant variance between groups at .01
* significant variance between groups at .05

5.3 Forest Association Groups

5.3.1 Forest Association Group A

This group includes upland transects from Hockley, Mono Cliffs and Palgrave, and slope forests at Glen Haffy and Hockley found on deep glacial deposits of northern sites.

Composition

The dominant and subdominant deciduous and coniferous species are presented in Table 5.2. The forest cover is dominated by sugar maple, with an importance value of 175. The forest also has sub-dominant species that include white ash (41), American beech (26), basswood (17) and eastern hemlock (15). As seen in Figure 5.1, this group has the greatest abundance of American beech and butternut (*Juglans cineria*).

Structure

This forest has the highest percentage of deciduous cover at almost 100% for both older and younger stems, two of the variables that varied significantly between groups (Table 5.4). This forest also has the highest ratio of old stems, indicating the stability and low level of disturbance at these sites. Similarly, this group has one of the lower measures of multistems, another significant variable (.01), and lowest snag density (2.7). This is also evident in the high percentage of canopy cover (81.8%) and low percentage of ground cover and stem densities in all layers except sapling, which was comparable to the other groups.

Dynamics

The average cover indicates that these stands are in a late successional state, dominated by sugar maple in association with American beech and at some sites, eastern hemlock. It is likely there has been some past disturbance at some of the transects, since the upper canopy is often dominated by larger white ash at these stops. Maple is likely replacing an upper strata of white ash, basswood and at some sites black cherry, butternut and American elm. At other locations, the upper canopy is dominated by large sugar maples with few younger trees and no evidence of a second canopy. In this case, the sugar maple cover is replacing itself. At other locations the canopy is predominantly a younger cover, usually dominated by sugar maple.

5.3.2 Forest Association Group B

This group includes sites that are found on the shallow bedrock plains above the Escarpment and on lower slopes where there are poorly drained lowlands and moderate disturbance. Transects in this group include the lower slopes of the face and valley transects at Mono Cliffs, Glen Haffy, Palgrave and Silver Creek as well as the upland sites at Speyside, Inglewood, and Terra Cotta.

Composition

The upland forests of this unit differ from the cover found on the upland forests with deep glacial material. The forest communities on the shallow soils of the limestone plains have a greater variety of species related to variations in local site conditions. The transect with the greatest variation in species was found on the lower face of Glen Haffy where there are a number of stream channels and natural springs. This is evident by the occurrence of species with a greater affinity to water, such as American elm and eastern white cedar.

The dominant tree of this group is once again sugar maple, but its importance value has decreased to 103. There is also a wider variety of important species in the forest cover. One group includes white ash (33), basswood, ironwood, American elm (16) and white birch - species common in the study area but usually with a lesser role in the mature forest canopy. Other species dominant in this group include eastern hemlock and yellow birch (Figure 5.1). There is also a smaller group of trees, including silver maple and red maple (*Acer rubrum*), specifically located in the poorly drained sites on the plain. These species score high values at a few specific sites with silver maple (17) dominating the canopy in areas where there is standing water, such as Speyside, Terra Cotta and Inglewood.

Structure

This group is predominantly deciduous, although not as much so as Group A (Table 5.4), and has a denser forest structure than the upland deciduous forest in Group A. Stem densities of old stems (28.5) are highest for all groups and relatively high for younger stems and saplings. The canopy cover and groundcover are comparable to Group A, and are higher and lower, respectively, than the other groups.

Dynamics

The dynamics at these sites vary due to several factors directing the forest communities. On the drier sites, sugar maple is the dominant tree but there is a high diversity of sub-dominant trees in the forest because of successional species filling in gaps where disturbance has occurred, such as at Glen Haffy and Speyside (Table 5.3). White ash is the dominant replacement tree which will share the canopy with sugar maple. At the wetter sites, the dominant combination is silver maple and red maple, which are replacing themselves as is evident in the lower vegetation layers. Other lowland sites have high concentrations of yellow birch and eastern hemlock which also appear to be replacing themselves.

The bottomland at Palgrave is not as extensive as that found at Alton and the mixture of trees reflects the variety of stops and variability of moisture levels. The sites include dense stands of white cedar, and mixed stands of yellow birch, white cedar, red maple, with American elm as a sub-dominant in the understory. The stands appear to be regenerating themselves, although it is likely that the fringes of the bottomland are filling in with sediment and are converting the site to a more mesic forest including young stems of eastern hemlock and sugar maple.

5.3.3 Forest Association Group C

This group includes eight transects including all those at Silver Creek except the valley transect, the face transects at Forks and Mono Cliffs, and the valley segment at Hockley.

Composition

The dominant tree is sugar maple but it does not score as highly as in the previous groups, with an importance value of 92 (see Table 5.2). The subordinate species are a range of successional and secondary species of white cedar (37), white ash (29), basswood (22), ironwood (29), white birch (19), and silver maple (11). There are a number of species with their highest abundances here, including blue beech, ironwood, alternate-leaved dogwood, basswood, mountain maple, balsam poplar and trembling aspen (Figure 5.1).

Structure

This is predominantly a deciduous group with high ratios in both older and younger stems (Table 5.4). This group has an average ratio of old to young stems and number of multistems and multistem cover. There is a slightly higher snag density in this group; conversely, the density of stems is slightly lower for all three layers. The ground cover is somewhat higher than the other deciduous communities (Groups A and B) while the canopy cover is slightly lower.

Dynamics

The dynamics at this site are varied. The higher scores for sub-dominant or late-successional in the mature deciduous forests indicate these sites are in a state of transition or stress. Sugar maple is the dominant tree in the understory but there are high numbers of ironwood, basswood, and white birch as well which create diverse communities. These high numbers are evident in Table 5.2 for species in the disturbance/gap category.

5.3.4 Forest Association Group D

This group includes high gradient, fast-flowing stream channels that cut deep and narrow valleys into the bedrock and glacial slopes at Forks, and low gradient streams and floodplains found at Alton.

Composition

The dominant species is eastern white cedar (89), occurring at almost all stops and often with high density and cover values. Other common species include American elm (38) and balsam fir (37) which also occur at most stops but do not form as dense a cover as the cedar. Species of lesser importance include white birch (29), black ash (21) and white ash (18). Several species are unique to this group including speckled alder (*Alnus rugosa*), shining willow (*Salix lucida*) and tamarack (*Larix laricina*) (Figure 5.1).

Structure

This is the youngest community with an old ratio of only 35.2. It is also a mixed forest with a combination of sugar maple and white pine. This is evident in the old and young deciduous ratios which are near 60%. This group has similar values for multistems, snags and stem densities to many of the other groups. There is a lower score for sapling densities. The open nature of these transects is reflected in the low score of canopy cover (47.7%) and the high percentage of ground cover (81.9%).

Dynamics

Temporal trends are not as obvious in this grouping. At many transects it appears the dominant cover species is replacing itself. This is apparent with both floodplain species, including eastern white cedar and American elm. In some cases, early- and mid-successional species are also found in the sub-canopy but appear to be opportunists and are not replacement species. The only instances where there is an obvious dominant tree layer with few younger individuals occur on the Forks stream transect where a number of large shining willows form large multistem, stream-side canopies, but there was little evidence of replacement trees in the understory.

The transects along low-energy stream channels exhibited a varying pattern of forest cover and structure between sites. In the poorly-drained lowland at Alton, eastern white cedar is the dominant cover with an understory of smaller balsam fir and speckled alder. A mixture of older trees occurs in the canopy including tamarack, white birch and white spruce (*Picea glauca*). These trees are often filling gaps in the forest where there has been local disturbance such as windfall. Eastern white cedar is also a dominant in the understory and is likely replacing itself.

Along the Credit River transect at Alton, the forest cover is quite open with only a few scattered individuals of Manitoba maple (*Acer negundo*) and black ash. At other locations, there are dense stands of eastern white cedar somewhat similar to the adjacent bottomland described previously. There are few younger trees and those recorded was mainly Manitoba maple, which commonly produces shoots from larger trees.

5.3.5 Forest Association Group E

This group consists of all four transects at Limehouse and is a mixture of upland forests, small plantations and old fields. The transect on the upper face at Limehouse runs along the ridge of the slope as well as the edge of an old field. Several sites on this transect are within the edge of the forest area typical of undisturbed upland, where sugar maple is the dominant canopy tree and is replacing itself. A sub-canopy is found in openings along the crevice area of the slope, which is dominated by species such as mountain maple. Along the edge are old field species such as European buckthorn, downy hawthorn (*Crataegus mollis*), narrow-leaved hawthorn, apple and young white ash. There is also a small group of planted white pine which is neither regenerating itself nor being actively managed.

Composition

The diversity of land units combined with human and natural disturbance creates a complex mixture of tree species with no dominant cover. The dominant species include a combination of white pine (54), white ash (53) and sugar maple (52). Less dominant species include several field species - apple (31) and downy hawthorn (25). There are also moderate scores for American elm (25) and white cedar (17).

Structure

Young forests in this group have the second lowest old ratio (47.8). Although white pine and white cedar are important components of the forest, the deciduous ratio is quite high at 70.4 for the old stems and even higher for the young stems (81.6), indicating the directional change to a sugar maple-white ash forest cover. This group had the highest score for multistems, quite similar to Groups B and D. The transitional nature of these sites is evident in the high density of young stems (30.1). The open nature of these forests is reflected in the higher ground cover percentage (47.4) and the lower canopy cover (67.7).

Dynamics

A directional change is occurring in this community with open fields, orchards and small pine plantations returning to a mixed forest dominated by sugar maple with white ash and white pine. The vegetation cover at the more open sites where fields have been abandoned is dominated by a mixture of successional trees including white ash, black cherry and white cedar, in association with remnant apple and downy hawthorn. Some of these trees are also found in the sapling layer although it was dominated by white ash and sugar maple.

5.3.6 Forest Association Group F

This group consists of transects dominated by forest cover that has been initiated by human disturbance. These sites are dominated by plantations of white and red pines that are in various stages of management from active to abandoned, and include several of the upland transects at Palgrave and one upland transect at Alton.

Composition

The dominant trees reflect management strategies, with a mixture of planted white and red pine with importance values of 84 and 82 respectively. These species form individual dominant canopies and are not mixed to any degree. A number of species have moderate scores that either form a replacement canopy or sub-canopy. These include white ash (22), black cherry (35) and balsam fir (35). Jack pine was of lesser importance (15) and restricted to the second plantation at Palgrave. Overall this group has a comparatively low diversity (Figure 5.1)

Structure

This group is predominantly coniferous in the canopy, with an old deciduous ratio of 6.7. However, this is reversed in the understory and sapling layers where the ratio is 59.9. This group had the highest density of older stems (35.2) which relates to the density of the plantings, as well as the highest sapling density, indicating a strong transition occurring at this lower level. The lowest density of multistems was recorded in this group, which reflects the structure of plantations with the emphasis on straight, single stems. In contrast, this group had the largest number of snags. The canopy cover was lower than the deciduous forests and the ground cover was relatively low compared to the other groups.

Dynamics

The dynamics of these transects represent the cessation of management at these sites. It appears that natural processes are replacing human modification and that natural tree replacement is occurring as the older pines died off or are knocked down by wind. At many stops saplings and shrubs such as red-berried elder provide a strong ground cover. There is little suggestion from the data that the pine forests are regenerating themselves. The younger trees are dominated by black cherry and either white ash or balsam fir. At the Alton site, where the plantation transect is adjacent to the cedar bottomland swamp, the dominant understory tree is balsam fir. In comparison, on the well-drained upland sites at Palgrave, white ash and black cherry are the dominant understory trees. Regeneration by these species is especially evident at stops where wind has created openings in the canopy.

5.4 Discriminant Analysis

To obtain a better understanding of these relationships, a multivariate analysis was completed using discriminant analysis. This allowed for a comparison of the distribution of the forest classification in relation to the landform and geomorphic processes of the physical systems. The six forest association groups were assessed in the analysis using the seven geomorphic/physical indicators. The results show a significant relationship at a confidence level of .01 between the vegetation groups and several geomorphic/physical indicators, the strongest one being the level of human disturbance.

The first three functions of the analysis explain 98.5% of the variance (Table 5.7). The first function explains 45.5% of the variance and shows the highest correlation for human disturbance and, to a lesser extent, with land unit (see Table 5.8). This function is significant at .001 (Wilk's Lambda <.001, Table 5.9). The second function, which explains 35% of the variance, shows a negative correlation of ground cover to human disturbance and landscape position. It is also significant at .001. The third function, significant at .005, reveals a strong correlation for multistems which is correlated somewhat with ground cover and azimuth and a negative relationship with natural disturbance.

Table 5.7 Structure matrix produced from the discriminant analysis of biophysical variables and the vegetation association groups

Biophysical Variable	Function			
	1	2	3	4
HDISLEV2	.709*	.524	.172	.440
LANDUNIT	.355*	-.337	.208	-.158
GRCOVER	.038	-.714*	.227	.661
CANCOVER	.078	.422*	.061	-.320
ANGLE	.023	-.199*	-.153	-.089
MULTIBAS	-.156	-.272	.949*	-.021
AZIMUTH	-.035	-.003	.269*	-.003
NDISTLEV	.082	.058	-.151*	-.121
OLDDEC2	-.580	.248	.181	.755*
LANDPOS	.008	-.380	-.319	-.549*
YOUNGDEC	-.094	.091	.108	.428*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions Variables ordered by absolute size of correlation within function.

* Largest absolute correlation between each variable and any discriminant function

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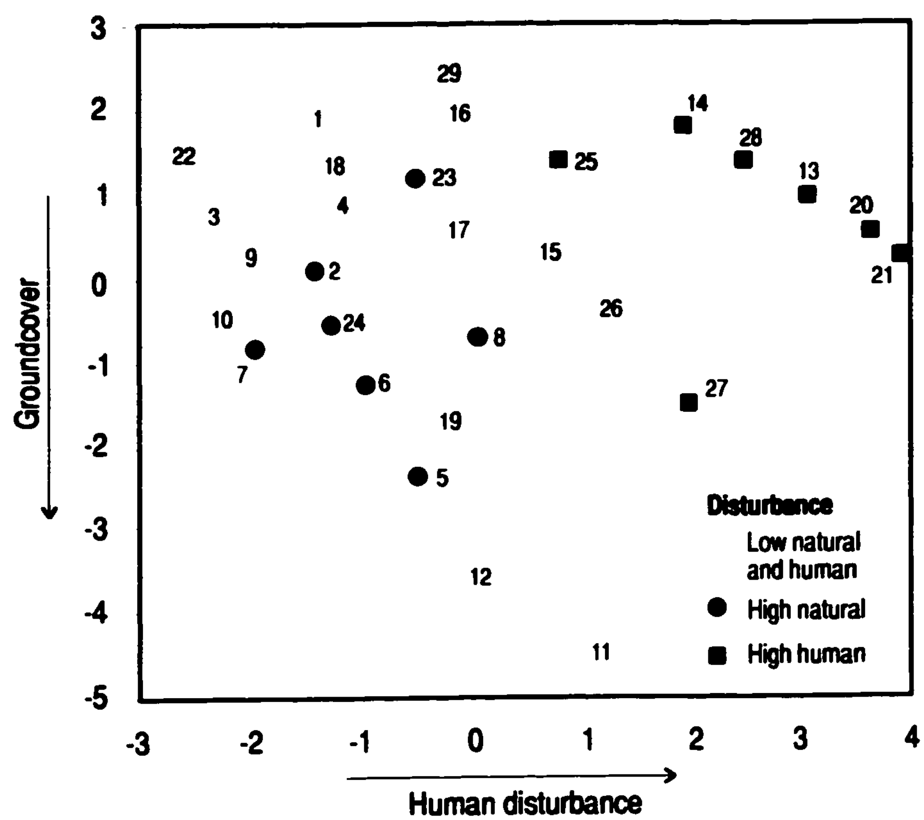
Table 5.8 Eigenvalue scores and % variance for first four axes of the discriminant analysis of the biophysical variables and forest association groups.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	3.008[a]	46.2	46.2	.866
2	2.279[a]	35.0	81.2	.834
3	1.132[a]	17.4	98.6	.729
4	.090[a]	1.4	100.0	.288

[a] First 4 canonical discriminant functions were used in the analysis.

Table 5.9 Wilk's Lambda for discriminant analysis of biophysical variables and forest association groups.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	.033	78.645	20	.000
2 through 4	.131	46.713	12	.000
3 through 4	.430	19.401	6	.004
4	.917	1.985	2	.371



1. Hockley upland 2. Hockly valley 3. Hockley slope 4. Terra 5. Forks valley 6. Forks slope 7. S. Creek slope 8. S. Creek rim 9. S. Creek valley 10. S. Creek upland 11. Alton swamp 12. Alton stream 13. Alton plantation 14. G.Haffy lower slope 15. G. Haffy upper slope 16. Speyside upland one 17. Speyside upland two 18. Palgrave upland 19. Palgrave valley 20. Palgrave plantation two 21. Palgrave plantation one 22. M. Cliffs upland 23. M. Cliffs valley 24. M. Cliffs slope 25. Limehouse ridge 26. Limehouse valley 27. Limehouse filed 28. Limehouse lower ridge 29. Inglewood

Figure 5.2 Canonical discriminant analysis of the forest association groups. The 29 transects are plotted as a function of disturbance level, either high human, high natural or low natural and human.

The distribution of the 29 transects was plotted against the first two functions on these axes in Figure 5.2. There was not a strong division of all groups along these two axes. However, there was a good division of the main groups identified in the TWINSPAN analysis. The members of Group II, which includes the plantations and the sites at Limehouse, are aligned on the right side of the plot along the X-axis (identified by ■ as high human disturbance). The six association groups are not identified on the graph but Group F is located at the far right, Group E is in the right centre while Groups A, B and C form an indistinguishable cluster on the left side. Therefore, there is a range of limited human impact in mature deciduous forests on the left side of the graph and increasing human disturbance in the old plantations on the right. In between are the mixed and regenerating fields and forests at Limehouse.

The second function, along the Y-axis, explains 35% of the variance (Table 5.7). Ground cover has the highest positive correlation along this axis and is somewhat negatively correlated with human disturbance and positively correlated with natural disturbance and land unit (Table 5.8). The main division along this axis is the separation of Group D from the rest of the samples, as is evident in the second division of the TWINSPAN analysis (Figure 5.1). Many of the sites at the lower end of the Y-axis are sites in open landscapes, including wide, low-gradient river channels and old fields (Figure 5.2). At the top of the graph are transects with the older deciduous and dense coniferous plantations which have limited light exposure and little ground cover.

The third significant axis (Wilk's Lambda <.005, Table 5.9), not depicted in Figure 5.2, is related to a high correlation with the multistem plants which had a negative correlation to natural disturbance. The arrangement of sites along the Z-axis indicates that the older deciduous and coniferous forests of Groups A and F, respectively, had low multistem numbers while those at Limehouse, Group E, had a high number (Table 5.8). There was no discernible pattern for the other groups.

One trend evident from this analysis was the pattern of natural and human disturbance along the gradients. Structural variables, such as ground cover, may indirectly provide a measure of the roles of disturbance and stress. On a graph of the first two axes of the discriminant analysis, natural and human disturbance was plotted for the 29 sites (Figure 5.2). A distinction was made between high and low levels of disturbance. If the average score for the site was 4 or 5, then it was considered as high disturbance; a score of 3 or lower indicated low disturbance. The resultant pattern reveals the variance of the sites with human disturbance clustered on the right side of the graph. The pattern of natural disturbance was not as evident; there appears to be a clustering around the centre of the Y-axis, but it is not separate from the other less disturbed sites.

5.5 Canonical Correspondence Analysis

The CCA revealed a number of patterns between vegetation species composition and environmental variables (Figure 5.3). In CCA (Table 5.10), the first ordination axis consisted of disturbance levels and, to a lesser extent, position on the slope. Species distribution along the X-axis was related to high natural disturbance and slope or concavity positions, or higher moisture content to high human disturbance and drier sites. This was evident in the species, at the left side of the axis, associated with scars and stress sites on Escarpment faces such as trembling aspen, white birch, basswood, ironwood and red maple. At the opposite end are species associated with land use change, plantations and old fields and orchards. These are also usually found on the upland sites or plains and

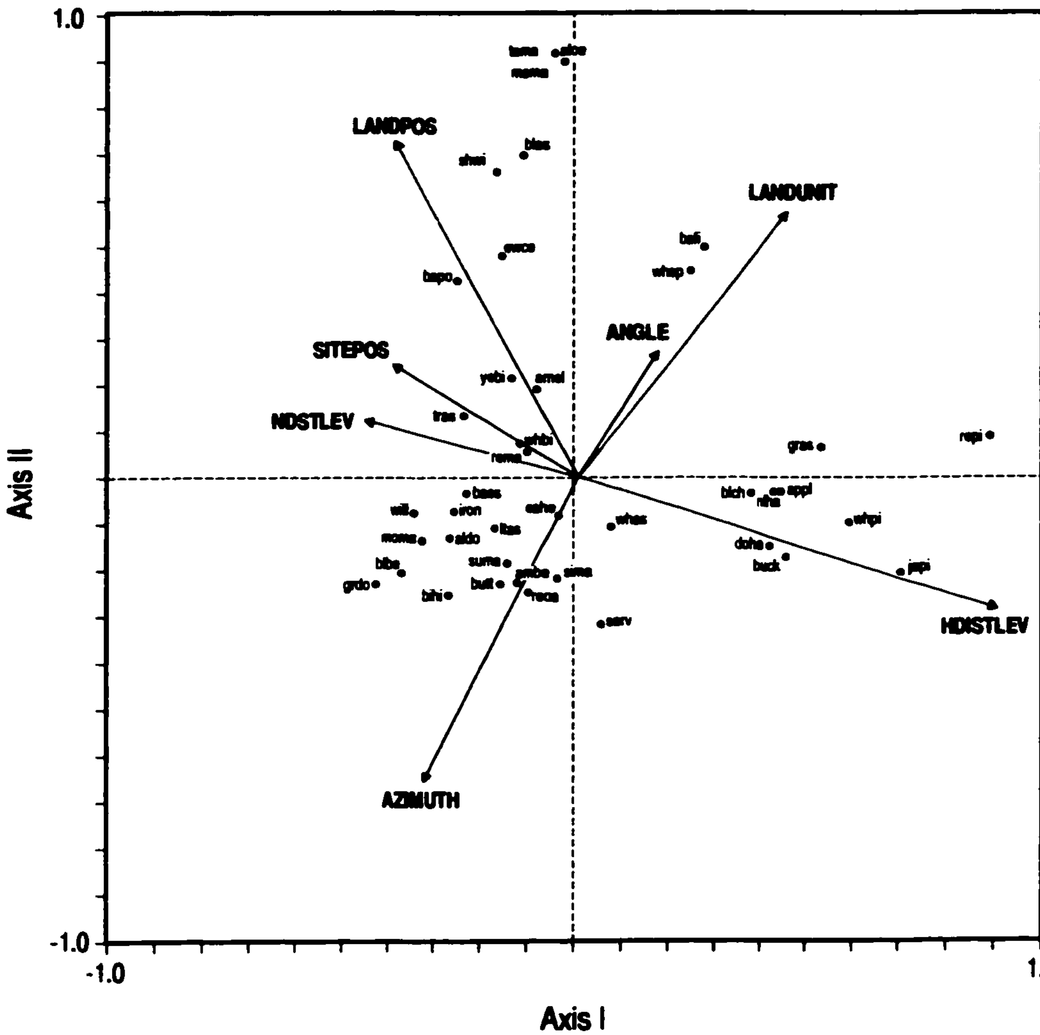


Figure 5.3 Relationships between seven physical variables and the forty vegetation species plotted within axes I and II of a CCA ordination. Arrows pointing in the same direction indicate positively correlated variables; perpendicular arrows suggest a lack of correlation; arrows pointing in opposite directions indicate negatively correlated variables. Species codes are provided in the Appendix.

drier sites, and include a mix of species such as white pine and red pine as well as apple, hawthorn spp., and black cherry. This was also evident in the distribution of the transects (not displayed). The plantations at Alton and Palgrave are located at the far right side of the X-axis while the slopes at Forks and Silver Creek and the stream channel at Hockley are situated at the opposite ends of this axis.

Table 5.10 Results of the CCA ordination of the tree species and physical variables for the 29 transects. The total unconstrained eigenvalue was 4.03. Species ordination diagram is shown in Figure 5.2.

	Axis 1	Axis 2
Canonical eigenvalues	0.57	0.52
Species variance accounted by axes (%)	14.1	13.0
Species variance accounted by arrows (%)	33.5	30.6
Species-environment correlations	0.886	0.925

The second axis indicates the distribution of species related to landscape position and slope angle. At the top or positive end of the Y-axis, there is a cluster of species associated with low-lying swamps and river channels (transects at Alton, Palgrave and Forks), including tamarack, white spruce, black ash and shining willow. At the opposite end are a number of species associated with upland forests, including a wide group dominated by sugar maple as well as American beech, red oak (*Quercus rubra*) and butternut. This is not strictly a moisture gradient; the upland sites included species found in small seasonal ponds on the shallow bedrock uplands, such as silver maple. Overall, though, there is a relationship to moisture along the Y-axis.

5.6 Bird Population Patterns

In total, 84 species were identified across the 29 transects. This does not include species identified during walk-ins to the sites or species observed flying over the site, such as Common Loon (*Gavia immer*) and Common Merganser (*Mergus merganser*) migrants or local species foraging, such as Eastern Bluebird (*Sialia sialus*). A complete list of species is included in Appendix B.

Several patterns of species were found for these sites including those classified as common, frequent and rare. Those that were common made up approximately 20% of the total diversity. Several species were ubiquitous across the sites - these included American Robin (*Turdus migratorius*), Black-capped Chickadee (*Parus atricapillus*) and Blue Jay (*Cyanocitta cristata*). As well, edge species or species associated with humans found at most sites included Downy Woodpecker (*Picoides pubescens*), Hairy Woodpecker (*Picoides villosus*), Brown Creeper (*Certhia americana*), Cedar Waxwing (*Bombycilla cedrorum*) and White-breasted Nuthatch (*Sitta carolinensis*). Common species of deciduous forest interior habitats were also well represented, including Eastern Wood-Pewee (*Contopus virens*), Scarlet Tanager (*Piranga olivacea*), Red-eyed Vireo, Wood Thrush (*Hylocichla mustelina*) and Rose-breasted Grosbeak (*Pheucticus ludovicianus*). Other common species associated more with mixed forests and disturbance included Winter Wren (*Troglodytes troglodytes*) and Black-and-white Warbler (*Mniotilta varia*).

Another group of species that were not common but occurred in approximately 50% of the transects included edge and field species such as American Crow (*Corvus brachyrhynchos*), American Goldfinch (*Carduelis tristis*), Indigo Bunting (*Passerina cyanea*), Brown-headed Cowbird (*Molothrus ater*), Song Sparrow, Northern Cardinal

(*Cardinalis cardinalis*) and Common Grackle (*Quiscalus quiscula*). Other site-specific species included Northern Waterthrush (*Seiurus noveboracensis*), Red-breasted Nuthatch (*Sitta canadensis*), Veery, Yellow-bellied Sapsucker (*Sphyrapicus varius*), Black-throated Blue Warbler (*Dendroica caerulescens*) and Black-throated Green Warbler (*Dendroica virens*).

There were also a number of species, roughly 50%, that had only one or a few records. Some of these were vagrants or unsuccessful individual males that appeared only during one season, or at the end of the season and likely were young birds dispersing following the breeding season. Examples of these include Black-billed Cuckoo (*Coccyzus erythropthalmus*), Alder Flycatcher (*Empidonax alnorum*), Canada Warbler (*Wilsonia canadensis*), and House Finch (*Carpodacus mexicanus*). More common were species that have restricted habitat requirements and were only found at one or two sites, but occurred there regularly. These included plantation species such as Blue-headed Vireo (*Vireo solitarius*) and Northern Goshawk (*Accipiter gentilis*); northern species such as Hermit Thrush (*Catharus guttatus*); cliff-associated species, Common Raven (*Corvus corax*) and Turkey Vulture (*Cathartes aura*); wetland species including White-throated Sparrow; field species such as Eastern Towhee (*Pipilo erythrophthalmus*) and Eastern Kingbird (*Tyrannus tyrannus*); and stream and pond species, Mallard (*Anas platyrhynchos*) and Spotted Sandpiper (*Actitis macularia*).

Finally, there were several groups of birds, including hawks and owls, that were likely under-represented in the counts because of the secretive nature of their life histories, such as hunting for food and nocturnal activities. Most hawks that breed in southern Ontario were observed over the study period but their numbers were probably lower than their actual population size. These species include the Accipiters - Sharp-shinned Hawk (*Accipiter striatus*), Cooper's Hawk (*Accipiter cooperii*), and Northern Goshawk, and several Buteos - Red-tailed Hawk (*Buteo jamaicensis*), Broad-winged Hawk (*Buteo platypterus*) and the provincially-threatened Red-shouldered Hawk (*Buteo lineatus*).

5.7 Classification of Bird Associations

A data set was developed based on importance values for all species observed at all stops at each of the 29 transects. The data set was used intact from the raw scores without any manipulation except for one record. There was one incident of Common Grackle (300 birds) recorded late in the breeding season in the cedar swamp at Alton. There were no other records for Common Grackle at this site during the study period season but there were occasional records at other times of the season. This record indicates the flocking pattern of this species in late summer as an early behaviour prior to migration. Similar behaviour was observed at another site, Speyside, but this occurred after the breeding season and was not recorded in this data set. A cluster analysis was run on the data with the Common Grackle record intact which produced a dendrogram with the Alton site as an extreme outlier and so it was decided to remove Common Grackle from this record and the analysis was run again.

A cluster analysis was completed for the 29 transects using TWINSPAN (Hill, 1979). The results of this analysis are presented in Figure 5.4. The cluster divisions of the sites are presented at the left side of the dendrogram. The first division reveals several broad groups with definite subgroups (Groups A-C). The larger Group I is composed of transects from upland forests, including both shallow bedrock sites and those on deep glacial deposits. It also includes many of the sites on the Escarpment face. Group II is

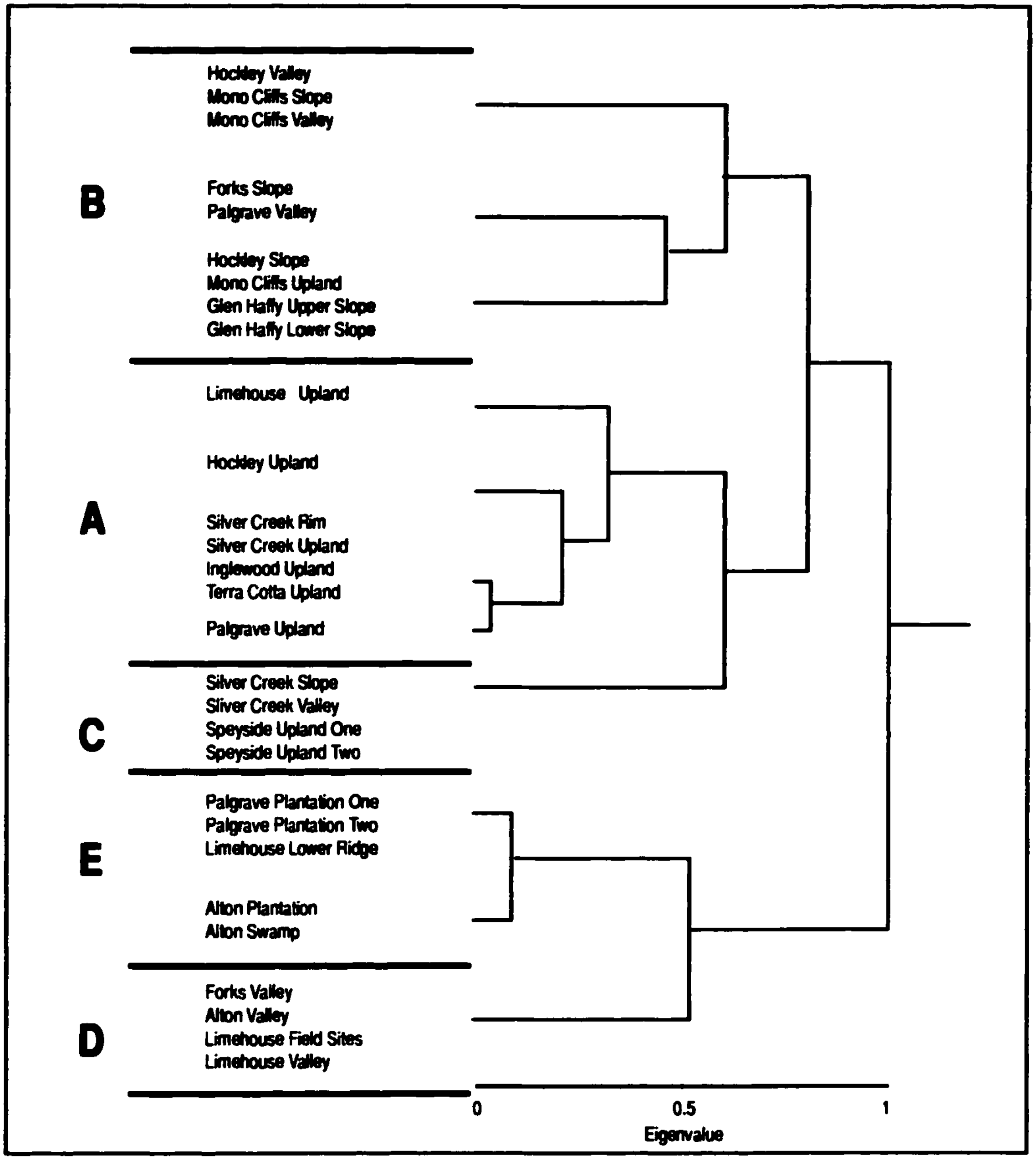


Figure 5.4 Dendrogram illustrating the results of a TWINSPAN analysis of the avian populations occurring at the twenty-nine sites. Similarity between avian associations increases from right to left.

composed of a smaller group of transects (Groups D and E) that includes the plantations, cedar swamp, and several of the open forest sites, including the stream channels and regenerating fields. Many of these sites have a strong coniferous component.

Group I is subdivided in the second division into two groups. One is a group that has many of the upland sites including those on deep glacial material and shallow bedrock (Group A); the other covers those sites mainly related to the face units (Group B). Group A includes transects on shallow bedrock at Inglewood, Terra Cotta, and Silver Creek as well as transects on deep deposits at Hockley and Palgrave. This group can be further subdivided at the third division, where a smaller group is formed that includes sites associated with natural and human disturbance and combines several upland sites from Speyside with face units from Silver Creek (Group C). Group B combines all of the face units except the two from Silver Creek as well as the valley sites from Mono Cliffs and Hockley.

Group II of the second division is also split into two groups. Group D is composed of sites found in the river channels at Forks and Alton as well as the regenerating forests at Limehouse. The final group, Group E, consists of plantations as well as the coniferous swamp at Alton and the stream and valley complex at Limehouse. However, before each of the bird groups is described, an overview of the results of the ANOVAs between the bird groups and the biophysical parameters will be presented.

5.7.1 Bird Associations and Biophysical Variables

The bird association groups were combined with vegetation structure indicators to assess the relationship between the pattern of bird populations and forest characteristics. This assessment was first addressed from a one-way ANOVA test to determine the variance between the averages of the vegetation indicators for each of the bird groups. The results show only one significant relationship at the confidence level of .01 - the ratios of deciduous to coniferous for the older stems (OLDDEC) (Table 5.11). At a confidence level of .05 there were correlations with multi-stem cover (MULTIBAS) and the ratio of deciduous and coniferous for younger stems (YOUNGSTEM). There were no significant relationships with the other variables, (OLDRATIO, MULTINUM, SNAGS, NEWSTEM, SAPLING, GRCOVER, and CANCOVER).

The distributions of the deciduous/coniferous ratio for the old and young stems had one of the strongest patterns between groups (Figures 5.5 and 5.6). For both these variables there is a general decrease in the average of percentage deciduous from Group A to Group E, although in both cases Group C is quite similar to A, and B and D are similar. The ratio for Group E is quite low, which is not surprising since these are primarily pine plantations. However, it is apparent in Figure 5.6 that there is an increase in the percentage of deciduous younger stems. The values for YOUNGDEC have a greater range than for OLDDEC, including the change in forest composition within the plantations. Other relationships will be discussed within the following bird group descriptions.

The results of the ANOVA for the physical variables did not reveal any strong correlations. The only variable that reached any level of significance was the transformed variable of land unit which was barely significant at .05 (Table 5.12). This reflects the distribution of transects especially within Group C, which are located on slope type B, and those in Group E, which are from the two sites not on the Escarpment. There was a higher level of human disturbance on average for transects in Groups D and E. The rest of

Table 5.11 ANOVA of vegetation structural parameters for the bird association groups identified by TWINSPAN

		Sum of Squares	df	Mean Square	F	Sig.
OLDRATIO	Between Groups	2155.973	4	538.993	2.215	.098
	Within Groups	5839.154	24	243.298		
	Total	7995.127	28			
YOUNGDEC	Between Groups	4340.076	4	1085.019	3.650	.018
	Within Groups	7135.096	24	297.296		
	Total	11475.172	28			
MULTINUM	Between Groups	288.159	4	72.040	2.404	.078
	Within Groups	719.264	24	29.969		
	Total	1007.423	28			
MULTIBAS	Between Groups	1032.171	4	258.043	2.851	.046
	Within Groups	2172.335	24	90.514		
	Total	3204.506	28			
SNAGS	Between Groups	77.104	4	19.276	.753	.566
	Within Groups	614.691	24	25.612		
	Total	691.795	28			
OLDSTEM	Between Groups	840.627	4	210.157	2.349	.083
	Within Groups	2147.153	24	89.465		
	Total	2987.779	28			
NEWSTEM	Between Groups	992.895	4	248.224	1.393	.266
	Within Groups	4276.551	24	178.190		
	Total	5269.447	28			
SAPLING	Between Groups	332.053	4	83.013	.543	.705
	Within Groups	3666.074	24	152.753		
	Total	3998.127	28			
GRCOVER	Between Groups	3678.998	4	919.750	2.326	.085
	Within Groups	9491.667	24	395.486		
	Total	13170.665	28			
OLDDEC2	Between Groups	2.58E+08	4	64551631.189	16.889	.000
	Within Groups	91729603	24	3822066.772		
	Total	3.50E+08	28			
CANCOV2	Between Groups	54340434	4	13585108.377	2.718	.054
	Within Groups	1.20E+08	24	4998503.405		
	Total	1.74E+08	28			

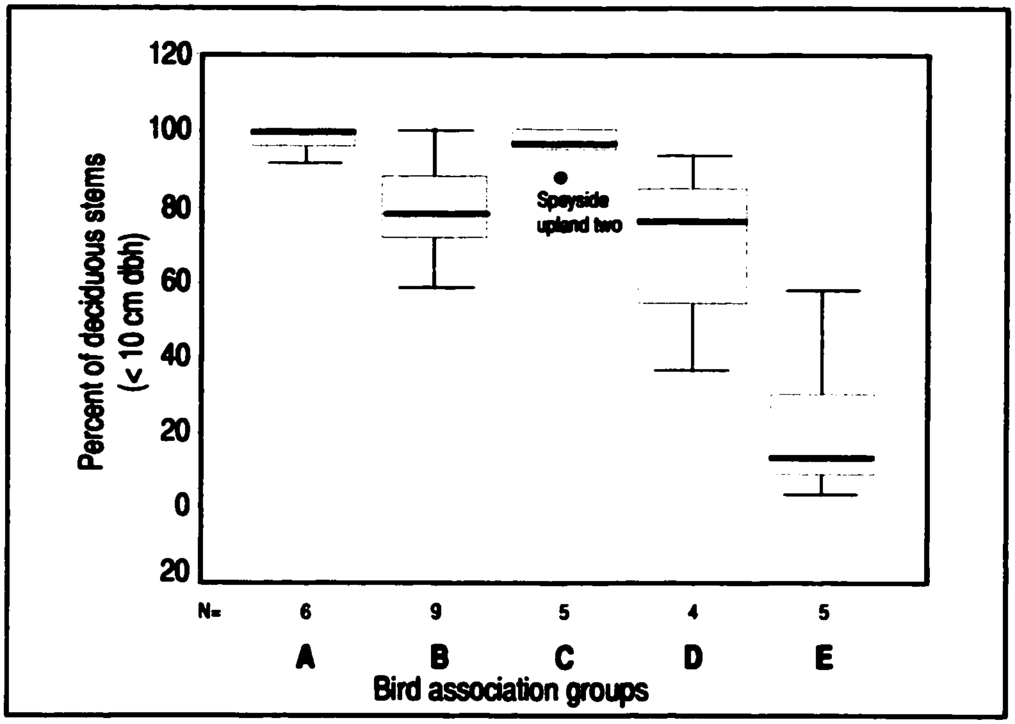


Figure 5.5 Box-plots of the ratio of old deciduous/coniferous stems for the bird association groups. The bird association groups were determined from classification analysis using TWINSPAN.

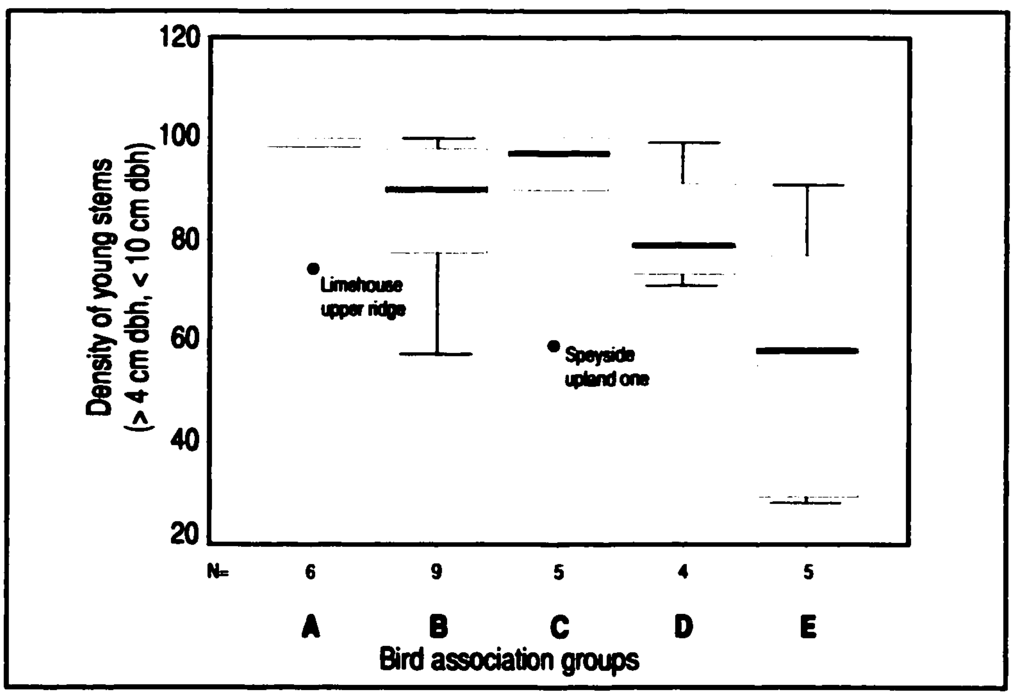


Figure 5.6 Box-plots of the ratio of young deciduous/coniferous stems for the bird association groups. The bird association groups were determined from classification analysis using TWINSPAN.

Table 5.12 ANOVA of physical parameters for the bird association groups identified by the TWINSPAN classification.

Physical characteristics		Sum of Squares	df	Mean Square	F	Sig.
NDISTLEV	Between Groups	5.894	4	1.474	.824	.523
	Within Groups	42.933	24	1.789		
	Total	48.828	28			
SITEPOS	Between Groups	2.394	4	.599	.693	.604
	Within Groups	20.726	24	.864		
	Total	23.120	28			
AZIMUT2	Between Groups	2998.163	4	749.541	2.311	.087
	Within Groups	7784.389	24	324.350		
	Total	10782.552	28			
LANDPOS2	Between Groups	417.690	4	104.422	1.683	.187
	Within Groups	1489.000	24	62.042		
	Total	1906.690	28			
LANDUT2	Between Groups	251.086	4	62.772	2.781	.050
	Within Groups	541.672	24	22.570		
	Total	792.759	28			
HDISLEV2	Between Groups	.490	4	.123	2.106	.111
	Within Groups	1.397	24	5.822E-02		
	Total	1.888	28			
ANGLE3	Between Groups	519.755	4	129.939	.915	.471
	Within Groups	3409.556	24	142.065		
	Total	3929.310	28			

the patterns between the physical variables and bird groups will be discussed in the following section.

5.7.2 Bird Association Group A

This group includes transects found on the limestone plains where there is shallow bedrock including Terra Cotta, Inglewood, Silver Creek upland and rim and Limehouse upland. It also includes several sites on deeper deposits including Palgrave and Hockley upland. All these sites are minimally impacted by natural and human disturbance.

The dominant birds of this group, as presented in Table 5.13 are primarily species typical of deciduous forest interior species in southern Ontario. The birds that scored the highest importance values are Red-eyed Vireo (37), Eastern Wood-Pewee (18) and Ovenbird (13). Edge and resident species also have moderate scores such as American Robin (15), Black-capped Chickadee (13) and White-breasted Nuthatch (10). Other associated species, some not included in Table 5.13, include American Goldfinch, Blue Jay, Veery, Brown Creeper, Hairy Woodpecker, Rose-breasted Grosbeak, Scarlet Tanager, and Wood Thrush.

Vegetation

This group is associated with deciduous forests, scoring very high values of deciduous ratios for both older and younger stems (Table 5.14). These variables are two of only several variables identified as significant from the ANOVA test (see Table 5.12). Old deciduous stems are significant at .01 while young stems are significant at .05. These forests are primarily sugar maple forests with white ash and American beech in the more mature stands. This group has higher scores for multistem dominance, which is significant

Table 5.13 Dominant bird species and bird association groups identified by the TWINSPAN classification. The numbers refer to the species Importance Values calculated as a score out of 200. These values have been calculated as a combined total for each association group.

DOMINANT BIRD SPECIES	BIRD ASSOCIATION GROUPS				
	GROUP I			GROUP II	
	Group A	Group B	Group C	Group D	Group E
Deciduous Interior					
Red-eyed Vireo	37	24	15	3	5
Eastern Wood-Pewee	18	12	12	1	5
Ovenbird	13	15	10	2	15
Black-throated Blue Warbler	1	5	-	1	-
Scarlet Tanager	7	7	5	1	1
Wood Thrush	7	5	6	1	1
Resident/Edge					
Black-capped Chickadee	13	25	14	29	41
Blue Jay	8	11	8	14	13
American Robin	15	13	9	13	11
Northern Cardinal	1	1	-	8	1
White-breasted Nuthatch	10	4	9	-	1
Hairy Woodpecker	5	4	3	1	1
Coniferous Interior					
Pine Warbler	-	1	1	5	18
Red-breasted Nuthatch	-	1	-	1	14
Yellow-rumped Warbler	-	-	-	-	10
Chipping Sparrow	-	-	-	-	9
Mixed/Disturbance					
Black-throated Green Warbler	1	13	1	4	3
Black-and-white Warbler	1	7	1	4	-
Mourning Warbler	-	-	4	2	-
Field/Shrub					
Song Sparrow	-	-	6	16	1
White-throated Sparrow	-	-	-	4	2
Common Yellowthroat	1	-	2	7	1
Indigo Bunting	3	-	1	13	4
Riparian					
Winter Wren	3	9	6	5	5
Northern Waterthrush	3	2	8	5	1
Veery	5	3	12	-	-

Table 5.14 Bird association group characteristics of related forest composition and structure. The bird groups are based on the TWINSPAN classification. Forest structure variables that had significant variance between groups are identified by the asterisk(s). The values for the ratios (old/young, old dec, and young dec) and cover (ground and canopy) are expressed as percentages. The values for the multi-stems (multistem and multibas), snags and stems (old stem, new stem and sapling) are averages of the observed totals. Forest composition and dynamics are based on the dominance of species in each forest layer.

Bird Group	Association Composition		Forest Structure Characteristics										
	Dominant Species	Forest Canopy	old ratio	old dec**	young dec*	multi stem	multi bas*	snags	old stem	new stem	sapling	ground cover	canopy cover
Group A	Red-eyed Vireo E. Wood-Pewee-Ovenbird	sugar naple white ash - American beech	70.0	97.5	99.1	11.9	20.6	6.5	25.0	15.4	16.0	39.0	85.7
Group B	Red-eyed Vireo-B.C.Chickadee B.Thr.Green Warbler-Winter Wren	sugar maple white ash - American elm	63.0	77.6	85.0	8.9	16.0	6.4	25.3	19.1	14.4	30.0	79.1
Group C	Red-eyed Vireo-B.C.Chickadee Veery-Northern Waterthrush	sugar maple white cedar - white ash	51.6	95.6	86.0	9.9	17.8	5.4	16.8	18.0	26.0	38.1	70.5
Group D	Black-capped Chickadee Song Sparrow-Indigo Bunting	white cedar American elm - white birch	25.7	69.0	82.3	14.8	27.7	5.69	19.4	34.2	15.7	66.0	52.0
Group E	Black-capped Chickadee Pine Warbler-Red-Br. Nuthatch	white pine - white Ash - sugar maple	68.0	21.3	57.3	4.2	7.0	10.4	34.6	17.3	21.2	43.0	61.1

** significant variance between groups at .01
* significant variance between groups at .05

at .05, and the highest canopy cover which is reflected in the low scores for ground cover, sapling and younger trees.

Geomorphic

The transects of Group A are predominantly from slope type B (Table 5.15). The slope angle has a lower range than most other groups. They are located mainly on the uplands on both shallow and deep surface materials, and have moderate scores for both natural and human disturbance.

5.7.3 Bird Association Group B

This is a large group that includes many sites found on the Escarpment face. These include all transects at Mono Cliffs, upland and stream transects, both face units at Glen Haffy, the face at Forks, as well as the valleys at Hockley and Palgrave.

In this group, Red-eyed Vireo is again the dominant bird with an importance value of 24 (Table 5.13). Species with lesser scores that could be considered sub-dominants include a mixture of species found in forest interior such as Ovenbird (15), Eastern Wood-Pewee (12), and Rose-breasted Grosbeak (10). Other interior species include Scarlet Tanager (7), and Wood Thrush (5). Resident and edge species include Black-capped Chickadee (25), American Robin (13), White-breasted Nuthatch (11), and Blue Jay (11). There are also several species that favoured the increase in mixed forests associated with these active slopes; these include Black-throated Green Warbler (13), Winter Wren (9), and Black-and-White Warbler (7).

Vegetation

This group is found in the slope forests of the Escarpment that often has a higher concentration of coniferous species, especially white cedar, as is evident in the deciduous

Table 5.15 Characteristics of the physical variables for the bird association groups identified by the TWINSPAN classification. Physical parameters that have been identified as showing variance between groups are identified by the asterisk(s). An explanation of each variable follows the descriptions in chapter four. The values for disturbance are averages of the combined scores.

Avian Groups	Dominant Bird Species	Land Unit*	Angle	Azimuth	Landscape Position	Site Position	Natural Disturbance	Human Disturbance
Group A	Red-eyed Vireo E. Wood-Pewee-Ovenbird	B	flat - 14°	NE	upland/ridge	plain/convex	2.14	2.29
Group B	Red-eyed Vireo-B.C.Chickadee B.Thr.Green Warbler-Winter Wren	A,C	flat - 26°	E	slope/valley	convex/ concave, plain	3.00	1.56
Group C	Red-eyed Vireo-B.C.Chickadee Veery-Northern Waterthrush	B	flat - 21°	E-SE	upland/slope	plain-slope	2.50	1.75
Group D	Black-capped Chickadee Song Sparrow-Indigo Bunting	B,C other	flat	none	upland/ridge/ valley	plain/convex	2.00	2.50
Group E	Black-capped Chickadee Pine Warbler-Red-Br. Nuthatch	other	flat - 16°	SW-NE	upland/valley	slope/valley	1.80	3.80

* significant variance between groups at .05

ratio (78%) (Table 5.14). The primary cover is still dominated by sugar maple but there is a higher diversity of secondary species such as basswood and ironwood. This group also has lower values for the density of stems, groundcover and canopy cover.

Geomorphic

These transects include many of the sites on the steeper slopes of the Escarpment (Table 5.15). The transects are primarily those found on larger slope systems that are typically slope types A and C. These sites have the highest score of natural disturbance as well as the lowest scores of human disturbance.

5.7.4 Bird Association Group C

This group consists of four transects - the face and valley units at Silver Creek and the two upland trails at Speyside. It is not dominated by any one species, but is a mixture of resident edge species, upland forest interior and a group associated with riparian and disturbed forests. The dominant resident and edge species include Black-capped Chickadee (14), White-breasted Nuthatch (9) and American Robin (9). Birds of the deciduous forest interior also have relatively high values including Red-eyed Vireo (15), Eastern Wood-Pewee (12) and Ovenbird (10). Species associated with the forested and shrub riparian transects are also present; these included Veery (12), Northern Waterthrush (8), and Winter Wren (6). Shrub-associated species include Song Sparrow (6) and Mourning Warbler (4).

Vegetation

The forests associated with this group are dominated by sugar maple and have deciduous ratios very similar to Group A (Table 5.14). Tree densities are slightly lower than many other groups but this group has the highest sapling density, reflecting the disturbance levels at many of the stops. This is also evident with the larger level of ground cover and related decrease in canopy cover.

Geomorphic

This group is closely related to Group A with respect to landform characteristics (Table 5.15). It is also associated with slope type B. The landscape position is primarily upland and face. This group has slightly higher natural disturbance and slightly lower human disturbance scores. The angle of the slopes ranges from flat plains to 21° and faces primarily eastward.

5.7.5 Bird Association Group D

Four transects make up this group, which includes less forested transects along the river channels at Forks and Alton and the two transects at Limehouse. One transect stands out from the rest, Limehouse, since it is a regenerating old-field. The transects vary in stream energy - the Alton unit is a slower, meandering channel on a low-lying plain while the Forks site is a narrow, high-gradient stream found directly below a major waterfall.

The dominant birds for this group include edge and resident species such as Black-capped Chickadee (29), American Robin (13), and Blue Jay (14). This group is also dominated by field species including Song Sparrow (16) and Indigo Bunting (13) (Table 5.13). Associated species include Northern Cardinal (8), Common Yellowthroat (*Geothlypis trichas*) (7), and White-throated Sparrow (4). There are also moderate scores for a number of forest birds including Northern Waterthrush (5), Winter Wren (5), Black-throated Green Warbler (4), and Black-and-white Warbler (4).

Vegetation

White cedar is one of the more dominant species in this group, although a strong mix of deciduous trees is evident with the relatively high deciduous ratio (69). This group had the highest level of multistems, as depicted in the results of the ANOVA for vegetation groups (Figure 5.12). There is a close association between this group and Group D of the vegetation classification. This group also has high values for stem density, especially young stems which are predominant in stream valleys. The largest score for ground cover was recorded by this group and consequently, it also has one of the lower measures of canopy cover.

Geomorphic

This group has sites primarily on upland plains or in stream valleys. There are low measures of slope angle which is reflected in the site and landscape positions on plains. Natural disturbance is lower than in most of the groups, while human disturbance has the second highest value (2.5) mainly because of forest removal and plantations established at Limehouse (Table 5.15).

5.7.6 Bird Association Group E

This group includes four sites, three of which are mature pine plantations at Alton and Palgrave as well as the coniferous valley at Alton. All of these sites are found beyond the Niagara Escarpment and are sites severely modified by human plantings. The only site within the Escarpment complex is the valley at Limehouse.

As in Group D, the dominant species is Black-capped Chickadee (41) (Table 5.13). Other edge and resident species with high scores include Blue Jay (13) and American Robin (11). There is also a group of birds that are typical of coniferous forests -

Pine Warbler (*Dendroica pinus*) (18), Red-breasted Nuthatch (14) and Yellow-rumped Warbler (*Dendroica coronata*) (10). Surprisingly, Ovenbird (15), often associated with deciduous forest interior, also has a high score as does Chipping Sparrow (*Spizella passerina*) (9) which is often considered an edge species (Canterbury et al., 2000). Species with lower importance values include Cedar Waxwing (8), Winter Wren (7), Brown Creeper (7) and Eastern Wood-Pewee (5).

Vegetation

This group is found primarily in older coniferous plantations and swamps. Limehouse valley is likely part of this group, since it has a high percentage of older white cedar along the river channel and a number of old-growth white pine along the associated valley ridge. The deciduous ratio is very low in the upper canopy, but as mentioned earlier these forests are currently in transition and there is a high level of deciduous stems in the younger levels (Table 5.14). This group also has the lowest scores for the multistems, a reflection of the management strategies in the plantations which produces straight, single stem poles. This group also has a higher number of snags which could be attractive to cavity-nesters such as Black-capped Chickadee. This group also has the highest record of stem density, again a reflection of planting strategies. Finally, this group has moderate ground cover and canopy cover.

Geomorphic

These transects are located primarily at control sites on undulating slopes related to glacial deposits. The slope angle has a relatively wide range from flat to 16°. The landscape position is mainly on plains or convex slopes. Natural disturbance has the lowest score of the five groups while human disturbance scores are the highest of all the groups (3.8) (Table 5.15).

5.8 Discriminant Analysis - Patterns between Bird Association Groups and Habitat

As was completed for the vegetation groups, the bird association groups were compared, by discriminant analysis, to the combination of vegetation structure and geomorphic indicators which can be combined as habitat indicators. The biophysical indicators for the analysis were determined based partially on the results of the ANOVA which identified those that had significant patterns with the bird groups. From these analyses it was decided to include vegetation structure indicators OLDDEC, YOUNGDEC, MULTIBAS, and OLDSTEM and geomorphic variables HDISTLEV, LANDPOS and NDISTLEV. It was decided to include several other variables to determine if there were underlying patterns that would become more evident with the combined, multivariate analysis. These included vegetation indicators OLDRATIO and SNAGS and geomorphic indicators SITEPOS and ANGLE.

The results indicated that one variable dominated the distribution of variance between the five groups at the .01 level. This created only one strong axis in the analysis, dominated by OLDDEC, the ratio of older deciduous stems to coniferous stems as was predicted with the ANOVA (Table 5.12). There are no other strong relationships within this function but there were correlations with OLDRATIO. This included small positive correlations with YOUNGDEC, ANGLE AND SITEPOS and negative correlation with SNAGS, HDISTLEV, and MULTIBAS.

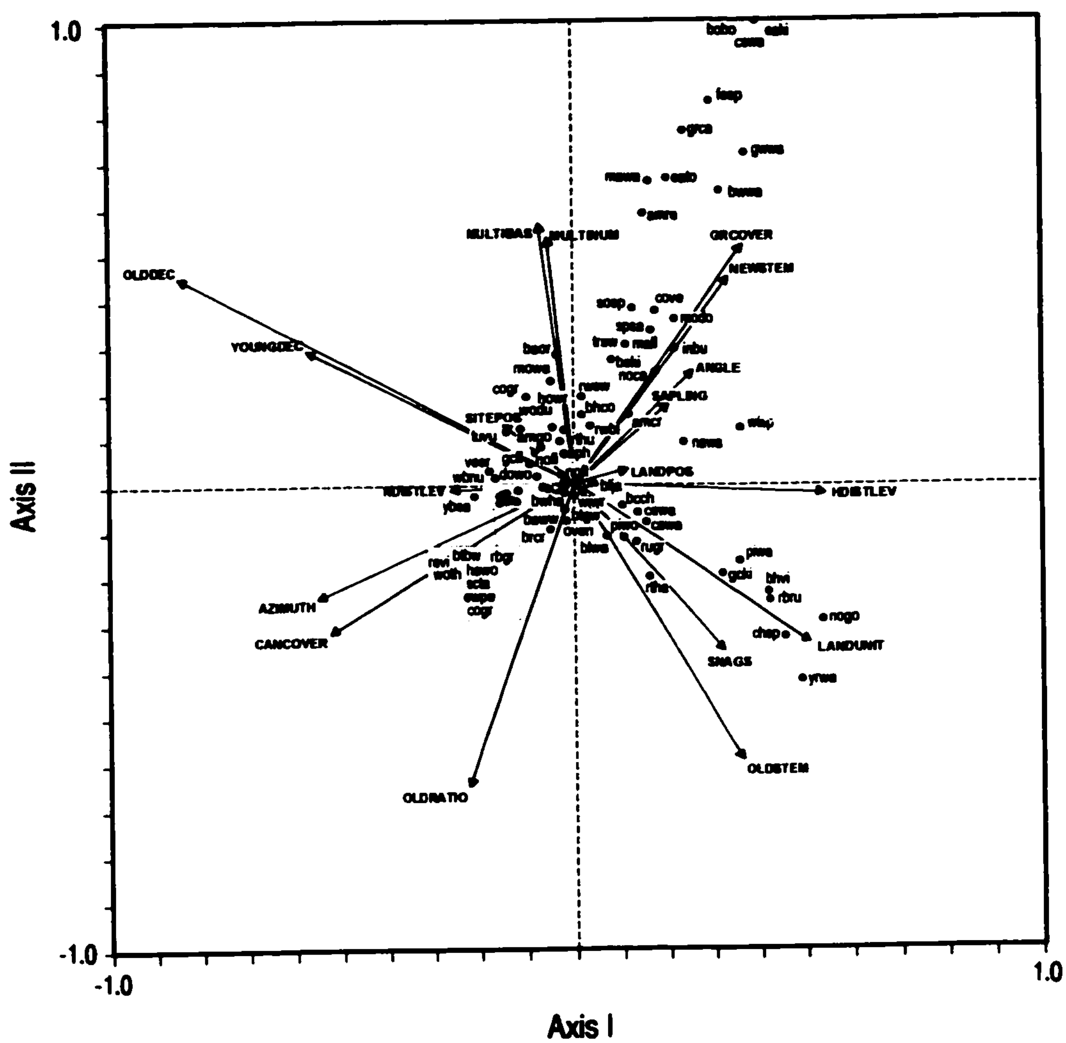


Figure 5.7 Relationships between eighteen biophysical variables and the seventy-one bird species plotted within axes I and II of a CCA ordination. Arrows pointing in the same direction indicate positively correlated variables; perpendicular arrows suggest a lack of correlation; arrows pointing in opposite directions indicate negatively correlated variables. Species codes are provided in the Appendix.

5.9 Canonical Correspondence Analysis

The results of the CCA of the bird data set with the biophysical variables are presented in Figure 5.7 and Table 5.16. The first or X-axis shows a strong relationship between species and vegetation type, both the ratio of old deciduous and young deciduous stems. There is also a correlation to site position and to a lesser degree natural disturbance. At the other end of the X-axis, there is a clustering of species related to the mature pine plantations of Group E. There is also a relationship with older stem density and snags, which were identified as highest in the plantations (Table 5.14), and to a lesser degree human disturbance. This variable is actually divided between the forest and field species which weakens the pattern. Therefore, along the primary axis there is a shift from birds of the mature deciduous forest, such as Red-eyed Vireo, Wood Thrush and Veery to Pine Warbler, Northern Goshawk, and Yellow-rumped Warbler, typical of the coniferous plantation. In between these extremes are a group of species that represent mixed forest cover, or those with a more northern tendency. These include Blackburnian Warbler, Ruffed Grouse (*Bonasa umbellus*) and Canada Warbler.

Table 5.16 Results of the CCA of bird species and biophysical variables for the 29 transects on the Niagara Escarpment. The total unconstrained eigenvalue was 1.84. Species ordination diagram is shown in Figure 6.7.

	Axis 1	Axis 2
Canonical eigenvalues	0.32	0.29
Species variance accounted by axes (%)	17.2	15.7
Species variance accounted by arrows (%)	22.7	20.6
Species-environment correlations	0.971	0.961

The second axis reflects a continuum of age with the OLDRATIO variable at one end of the axis and a group of biophysical variables typical of young, regenerating forests at the other. This includes ground cover, new stem density, and sapling density. Many of the birds related to the older forest are linked to the high deciduous ratio, which weakens the pattern. There is a strong alignment of species along the positive end of the Y-axis. These species are related to the open forests and fields at these sites. Typical field species included Eastern Kingbird, Field Sparrow (*Spizella pusilla*), Common Yellowthroat and Song Sparrow. Also included in this group are a number of species that are found along open stream channels including Belted Kingfisher (*Ceryle alcyon*), Spotted Sandpiper and Mallard. This is evident by the position of the angle and landscape position variable. The positive correlation with the variables, ANGLE and LANDPOS, reinforces the nature of these sites as low-lying, water receiving valleys.

5.10 Comparison of Bird/Vegetation Groups

In the final analysis, the results of the clusterings were compared to determine similarities and overlap in an attempt to determine combined biological groups that relate to the physical system. This allows the development of functional land units that will define the Escarpment landscape. To complete this comparison, the two classifications were aligned to determine the similarity within the groups. It is emphasized that this is strictly a subjective analysis of similarity to assist in developing a core group of biophysical land units applicable at the landscape scale.

The two classifications are presented in Figure 5.8. A great deal of overlap exists between the two, with combined groups between the two lists overlapping within one group or with components of the next related group. Those groups that show a

Figure 5.8 A comparison of the bird and vegetation groups identified in the cluster analyses. Similar groups are aligned opposite each other, with coincident members also arranged opposite each other, especially when they had equivalent combinations in an opposite group.

VEGETATION ASSOCIATIONS			BIRD ASSOCIATIONS		
GROUP I	Group F	Alton plantation	Alton plantation	Group E	GROUP I
		Palgrave plantation one	Palgrave plantation one		
		Palgrave plantation two	Palgrave plantation two		
	Group E	Limehouse valley	Limehouse valley		
		Limehouse upper ridge	Alton swamp		
		Limehouse lower ridge	Limehouse lower ridge	Group D	
		Limehouse field	Limehouse field		
GROUP II	Group D	Alton valley	Alton valley		
		Forks valley	Forks valley		
		Alton swamp	Silver Creek valley	Group C	GROUP II
	Group C	Silver Creek rim	Speyside upland two		
		Silver Creek upland	Speyside upland one		
		Silver Creek slope	Silver Creek slope		
		Mono Cliffs slope	Mono Cliffs slope	Group B	
		Forks slope	Forks slope		
		Hockley valley	Hockley valley		
	Group B	Glen Haffy lower slope	Glen Haffy lower slope		
		Palgrave valley	Palgrave valley		
		Mono Cliffs valley	Mono Cliffs valley		
		Silver Creek valley	Hockley slope		
		Speyside upland two	Mono Cliffs upland		
		Speyside upland one	Glen Haffy upper slope		
		Terra Cotta upland	Terra Cotta upland	Group A	
		Inglewood upland	Inglewood upland		
	Group A	Glen Haffy upper slope	Silver Creek upland		
		Mono Cliffs upland	Limehouse upper ridge		
		Hockley slope	Silver Creek rim		
		Palgrave upland	Palgrave upland		
		Hockley upland	Hockley upland		

Figure 5.9 Classification of land units (A-G) based on the combination of bird and vegetation groups as identified in the TWINSPAN classifications. This set of land units is described in Chapter Six.

VEGETATION ASSOCIATIONS				BIRD ASSOCIATIONS		
GROUP I	Group F	Alton plantation	A	Alton plantation	Group E	GROUP I
		Palgrave plantation one		Palgrave plantation one		
		Palgrave plantation two		Palgrave plantation two		
	Group E	Limehouse valley		Limehouse valley		
		Limehouse upper ridge		Alton swamp		
		Limehouse lower ridge	B	Limehouse lower ridge	Group D	
		Limehouse field		Limehouse field		
GROUP II	Group D	Alton valley	C	Alton valley		
		Forks valley		Forks valley		
		Alton swamp		Silver Creek valley	Group C	GROUP II
	Group C	Silver Creek rim		Speyside upland two		
		Silver Creek upland		Speyside upland one		
		Silver Creek slope	D	Silver Creek slope		
		Mono Cliffs slope		Mono Cliffs slope	Group B	
		Forks slope		Forks slope		
		Hockley valley	E	Hockley valley		
	Group B	Glen Haffy lower slope		Glen Haffy lower slope		
		Palgrave valley		Palgrave valley		
		Mono Cliffs valley		Mono Cliffs valley		
		Silver Creek valley		Hockley slope		
		Speyside upland two		Mono Cliffs upland		
		Speyside upland one		Glen Haffy upper slope		
		Terra Cotta upland	F	Terra Cotta upland	Group A	
		Inglewood upland		Inglewood upland		
	Group A	Glen Haffy upper slope		Silver Creek upland		
		Mono Cliffs upland		Limehouse upper ridge		
		Hockley slope		Silver Creek rim		
		Palgrave upland	G	Palgrave upland		
		Hockley upland		Hockley upland		

relationship have been identified in Figure 5.9 by outlining the group in bold and assigning a letter code (A-G). These groups will be considered as core land classification units to be discussed in the following chapter.

Bird and vegetation groups have been described individually and the resulting land units will be described in Chapter Six. At this time, the core groups only will be identified. In total, seven groups have been determined from this classification. Several (Groups A and B) are related to human disturbance, including plantations (A) and regenerating fields (B). There are several groups related to valley units. Group C includes those sites along river channels that have open riparian communities, possibly related to human modification. Group E are Escarpment river channels and lower concavities either in drainage zones or small stream systems. Natural disturbance and face units characterize Group D. The final two groups both include a pair of sites that could be considered the core sites for groups centred on the uplands. Group F represents uplands on the bedrock plains with shallow surface materials and Group G are sites on uplands that have deep glacial deposits and rolling topography. Finally, the remaining two sites do not constitute a group but are characteristic of separate landscapes. This includes the Alton swamp and Silver Creek Rim.

5.11 Summary

The results of the analyses have revealed a number of patterns both between the vegetation and physical systems as well as the avian component and the vegetation and geomorphic complexes. From the cluster analysis, forest and avian groups were presented that are associated with the Escarpment land units. The vegetation classification identified six groups. The main division was between sites with obvious human modification, plantations and regenerating old fields and orchards, and those that constituted natural forests. The natural forests could be further divided between sites in valleys, faces and uplands, although Group B is a combination of valley and upland sites with poor drainage. The bird groups have similar divisions, there were two main groups divided by vegetation cover and indirectly by human disturbance. The first group was subdivided between sites with plantations and high coniferous forest cover and those with open riparian valleys and fields. The other main division occurs between stable upland forests and active slopes.

The combined results of the discriminant and ordination analyses revealed several patterns. The distribution of forest associations is related to landscape position and associated processes. Two of the more important factors are human and natural disturbance. Moisture was also considered a significant control indirectly based on the importance of physical variables such as landscape position and slope angle. Avian population patterns were not as strongly linked to the landform variables. The dominant control of bird distribution was the forest composition, specifically the ratio of deciduous cover and the extent of forest cover and fields.

These results reveal the complexity of the Escarpment land systems, but also some overlying relationships between the geomorphology, vegetation and avian species. Wildlife habitat is determined by the combinations of geomorphic form and process and the resultant vegetation cover. To take this information and make it applicable in land use decisions requires developing a set of relationships between the geomorphic form and process, the vegetation cover and related bird populations. These descriptive-type models can be developed for the main land units identified in this chapter. In the following chapter, this information will be used to construct a series of descriptive models that attempt to describe the interrelationship between biological and physical components.

Chapter Six
Vegetation, Bird and Land Systems

6.0 Introduction

In this chapter, the results of the field work and data analysis are combined to provide an interpretation of the structure and function of the Escarpment landscape systems. This will begin with examining the information obtained on the face units. A model will be presented linking the vegetation communities and dynamics with slope processes. This will then be discussed with respect to previous knowledge of Escarpment slope systems, concluding with a general Escarpment Slope Model (ESM). This procedure continues with the upland and valley units and similar models are presented.

In the second section, the results of the bird study will be examined. Diversity and abundance of species will be considered with respect to the components of each landscape unit. It will provide a framework connecting the bird population distributions with the geomorphic landform and processes and the vegetation structure and dynamics. The relationships of birds to the biophysical system will be assessed and incorporated into models for each of the Escarpment landscape systems.

In the third section, the results of the combined biophysical information and wildlife populations are considered for face units as well as the surrounding landscape sites. This combines the units from the uplands, the faces and the valleys to produce a more comprehensive understanding of the functioning of the Niagara Escarpment landscape system. This section will address the relationships between the combinations of these units within the framework of the Escarpment Landscape Model (ELM). This produced nine land units, based on the results of the vegetation and avian classifications and ordinations as well as field interpretation of structure and process in these systems.

The results of the geomorphic and vegetation analysis produced several patterns. Although the Escarpment landscape is a complex set of systems, there are several dominant controls that help to organize the vegetation communities in relation to the landforms and biophysical processes. There were differences between the uplands of the northern and southern sections of the research site, as well as differences between land units and site. Human disturbance within the forest was situated more on the upland portions of the Escarpment while higher magnitude natural disturbances were likely on the steeper face segments and to a lesser extent in stream valleys with steeper gradients and high stream flow. Although moisture levels were not measured directly, it is also evident from the investigation of forest dynamics and from field observations that moisture levels are also related to these patterns. Thus the Escarpment landscape is a function of the combined effects of the landform pattern and the overlying natural and human disturbances. This creates a complexity of environmental controls that leads to a complex biophysical system which adjusts to the pattern of disturbance and stress.

6.1 Geomorphic/Vegetation Systems

The results of the analysis separated the vegetation communities into several groupings that reflected these physical controls. The main controls found in the discriminant analysis created a pattern that was determined by disturbance levels and possibly moisture. These are related to the micro-environment and the geomorphic processes. However, at the larger scale, the main controls that distinguish the initial grouping of the vegetation communities were divisions based on human disturbance and landform. The first division in the cluster analysis occurred between the natural forests and the plantations. The next major division separated the open riparian valley units from the upland and slope units. Several groups can be identified within the larger group of face and upland units. This includes poorly drained uplands on shallow bedrock, face and rim units, and deep glacial deposits on upland units. In general, the distribution of vegetation will be related to the combination of micro-environment or stress, disturbance and biological competition (Grime, 1977; Southwood, 1988).

Landscape Position

One of the dominant controls identified through a combination of the analyses is the position of the transect in relation to the Escarpment. As discussed in Chapter Four, landform characteristics such as slope angle and landscape position are general characteristics that serve to identify underlying controls such as moisture and energy (Osterkamp et al., 1995; McGarigal et al., 2000). In this case, there are several factors that differ between landscape position. All of the sites in Group D are linked to stream flow or poorly drained lowlands. For this study, all of the valleys that were associated with the Escarpment had some flow of water associated with them. This is a common pattern on the Escarpment, as water draining these slopes will flow through pre-existing drainage networks, such as re-entrant valleys (Straw, 1968) or create new channels through erosion. Moisture was also a factor for upland and face units where there was poor drainage and ponding of water.

Human Disturbance

The other main control that was determined through the analysis was the importance of human disturbance in modifying the vegetation cover. The most obvious group was F which was dominated by pine plantations. Human removal of the natural forest cover and replacement with a different species will obviously have a major impact on the vegetation community. This was evident in this study where several large plantations were quite different in many areas, including vegetation structure. One of the strongest patterns in vegetation structure was the variation in the coniferous and deciduous ratios. Other structural differences were identified as well, including the density of stems and the lack of multiple stems.

Group E had a moderate level of human disturbance including extended trail systems, selective logging and small plantations. These disturbances produced local patterns in the vegetation that led to a mixed forest cover with varying ratios of deciduous and coniferous cover. These patterns created a relatively diverse collection of species and there were a number of species that attained a higher level of importance there than on less disturbed sites. Species such as white ash, white birch and American elm scored relatively high when they acted as successional species that filled the gaps created from stress and disturbance from small clearances.

Natural Disturbance

Natural disturbance was not as dominant a control and there was no obvious group that was strictly related to natural disturbance. This could be a reflection of the limited number of sites with strong disturbance as well as the restricted nature of natural disturbances. Unlike the human disturbance found in the plantations or the old fields, natural disturbances are usually localized events, such as landslides which only extend across a single stop along a transect. These tended to act more like the local human disturbances described for Group E. The sites with higher scores of natural disturbance are found in Group C and to a lesser extent in Group B. Group C represents those sites on the slopes and the shallow upland plains, and includes sites at Mono Cliff and Silver Creek where the slopes are more active or experience more stress. The result is a more diverse forest cover and a denser cover of successional or secondary species. This group had higher levels of white birch, ironwood and basswood. Disturbance in the stream valleys creates a dynamic floodplain, especially in the high-gradient streams. However, the impact this has on forest cover is not as evident as moisture levels are more likely the dominant control of the species patterns. Species such as eastern white cedar, American elm, balsam poplar and black ash were found in the moister low-lying areas.

Bedrock Geology and Glacial Material

Another strong difference between Group A and B is the depth to bedrock and local topography. In Group A, the sites are located on upland deposits of glacial till and stratified drift. This is in the central area of the Escarpment where the Oak Ridges Moraine abuts the Escarpment creating a series of small moraines, kames, and related glacial features that override the Escarpment landscape. In contrast, further south, including a number of the sites found in Group B, the upland has shallow soils sitting on bedrock plains of dolostones which are dotted with small, poorly drained depressions and seasonal ponding. The effect on the vegetation cover is important in that it adds a separate community to the system, dominated by silver maple and red maple. There is still a strong presence of the species typical of the upland deciduous forests including sugar maple, white ash, eastern hemlock and American beech, but the overall pattern is more heterogeneous than on the deep, glacial uplands.

6.2 Geomorphic/Vegetation Face System

A model representative of the face units was created to summarize the complex of geomorphic processes and related forest communities and dynamics. Figure 6.1 presents this in a schematic diagram that identifies the level of disturbance or stress, the type of geomorphic processes and landforms, and the vegetation communities that are related to each. It also includes the general pattern of cycling of species that occurs within the forest cover.

Creep/Sheetwash

The bottom of the model represents faces that have a low level of disturbance, and are shaped primarily from gravitational forces moving material downslope by sheetwash or soil creep. These processes will tend to smooth out the slope of the face. The forest cover on these slopes is principally sugar maple and is associated with other trees typical of mature northeastern forests, including eastern hemlock and American beech. Other trees found in the canopy in low numbers include butternut, American elm, basswood and white ash; these could be remnants of more open canopies. Overall, the forest has a lower diversity of species and replacement of the forest cover is usually by gap replacement of individuals or small groups of trees (often sugar maple) that have suffered treefall from windthrow or similar processes.

Karst

Sites that experience extensive weathering from karst, such as found at the rim of the bedrock on type B slopes with almost indiscernible cliff faces, will have small gaps in the forest. These are sites of low to moderate disturbance and stress which, depending on

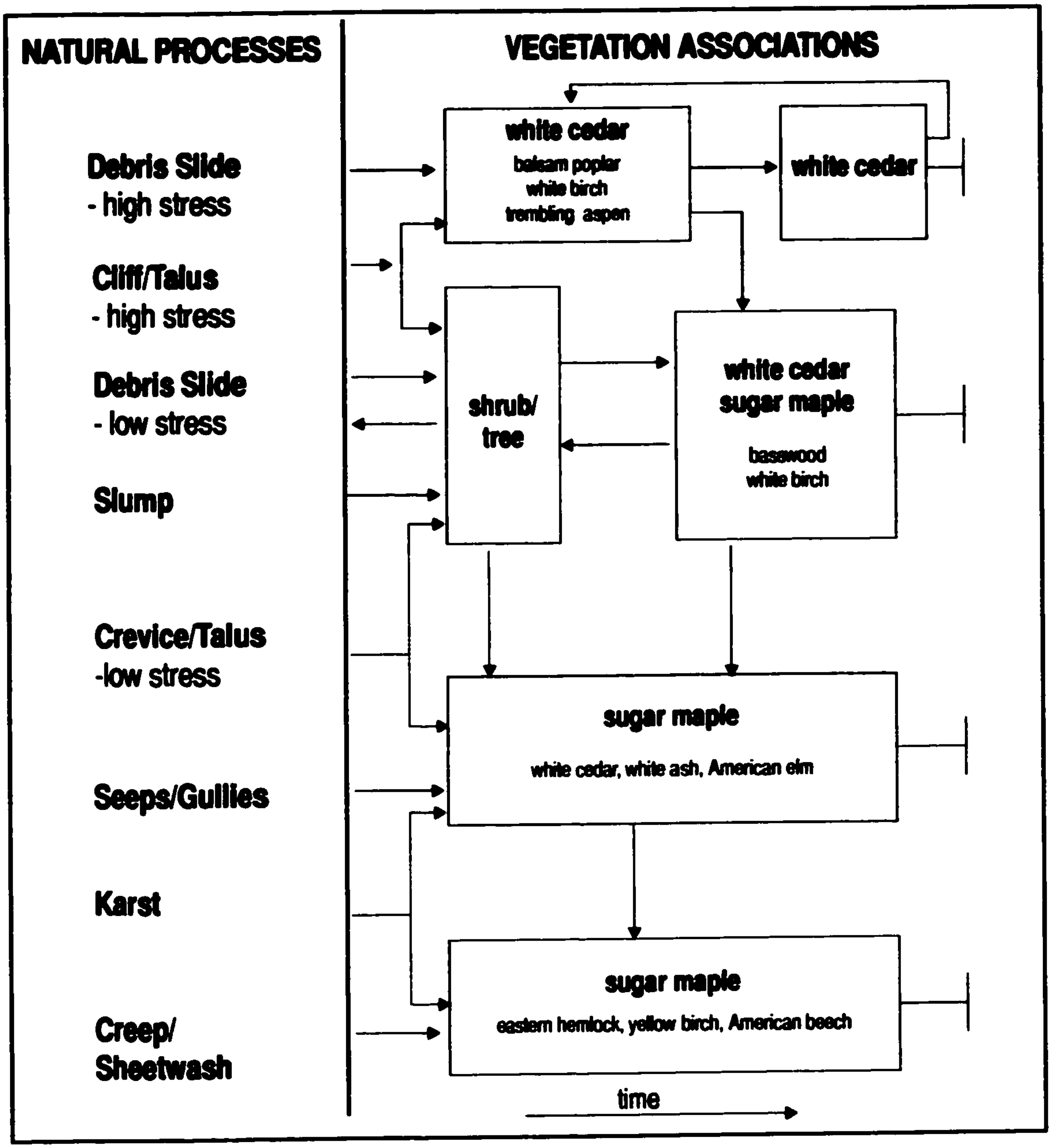


Figure 6.1 Relationships between geomorphic processes and vegetation communities for Escarpment slope units. The vegetation associations are representated by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

the level of each, will affect the forest cover. When there is little disturbance the resultant forest cover will be similar to the sugar maple forest described above. However, as the cliff face increases and weathering creates greater crevices and talus slopes, the forest cover will change. Typically, the dominance of the variety of species increases; sugar maple still dominates but not as strongly as in the low disturbance regime. It is joined in greater numbers in the canopy by species such as white ash, American elm, white cedar, and basswood. The importance of the undergrowth also increases, as shrubs and smaller tree species become an important component of the understory, especially species such as mountain maple and alternate-leaved dogwood.

Seeps/Gullies/Slumps

Another form of moderate disturbance is the addition of moisture to the face. This can alter the system in several ways. On some slopes, water enters the surface along seeps, where there is weather-resistant rock such as dolostones and sandstones. In some cases, this produces minor changes in the surface flow which weakens the slope, releasing blocks and material downslope. For example, one stop at Hockley had a greater presence of white ash combined with the sugar maple cover and a large number of alternate-leaved dogwood stems in the understory (Appendix A, Figure A.12, Transect 1, stop D). When stress is increased on the slope, small debris slides can occur, especially on steeper slopes such as at the Forks where resistant bedrock layers are present. At this site, a series of small slides has occurred along the lower edge of the buried bedrock layer. As the size of the debris slide increases, the vegetation cover will also change. With increased disturbance there is greater diversity of vegetation and the regenerating layer will be a greater mixture of species, typically sugar maple, white cedar, basswood and white birch.

In other situations, moisture does not lead to disturbances of the surface material in the form of slides, but its presence in the form of small streams and seeps, attracts species that prefer a wetter environment. This occurs where the face is less steep and is more common on the lower slopes and concavities. The effect is an increase in the diversity at the site with a combination of drier ridges and wetter concavities. Similarly, moisture can have an impact in the lower section of the face or the concavity, if the stream channel runs parallel to the base of the slope. As before, the addition of moisture increases the diversity. Often the dominant forest cover is still sugar maple, with eastern hemlock and white ash. However, there is a longer list of associated species found on these slopes including American elm, eastern white cedar, black ash and basswood.

Another type of moderate disturbance and stress occurs on upper slopes, especially at the Forks, where stratified drift deposits create dry conditions. At these sites, soil is limited and consequently, the forest cover is quite diverse, a mixture of eastern white cedar, white birch, basswood and sugar maple. Similar diversity was found in the lower strata, where smaller stems were dominated by ironwood with eastern white cedar, white ash and trembling aspen.

Crevice/Talus

A pattern similar to the one described above occurred on the talus slopes found below cliff faces, especially those at Mono Cliff. Regeneration on the blocks and talus below the cliff face creates a forest that is quite mixed, including sugar maple, eastern white cedar, trembling aspen, white birch and basswood and in lower numbers American elm, balsam fir, yellow birch and American beech. However, the forest structure differs from the slope at Forks; it is more open and there is a greater jumble of shrubs, trees and other material. This allows for greater development of an extensive undergrowth with species such as mountain maple and alternate-leaved dogwood which dominate the upper slope.

The exposed bedrock of these small cliff faces creates a stressful environment. The talus development is not as great on a large cliff but there is more breakdown of the bedrock at the small cliffs which leads to a mixture of bedrock, talus, and fallen trees. This creates a stressful environment where the soils are shallow and water flows into the bedrock readily. The vegetation response to this stress is an increase in species diversity, particularly successional and gap species such as white ash, basswood and ironwood. These species usually occupy a subordinate role in forest dynamics but have an increased importance in this canopy. There is also an extensive cover of shrub and small tree species such as mountain maple and alternate-leaved dogwood that take advantage of the gaps in the forest cover. The overall effect is a different forest cover at the face of the exposed bedrock, shifting from a large canopy with a lower strata of replacement trees to one with several lower strata including shrubs, saplings, young and older trees. There are also gaps created in the canopy that allow greater light penetration.

Cliff/Talus

The level of stress and disturbance increases with the rate of rock delivery and the extent of the cliff face. As shown in Figure 6.1, the cliff/talus system leads to several communities including a system similar to those on the slides where regenerating surfaces encourage the development of a combined shrub and tree cover. Alternatively, where the build-up of talus is substantial, the site is usually colonized by white cedar.

This process is most related to slope type A found at Mono Cliff. The steep cliffs create slopes with a distinctive lower ridge of large blocks that are replaced by smaller talus as one approaches the cliff face. The large blocks are from an earlier period, likely post-glacial, when they were released from the cliff face and toppled downslope by tension release. More recently the slopes have been shaped by talus accumulation from weathering processes on the cliff face. There was no evidence of recent large blockfalls and they are not considered a common occurrence on the Escarpment (Moss and Milne, 1995).

Debris Slides

Several sites have recently experienced moderate to large debris slides. Response to these disturbances can take two pathways (Figure 6.2), one in which the slide 'benefits' the forest system by providing sites high in nutrients and lower stresses and another in which it is more of a 'detriment', creating a site of higher erosion and more stressful conditions. These terms are only used to describe the resulting conditions - it is recognized that both pathways are important components of the overall system.

On the left side of Figure 6.2, the debris scar is a site of active vegetation re-establishment. The scar surface will initially be a mixture of seedlings, shrubs, herbaceous plants, and the individual trees that survived the event. The scar is a site of improved resources which means it is receiving moisture and nutrients. Typically, this occurs on the lower sections of the scar or on benches where the slide material has been deposited. As the site enriches, the scar recovers to a mixed surface of trees, saplings and shrubs. With

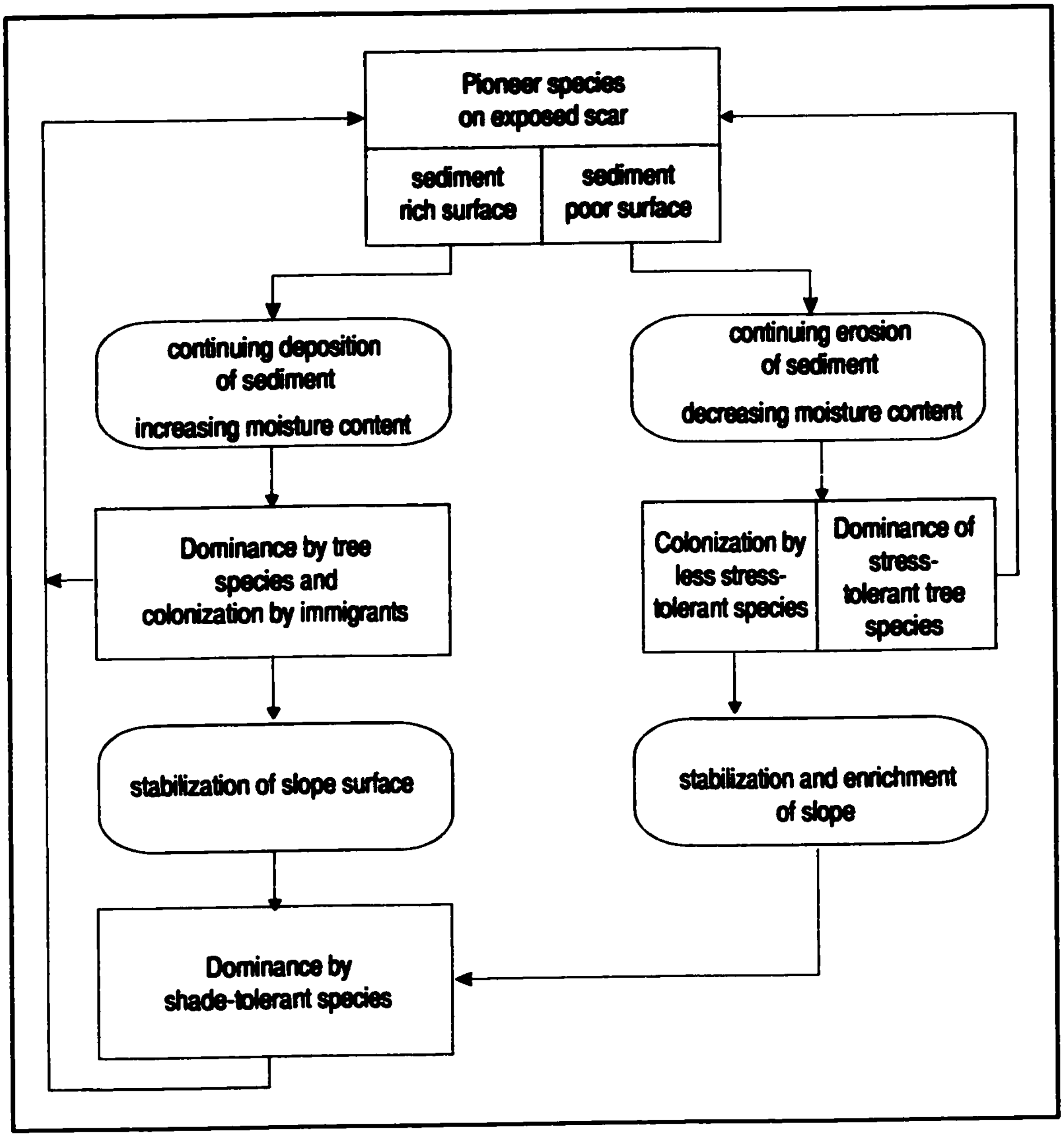


Figure 6.2 Generalized pathways of vegetation succession on debris slide scars(developed from a concept applied to floodplains in Hughes, 1997).

time, the site can return to a closed forest canopy and shade-tolerant species will dominate the canopy.

In this study, this type of scar surface was observed at Silver Creek (Appendix A, Figure A.5, Transect 3, Stops A and D). The recovery forest is a combination of older stems, including sugar maple, white ash and basswood, and younger stems including ironwood, sugar maple, basswood, black ash, red oak, trembling aspen, bitternut hickory (*Carya cordiformis*) and blue beech. Similarly, the sapling layer was quite diverse and included species mentioned above as well as mountain maple, alternate-leaved dogwood, round-leaved dogwood, nannyberry (*Viburnum lentago*), purple-flowering raspberry and staghorn sumac (*Rhus typhina*). With this type of scar, it is typical to have a series of small slides that maintain the successional nature of the site. As new material is released from the head and walls of the scar, trees and shrubs are transported downslope where they sometimes re-root (Milne and Moss, 1988).

On the right side of Figure 6.2, the scar surface is a site of poor resources. This can occur in the upper reaches of the slide near the headwall or in well-drained deposits. Forest regeneration on this type of scar can be quite limited, both in terms of species diversity and complexity. Some scars have limited growth, and forest cover is dominated by only a few species, usually eastern white cedar as well as white birch, balsam poplar and trembling aspen. These sites are often on the upper section of the scar, on steeper slopes that experience extensive creep, sheetwash and gullying. As depicted in the model, the continual removal of surface material encourages colonization by stress-tolerant species. At this point, there are several pathways of forest change. In one case the forest reaches an endpoint with the establishment of a relatively open canopy of stress-tolerant, pioneer tree species, usually eastern white cedar. Alternatively, the forest can progress to a cover of less stress-tolerant species, such as white birch, balsam poplar and trembling aspen. This will lead to increased stabilization and enrichment of the surface material which could direct the forest cover to one dominated by shade-tolerant species as depicted on the right side of Figure 6.2.

This successional pathway was evident on the steep face at the Forks site, downstream from the waterfall. The scars appear to be quite old and an equilibrium has been established between the eastern white cedar cover and surface erosion. In the bowl of a more recent scar there is some regeneration occurring with a combination of eastern white cedar and balsam poplar stems. However, on the surrounding slopes, the forest cover is quite open with larger cedar trees. Here, high stress levels create a semi-stable mixed cover which experiences extensive sheetwash and creep. A similar pattern was described at Blue Mountain; on the upper shale/clay slopes there was an open association of trees dominated by white cedar which appeared to establish a stable association (Milne and Moss, 1988).

6.2.1 Escarpment Slope Model (ESM)

Chapter Three presented a site-specific model that defined the relationships between geomorphic processes and forest dynamics at Blue Mountain (Figure 3.6). In this section, that model has been combined with other studies of Escarpment slope systems as described in Chapter Three and the results of this study to create a general slope system model of the Niagara Escarpment or the Escarpment Slope Model (ESM) (Figure 6.3). The ESM identifies the inter-relationships between physical and biological processes found on the face of the Escarpment. Specifically, the model identifies the response of forest

Geomorphic Process	Slope Type	Disturbance Size (m^2)	Recurrance Interval (yrs)	Forest Dynamics			
				Open Surface	*Open Forest*	*Closed Forest*	
creep sheetwash	C	1-10	<1		Gap		End
rockfall/ karst	A B			Talus	Shrub	Mixed	
slump	B C	10-100	10-30	Scar	Shrub	Mixed	End
debris slide	C	100+	20-100	Scar	Shrub	Mixed	End
blockfall	A			Talus	Shrub		

Figure 6.3 Escarpment slope model (ESM) relating geomorphic processes to forest dynamics for slope types of the Niagara Escarpment.

systems to the spatio-temporal complexity of geomorphic processes operating across different Escarpment slope types. This model has been improved upon by verifying the relationships put forward in Moss and Milne (1998) as well as expanding on the knowledge of the relationships between forest dynamics and the geomorphic processes. This model also contributes to the knowledge of slope type B systems. Previous detailed field studies have focused on slope types A (Moss and Rosenfeld, 1978; Moss and Nickling, 1980) and C (Milne and Moss, 1988).

The lithology and geologic structure of the Niagara Escarpment dictate a suite of specific geomorphic processes that modify land surface form. These geomorphic processes range in magnitude from low-energy, small-magnitude events such as soil creep, sheetwash, and rockfall to larger disturbances initiated by large debris slides and blockfalls. These larger disturbances occur over an area of at least several hundred square metres. As noted, the recurrence of these events also varies. The low-energy events occur on a regular basis, whereas more disruptive events occur less frequently and more irregularly as a result of variations in the magnitude of weathering and erosion processes.

Individual events are determined by the combination of bedrock structure and local hydrology. The movement of water to the surface of the face is often critical in the initiation of debris slides. At the same time the weathering rate of the bedrock will provide the material for movement. The forest dynamics depend on the particular combination of slope processes and landforms. When disturbance is low, there is little disruption of the vegetation cover. Forest dynamics are typically by single tree replacement, creating gaps in the forest canopy that quickly return to a closed forest. Larger gaps are formed when slumps and debris slides occur. In these cases, the forest cycle includes the establishment of a shrub cover which remains dominant if there is continual or frequent disruption. Sometimes these scars are sites of seeps where water enters the slope surface materials, promoting further movement of slope material and leading to a continuously exposed slope and a stressful high-moisture environment. Some scars are eventually covered by a successional forest that returns to the locally dominant forest cover, identified as the end phase in Figure 6.3. Larger debris slides can be governed by similar processes but they are more likely to exist as open scars for longer periods. These are often complex micro-environments, subject to moisture and temperature stresses or slide re-initiation, that create many combinations or pathways of revegetation (Milne and Moss 1988).

The processes described above are more common on slope segments where the surface is primarily composed of clay, weathered shale bedrock, or glacial deposits. When the slope is located below limestone cliffs, as found with Type A slopes, a deep talus base develops. This type of slope is dominant in the northern sections of the Escarpment on the Bruce Peninsula (Figure 3.1). Most faces have frequent rockfalls in which small blocks of weathered bedrock are delivered to the base of the cliff. When rockfall is steady, a stressful slope environment is created that limits vegetation establishment and growth. These slopes usually have a dominant shrub layer, sometimes interspersed with individual trees which fluctuate in dominance depending on the frequency of talus accumulation. In some cases, large blocks are released from the face, initiating debris slides which disturb all vegetation in their path. Eventually a combination of shrubs and trees cover the large blocks and talus on the blockslide scar, although this successional process may be delayed depending on the environmental stress and the amount of rooting material covering the slope (Moss and Milne 1998).

6.3 Geomorphic/Vegetation Upland System

The upland system can be divided into two general categories, as depicted in the upland model (Figure 6.4): upland forests controlled by natural processes and those altered by human processes. Those dominated by human processes can be sub-divided based on the level of disturbance, including the scale of land clearance and the size of the replacement vegetation community. Further subdivision of the upland units occurs between sites with large deposits of glacial till and stratified drift and those with exposed bedrock or karst plains where poor drainage creates seasonal ponding within the drier uplands.

Glacial Deposits

Where there are substantial glacial deposits, natural processes are similar to those on face units described in the previous section. The glacial deposits have left steep local and hummocky terrain, creating quite distinct microclimates. Although these small hills can be quite steep, there was little evidence of mass movements of any size and where the main movement is by treefall, soil creep and sheetwash. Consequently, a stable forest cover similar to that on low disturbance slopes develops. The main cover is sugar maple with several sub-dominants, white ash and American beech, consistently found in the cover. At specific sites, other species such as black cherry and white birch become locally important. Overall, these are low-diversity forests with little regeneration occurring, and are likely to replace themselves by gap-replacement at sites of treefall or windthrow.

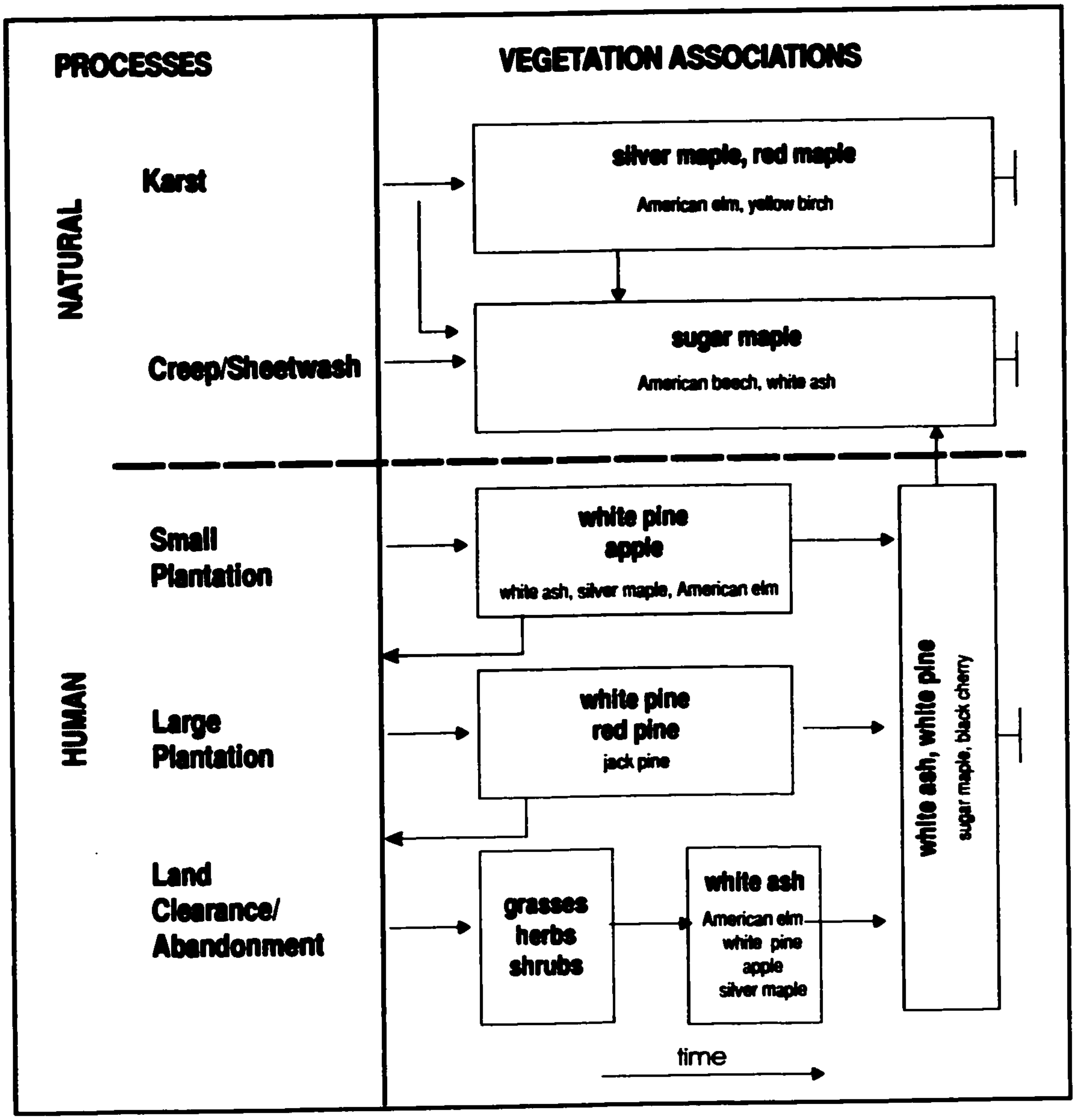


Figure 6.4 Relationships between natural and human processes and vegetation communities for Escarpment upland units. The vegetation associations are represented by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

Bedrock Plains

In contrast, there is limited soil cover on the bedrock plains in the south, and karst processes are more predominant. Although the forest cover here shows some similarities with the deciduous forest community that forms on the deep glacial deposits, overall there is a greater diversity of species overall. On the more mesic sites in these forests, the cover is dominated by sugar maple with no strongly associated trees, although some may have local significance. At Silver Creek, for instance, red oak was important in the upper canopy and blue beech in the lower canopy while at Terra Cotta, white birch was common at several stops.

An important component of the forests on the bedrock plain is the presence of small ponds, especially during the spring. A different forest cover dominates these sites, with a tree canopy composed of silver maple and red maple. Of less importance in these forests, but occurring regularly, was American elm and yellow birch. The younger layers of stems and saplings suggest that this forest is also replacing itself; silver maple and red maple dominate all layers of the forest strata. There was no evidence of disturbance at these sites. The main fluctuations in this system are stress-related changes to moisture levels. As it is, this system has adjusted to seasonal variation in moisture; if this were to change it could eliminate this land type from the Escarpment system.

Plantations

One major disturbance to the upland forest systems has been forest removal followed by the establishment, management and in some cases the abandonment of pine plantations. This is more common on the upland areas of the Escarpment in this region, although the larger occurrences were at the two sites not in the Plan area. Several levels of human modification were identified, from small pockets of pine planted in abandoned fields to large plantations that are naturally regenerating or are still being managed.

The sites with mature plantations had a forest cover of red pine and in some cases white pine. In some instances small numbers of jack pine and green ash were included in the canopy cover. These forests are not currently being managed and are naturalizing. Change is initiated primarily by treefall and the maturing pines are likely susceptible to windthrow. There was evidence within each site of small patches created from wind events. The architecture of the stands and light soils may contribute to this susceptibility. The direction of change was toward a deciduous or mixed forest. The principal replacement stem was black cherry and to a lesser extent white ash. Black cherry was a strong dominant in the young stems as well as the sapling and seedling layers. At one site, balsam fir was a main component of the understory. As depicted in the model, it is likely this forest will eventually be dominated by sugar maple and other related deciduous species such as American beech. There was also a strong shrub component in the undergrowth which was mainly eastern red elderberry (*Sambucas pubens*) and alternate-leaved dogwood.

Abandoned Fields/Orchards/Plantations

Where a combination of fields, orchards and small plantations exists, a very diverse successional pattern emerges following abandonment. At sites with small pine plantations the dominant trees were apple and white pine with sub-dominants of white ash, sugar maple and American elm. There was a high diversity of stems in the sapling layer which is also dominated by apple and white pine. The composition of the sapling layer suggests the direction of change in the forest will be toward a white ash and sugar maple canopy.

These species will form the mature forest as the apple and pine die off, although the pine could maintain a strong presence in the canopy for quite some time. In the abandoned fields, the dominant tree was white ash with some American elm and white pine. This may be a local response to the presence of small plantations and mature forests. The change is likely toward a combined canopy of white ash and sugar maple, as evidenced by the younger stem and sapling phases. These successional forests are quite diverse with a variety of shrubs and young trees in the undergrowth including narrow-leaved hawthorn, alternate-leaved dogwood, apple, downy hawthorn, round-leaved dogwood, buckthorn and red-osier dogwood (*Cornus stolonifera*). As with the small plantation, this forest will likely move toward a canopy dominated by white ash and sugar maple.

In many of the mature sugar maple stands, several large white ash stems are found at the top of the canopy. However, there is little evidence in this study of a transition forest dominated by white ash. These trees have larger basal areas, which indicate they were one of the earlier trees to cover the site and are being replaced by the smaller sugar maple. It is likely that part of these forest sequences involves a more open forest with a white ash and sugar maple cover as is developing in the open fields at Limehouse. These older successional forests have a smaller density of stems such as basswood, American elm, and ironwood. In some cases, this cover includes trembling aspen, balsam poplar and large-toothed aspen. In time, white ash and related species will eventually be replaced by sugar maple as it out-competes the ash stems and is joined in the canopy by the more shade-tolerant American beech and, in some cases, eastern hemlock.

6.4 Geomorphic/Vegetation Valley System

The vegetation communities of the valley units are shaped by several processes which can be distinguished by the size of the channel or floodplain and by the fluvial processes related to the gradient of the stream (Figure 6.5). The channels that cut through the Escarpment have a high gradient and are narrow with little floodplain. The streamflow will be greater than the low-gradient streams, causing bank erosion and reworking of the streambed, especially during spring runoff. As the river flows onto the small plains below the Escarpment, the gradient declines and the floodplain widens, changing the regime of the stream. The flow rate will be less and sediment transfer is reduced. In some cases, the high-gradient channel is relatively short, for example, 0.5 to 1km downstream from a waterfall (e.g. the Forks) or it can be quite long depending on the shape of the valley and landscape through which it is draining (e.g. Hockley Valley). At the top of Figure 6.5, the valley system model shows channels that have a high-gradient and are fast-flowing, especially during peak flood events. This leads to bank erosion and small point bar development. The effect is a small, moderately disturbed floodplain. In response, the vegetation communities are a combination of trees and shrubs with a heavy ground cover. These floodplains will be nutrient-rich and successional species take advantage of the open surfaces (Hughes, 1997). Riparian species such as willow, red-osier dogwood and eastern white cedar are the dominant trees on these sites. As seen in Figure 6.5, the main forest community is dominated by eastern white cedar although large individuals of willow may be important on the immediate stream bank. At less disturbed sites away from the bank, there is a shift to a mixed forest still dominated by eastern white cedar, but the riparian species are replaced by a combination of species including sugar maple, white birch, and

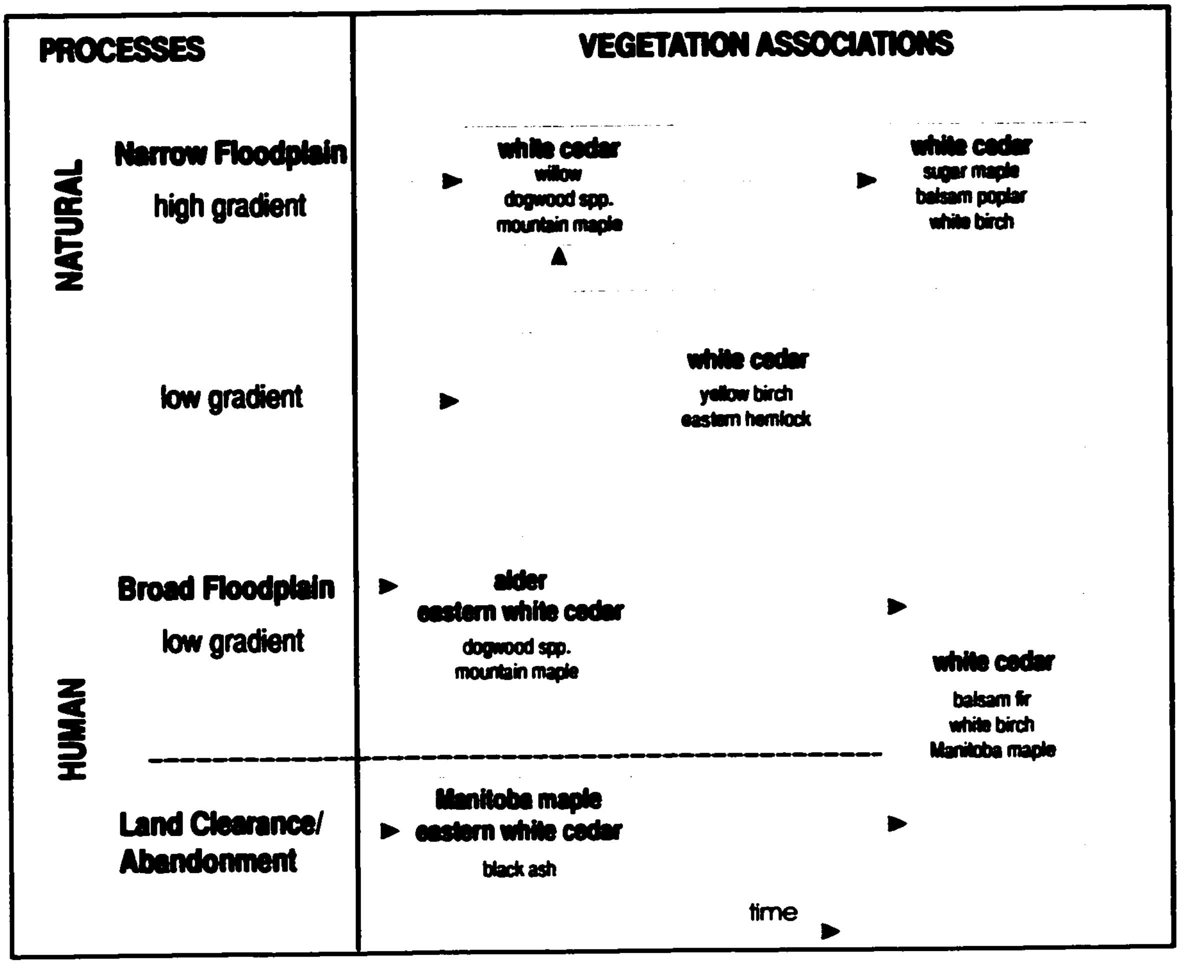


Figure 6.5 Relationships between natural and human processes and vegetation associations for Escarpment valley units. The vegetation associations are represented by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

balsam poplar. Some of the highest diversities within the sample squares were found in these floodplains.

In some channels where streams cut through the Escarpment slopes, the flow rate is not as great as the high-gradient streams. These streams can be considered as moderate-gradient and consequently, the erosive power of these streams is less and disturbance levels are lower. In these stream channels, vegetation communities can be considered as a transition forest between the high- and low-gradient channels, possessing similarities of both systems. The dominant vegetation is typically eastern white cedar and, as in the high-gradient channels, these sites display a high diversity of stems.

In low-gradient channels where flow rate is lower and the channel experiences less disturbance from fluvial processes, the forest cover of eastern white cedar is joined by yellow birch and eastern hemlock; this indicates a relatively stable system with no major disruptions. The main control at these sites could be changing levels of the water table, which creates moisture stress and changes the structure of the forest. In these cases, there would be a gradual infilling of the lowland and a shift to a forest cover more typical of the upland forests, such as communities found in the valley sites at Palgrave and Mono Cliff.

At Alton, the channel is typical of streams flowing through agricultural landscapes. It is a slow flowing stream with wide floodplains covered by a dense forested swamp. At some sites along the channel, forest cover has been cleared by humans. Consequently, the forest is a mixture of successional and riparian species that are gradually filling in the open areas. The dominant trees in these small openings are speckled alder and eastern white cedar; there is also a high shrub component with species such as dogwood, elderberry and mountain maple. In the larger openings along the river, there are several dominant communities: an open forest with only scattered Manitoba maple and black ash, and in some of the lower areas dense pockets of eastern white cedar. Many of these openings are being encroached upon by the surrounding forest. This forest is returning to the dominant swamp forest which is primarily eastern white cedar with balsam fir and white birch.

6.5 Bird Populations/Biophysical Processes

The analysis of the bird populations, as discussed in Chapter Five, revealed several patterns that corresponded to the land units and human disturbance. In the first division, natural forests were separated from sites of moderate to high human disturbance. In the next division, there was a separation in the natural forest groups of Group A from B and C. Sites in Group A are undisturbed upland forest-interior while groups B and C include sites on active and higher stress faces and upland units and sites where the forests are often more mixed in composition. This division is related to the combination of natural disturbance and a higher moisture regime. In the following sections, several general controls of the bird population will be discussed and then the pattern of bird distribution and associations will be addressed with respect to the three land units - upland, face, and valley.

Deciduous/Coniferous Ratio

Both, the discriminant and ordination analyses highlighted the control which vegetation physiognomy has on bird species distribution. There is a continuum of change in forest cover from deciduous to coniferous between Groups A and E. Group A is dominated by deciduous forest-interior species such as Red-eyed Vireo, Eastern Wood-Pewee and Wood Thrush while the plantations of Group E are primarily populated by coniferous-interior species including Red-breasted Nuthatch and Pine Warbler. The other groups, with a mixed forest cover, have variations in numbers that reflect both these end-points. Physiognomy, specifically deciduous ratios, has been debated as an important control of bird distributions (Mills et al., 1991).

Landscape Position

The position of the unit in the landscape was also identified as significant in all analyses. Several groups, A and D, occupied specific land units. This difference was a response to variations in the structure and composition of the forest and the presence of moisture. The valley communities had a high concentration of species that preferred mixed forests and only moderate levels of species found in either deciduous uplands, such as Red-eyed Vireo or coniferous forests, such as Black-capped Chickadee. A number of species had their highest scores in the valley units, such as Black-throated Green Warbler, Black-and-white Warbler and Indigo Bunting.

6.6 Bird/Biophysical Face Systems

The bird communities related to the geomorphic processes and vegetation dynamics (Figure 6.6) have been incorporated into this model. Several important trends are revealed in these results. It is apparent from the geomorphic/vegetation face model (Figure 6.6) that there is a transition along the disturbance and stress axis causing a shift from forests dominated by deciduous trees, specifically sugar maple, to a community with a stronger coniferous nature, primarily eastern white cedar. These relationships will be discussed by examining the different geomorphic processes and bird communities.

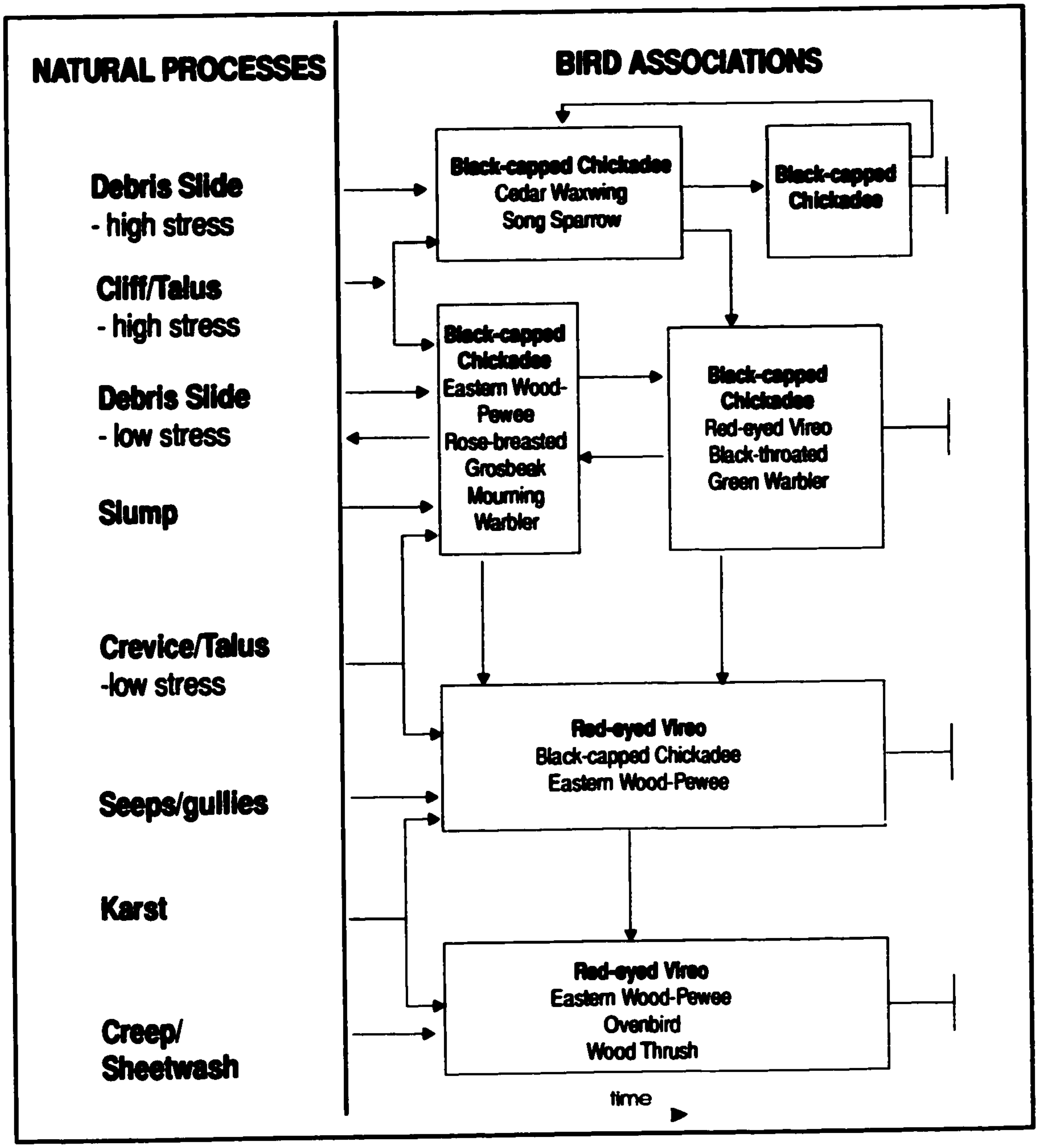


Figure 6.6 Relationships between geomorphic processes and bird associations for Escarpment slope units. The bird associations are represented by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

Treefall/Creep

At the bottom of Figure 6.6, the low disturbance forests are quite similar to the upland deciduous forests, discussed in the next section. The bird communities at these sites are typical of the neo-tropical migrant, forest-interior species which are dominated by Red-eyed Vireo, Eastern Wood-Pewee, Ovenbird and Wood Thrush. Small gaps are created in the forest cover from windfall or local seeps. In some cases, these gaps attract individuals not associated with the forest cover, such as Winter Wren, especially during migration. However, these small gaps do not attract the numbers or diversity of species that occur on scars of the larger debris slides.

Karst

As one moves up the scale of disturbance, the processes of karst and water flow increase the changes in the vegetation cover. This increases the presence of eastern white cedar and some other sub-dominant species have a higher presence. The response in the bird communities is minimal - the forest is still dominated by the forest-interior birds mentioned above. However, the change in vegetation does attract other species to the forest such as Black-throated Green Warbler. This species prefers mixed forests or sites where there is access to a combination of deciduous and coniferous stands as found at Hockley and Mono Cliff (Cadman et al., 1987). At Hockley, the slope leads to a lower slope which is covered by young eastern hemlock, and the valley bottom which is dominated by eastern white cedar. This species prefers these habitats but uses the upper slope for foraging. At Mono Upland, this bird was common on land units associated with the cliff faces and the upper rim forest, which was predominantly eastern white cedar and immediately adjacent to the deciduous upland forest.

Cliff/Talus

As the magnitude of the disturbance increases, so does the change in the vegetation cover and correspondingly the bird populations. The large cliff faces and talus slopes create a unique environment in southern Ontario that attracts several specific species, including Common Raven, Turkey Vulture and Northern Rough-winged Swallow (*Stelgidopteryx serripennis*). Cliffs have been identified in forest habitats as essential and important to a variety of wildlife species (Maser et al., 1979). Cliffs may influence wildlife communities directly by providing shelter, nesting and denning sites, and cover, or indirectly by influencing vegetation structure and diversity. Cliff sites in semiarid plains of Wyoming had greater topographic roughness than surrounding landscapes, more diverse vegetation structure and plant species, and a more heterogeneous habitat pattern. On cliff sites, where vertical and horizontal structure were greater than on control sites, bird species diversity was also greater. Diversity of birds typically was greatest at the base of talus in front of cliffs, where shrubs were taller and large patches of vegetation and rock existed. On control sites, where vertical and horizontal vegetation structure were more homogeneous, bird species diversity was lower and more uniform than on cliff sites (Ward and Anderson, 1988; Matheson and Larson, 1998).

On the Escarpment, vegetation at the base of the cliff is not typically a closed forest and often vertical structure is dominated by a shrub layer. However, individual trees can be the dominant tree on the slope as measured by relative height since they are further upslope. Also, there are often open areas with snags on the slope which provide preferred roosting or hunting sites for some species. Species diversity was quite high on the cliff transects, especially at Mono Cliff, but this is likely a response to several factors and not just to vertical structure. The talus slopes promoted the growth of shrubs which provides a food source for many species. Also, the east-facing slopes at Mono Cliff receive the morning sun which promotes a favourable thermal regime and may increase insect activity and consequently attract more bird species. Bird populations were higher on this site than on the opposing west-facing slope of the outlier. The outlier slope may not have had a high level of disturbance and consequently not the diversity in shrubs or food sources. This disparity between slopes was even more evident from records collected during the migratory period.

Cliff sites include gaps created by natural disturbance or edges that are the result of environmental stress. On the Escarpment an edge is created by the erosion of the bedrock, as found at Silver Creek. This opens up the forest to access by species such as Brown-headed Cowbird not typically found in the forest interior. It is regarded as an edge species that has a negative impact on forest-interior species. It uses edges to gain access to parasitize the nests of interior species (Gates and Gysel, 1978; Wilcove, 1985; Freemark et al., 1995; Robinson, 1998).

Debris Slides

Large scars from debris slides and blockfall have several effects on the bird populations. In some cases they promote increased foraging and nesting success for fugitive species which leads to an overall increase in diversity and abundance. In other cases, the site is depauperate, with few species and low abundance. In effect, this form of disturbance creates resource centres or resource wastelands. In Figure 6.6, this is represented by several pathways which lead to two different bird populations. As described earlier, there are two levels of stress associated with these disturbances. High stress slides are sites of limited vegetation recovery and a forest dominated by stunted eastern white cedar. The large debris slide at the Forks produced a scar that had limited recovery. The vegetation cover was sparse in many places and was often a dense cover of eastern white cedar. This vegetation cover did not attract many bird species; there was a low diversity and abundance of species at this stop. The species encountered included several shrub species - Song Sparrow, Black-capped Chickadee and Indigo Bunting.

This is in stark contrast to the scars at Silver Creek where a high diversity and abundance of birds were observed. Several species had higher scores at the disturbed sites than in the surrounding forest, including Great Crested Flycatcher, Rose-breasted Grosbeak and Veery. This increase may be due to greater access to food sources. Great Crested Flycatcher and related species including Eastern Wood-Pewee and Least Flycatcher were often found foraging in the scar areas, where the combination of open-space and forest edge promoted feeding on flying insects. These openings provide a hospitable environment for insect-attracting shrubs and flowering plants as well as flowering shrubs and fruit, which will attract species such as Rose-breasted Grosbeak and Baltimore Oriole (*Icterus galbula*). The warmer microhabitat could benefit the thermoregulatory physiology of insects, increasing insect activity and abundance.

One reason for higher resource levels in gaps is a greater primary productivity from increased light penetration which produces warmer microclimates (Halle et al., 1978). The increased warmth could also benefit a bird's energy budget especially during periods of colder temperatures during early season and cold mornings. Overall this allows an individual to maximize energy for the breeding effort and less for individual maintenance (Smith and Dallman, 1996). In this study, several of the sites where gaps were produced from slide activity or rockfall were enhanced because of the aspect of the slope. The sites with east or south-east facing slopes had high numbers and diversity of species during the survey period which was in the early morning. This period has a high concentration of sunlight because of the combined angle of the sun and slope.

Other trends showed that numbers of forest-interior species such as Red-eyed Vireo, Wood Thrush, Eastern Wood-Pewee and Ovenbird were lower at these sites. This emphasizes the importance of interior forest for producing higher levels of productivity. This does not suggest that these species avoided the more disturbed sites. Their values were lower, but not as low as other sites where these species were not common. Therefore the disturbed sites, although they do not provide nesting habitat, are important for foraging and serve an important role in the overall functioning of the face system.

There are many examples of vagile animals differentiating between undisturbed forest and patches resulting from anthropogenic disturbances (e.g., Odum, 1950; Johnston and Odum, 1956; Karr, 1968; May, 1982). This has also been reported for natural disturbances, suggesting that although the grain of the disturbance mosaic is less coarse for relatively large, vagile consumers such as birds than for small consumers such as insects or intertidal animals, the mosaic could still be reflected in population and community patterns (Wiens, 1976; Karr and Freemark, 1985; Feinsinger et al., 1988).

Feinsinger et al. (1988) report that bird communities rarely experience the sorts of disturbance that lead to pronounced community heterogeneity in all biotic elements. Small-scale disturbances are frequent now and in the past. Small gaps concentrate activity of plants and animals, but larger gaps, such as landslide scars, are not so extremely different from intact forest as to preclude local populations or favour entirely different sets of species. When large areas of forest are disturbed and habitats become extensively fragmented, forest specialists tend to disappear and fugitive bird species become ecologically dominant. Fugitive species are those that prefer or require disturbed or early-successional habitats, which can be canopy openings embedded in a matrix of forest. This creates an ephemeral, constantly shifting patch structure and forest interior (Lent and Capen, 1995). Lent and Capen (1995) found larger gaps (0.7-1.6 ha) were of sufficient size to attract a distinct group of breeding birds that were not found in the surrounding undisturbed forest. Before European settlement, the populations of many early-successional bird species were probably maintained by continuous colonization of similar temporary open patches in a forested matrix (Canterbury and Blockstein, 1997).

6.7 Bird/Biophysical Upland Systems

There are similar patterns revealed in the upland model (Figure 6.7) for the bird communities as were found in the vegetation upland model (Figure 6.3). At the top of the model, the two natural communities located on different surficial material indicate some differences in the bird communities, but this was not as distinct as for the vegetation communities. The differences in the upland forests on shallow bedrock and deep glacial deposits were not as obvious for the bird populations as they were for the forest associations. The bird groups were separated along a measure of disturbance, which alters the structure of the forests and to a lesser extent the forest composition. This results in the sites at Speyside being combined with the Silver Creek and Limehouse Upper where levels of stress and disturbance alter the vegetation structure by creating a state of succession or reduced growth and increasing the shrub cover, a characteristic not

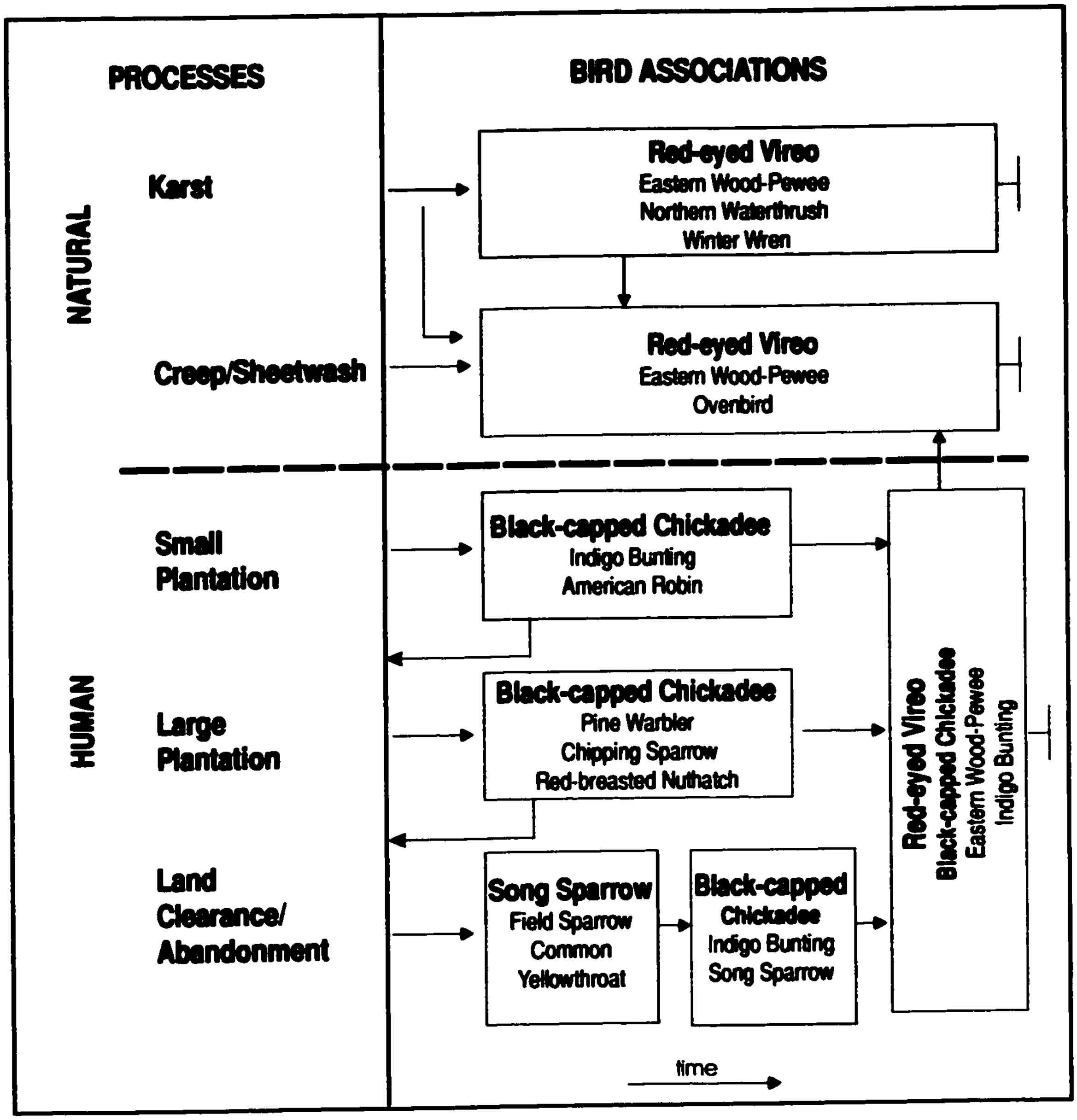


Figure 6.7 Relationships between natural and human processes and bird associations for Escarpment upland units. The bird associations are represented by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

identified in the forest composition analysis. Similarly to Group A, the sites in the deep glacial till, including Hockley, Mono and Palgrave, are combined with sites at Terra Cotta and Inglewood.

The cluster analysis shows that these forests are dominated by birds typical of forest interior in southern Ontario. In Groups A and B, species such as Red-eyed Vireo, Ovenbird, Eastern Wood-Pewee, Wood Thrush, and Scarlet Tanager dominated the bird populations. These species require a minimal area of forest-interior habitat to successfully reproduce. This emphasizes the importance of these sites on the Escarpment for species recognized as "of concern" by a number of provincial agencies (Milne et al., 2000a, Walsh et al., 2000).

Bedrock Plains/Glacial Deposits

Several distinctions can be made between upland sites that are on bedrock plains and deep glacial deposits based on species distribution, but they were not great enough to separate them in the cluster analysis. Some examples included the greater presence of Northern Waterthrush and Veery at sites on shallow bedrock, especially Inglewood and Speyside. On these plains, water collects in small ponds that are often seasonal, depending on summer water levels. During the research period, many of these ponds disappeared during dry periods in the summer. There were greater differences between these two landscape units during migration periods, especially during the spring when the water levels were higher. There were records of several waterfowl species at Terra Cotta and Inglewood that were not included in the summer breeding period, including Canada Goose (*Branta canadensis*), Mallard and Wood Duck (*Aix sponsa*). There were also breeding records of Wood Duck at Speyside.

Plantations

The impact of human disturbance was considerable on the variety of bird communities. These differed considerably along an axis of human disturbance between the plantations and abandoned fields. These vegetation communities registered a large number of species not found in other communities. In the large plantations, the coniferous-interior species in this group had the greatest variation of any of the other groups. These sites represent some of the more unique habitats found in this area of the Escarpment, providing a habitat for species not commonly found in this area. This included species such as Yellow-rumped Warbler, Chipping Sparrow, Pine Warbler, Red-breasted Nuthatch, Blue-headed Vireo and Northern Goshawk.

This can be related to the dynamics of these forest units. The sites in this study are representative of plantations in a state of low management or abandonment. These forests are slowly being replaced by a deciduous forest that currently occupies the understory and is composed of successional species including black cherry and shrubs such as red-berried elderberry. This undergrowth favours ground-dwelling species such as Ovenbird, which surprisingly had high importance values for this forest type. Also unusual was the importance of Eastern Wood-Pewee at these sites, another species usually described as a deciduous forest-interior species.

The smaller plantations presented a very diverse grouping of birds because of the combination of pine forests, fields and old orchards as well as the natural pine and sugar maple slope forests. The combination of birds in these areas reflects this diversity with a variety of forest-interior species including Red-eyed Vireo; species related to the pine forests including Chipping Sparrow and Pine Warbler; as well as edge and field species including Northern Cardinal and Common Yellowthroat. This richness of species will decline as these forests fill in with sugar maple and white ash. The species will be similar to mixed forests of the upland and upper face if pine persists in the canopy.

Abandoned Fields

Similarly, the field bird communities included many species specific to this habitat, such as Field Sparrow, Eastern Kingbird, and Blue-winged Warbler (*Vermivora pinus*). These are transitional sites and many of the dominant species will be replaced with later successional and eventually forest interior species. A number of these species have been recognized as having local conservation concern (CVC, 1998). Many of these habitats are of concern as they are slowly replaced by forest cover (Askins, 2000).

Mosaic Forests

These combinations of forest types and ages are important to the overall functioning of the landscape. This mosaic increases the forest cover size, and possibly the forest interior of large forest tracts where there is a combination of natural and managed forests. The functional size of a forest stand could be increased for area-sensitive species if the 'patch' is surrounded by another forest type, regardless of the suitability of that type as habitat (Harris, 1984). An example is an upland deciduous forest with adjacent coniferous plantations, typical in some areas of southern Ontario, compared to forests and agricultural fields or developed lands. If an ecotone is not as abrupt, some negative edge effects (e.g., predation, brood parasitism, light and wind penetration) might be reduced, potentially allowing area-sensitive species to exist in relatively small stands (Kilgo et al., 1997).

This mosaic of forest types is typical of some of the larger forest patches in the area of southern Ontario which makes these sites of high potential for species survival. In general, populations of species decline because areas of suitable habitat decrease. Positive relationships have been found between patch size and species presence (Saunders, 1990) and abundance (Askins et al., 1990), or because of lower reproduction or higher mortality in remaining habitats (Knick and Rotenberry, 1995). Smaller patches have a greater edge-to-area ratio and consequently species from the external habitats may prey upon, parasitize or compete with the patch species (Schieck et al., 1995). The structure of landscapes, in which local study plots are embedded, may produce differences in apparent bird-habitat relationships derived from local plots (Knick and Rotenberry, 1995). This relationship was found in urban landscapes. Diversity and abundance of neotropical migrants in small forested patches consistently decreased as the level of adjacent development increased, regardless of forest size. 4 ha woodlots without any nearby housing had on average a richer, more abundant neotropical community than did 25 ha urban woodlots (Friesen et al., 1995).

6.8 Bird/Biophysical Valley Systems

Valleys and associated stream channels can be identified as high- and low-gradient channels. The high-gradient channels are found immediately below a break in the bedrock or where there is a steep face, creating a waterfall and high-energy streamflow. This is associated with areas of disturbance along the stream channel from bank instability, landslides and flood damage. Stream units could also be considered as separate based on channel size and expanse of floodplain.

The relationships between the bird associations and the biophysical processes for the valley systems are presented in Figure 6.8. Low-gradient stream channels in large floodplains have a dominant forest cover of eastern white cedar. The bird community found at these sites includes species typical of forest-interior coniferous forests, such as Black-capped Chickadee, Red-breasted Nuthatch and Northern Waterthrush.

Broad Floodplain/Low Gradient

In these systems, there are several disturbances operating at different scales. Small gaps are created in the coniferous swamp, either human-induced or natural disturbances. Bird populations in these gaps are a mixture of edge and interior species, similar to openings described in the face model (Figure 6.6). The dominant birds were Black-capped Chickadee, Winter Wren and White-throated Sparrow. As these forests regenerate, the bird community will return to the coniferous-interior community.

At other areas along the river channel, there has been a larger human disturbance, mainly through forest clearance. As these areas recover following abandonment, a mixed pattern of small habitats is created, including stands of eastern white cedar interspersed with openings dominated by a mixture of shrubs and deciduous trees. This attracts a variety of species and these sites usually have a high measure of diversity. Similar results were found along other stream channels in these river systems (Milne and Bennett, 2001). The bird community along this type of river system is dominated by Black-capped Chickadee and open field and meadow species including Song Sparrow, White-throated Sparrow, House Wren (*Troglodytes aedon*) and Indigo Bunting. As the forest expands and the meadows are filled in, several of these species will be replaced by interior species such as Yellow-rumped Warbler.

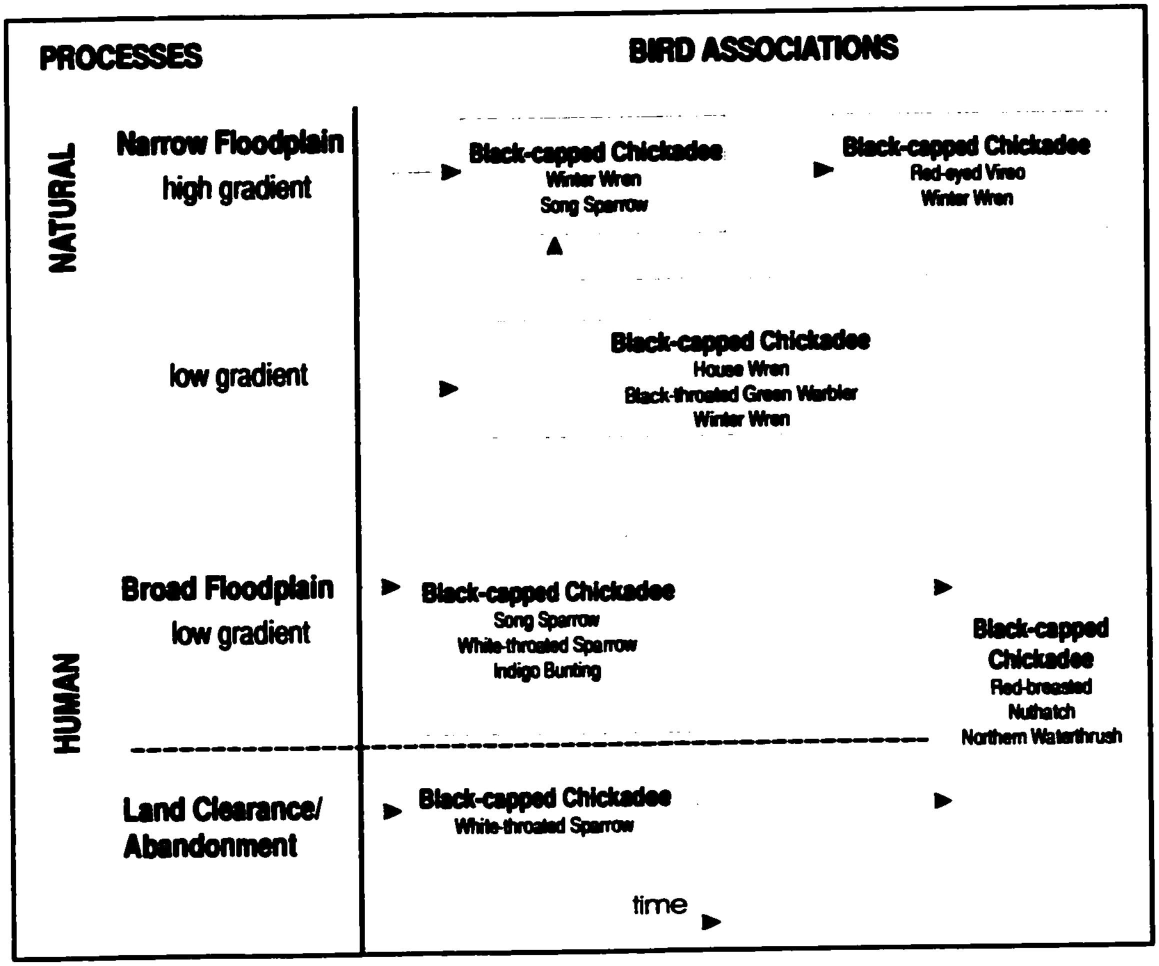


Figure 6.8 Relationships between natural and human processes and bird associations for Escarpment valley units. The bird associations are represented by the dominant species (based on Importance Values) at a point in time. The left side represents the initiation or persistence of a specific process. The right side represents possible end points. The arrows indicate pathways of change between dominant species.

Small Channel/Low Gradient

Moving up the model, there are low- to moderate-gradient streams situated in small channels at the base of the face or slope. These land units can be quite small and birds often overlap with species from the surrounding forests, including forest-interior birds such as Red-eyed Vireo. These communities are quite diverse but the dominant birds are Black-capped Chickadee, Black-throated Green Warbler and Winter Wren. This reflects the mixture of tree species found in these valleys; often the ratio of coniferous to deciduous is relatively equal. These units are relatively stable, there is little evidence of disturbance and the primary control is fluctuating water levels. These sites will be more susceptible to low water levels than larger stream channels. Over the long term the smaller valleys may fill in with sediment which will alter the vegetation community.

Small Channel/High Gradient

The final group involves sites that flow over the Escarpment face, creating large waterfalls and fast-flowing streams below the falls. This type of channel experiences higher levels of disturbance depending on the erosive action of the stream. Bank erosion is common and there are several sites where large blockfalls and slides occur following undercutting at the base of the valley slope. Sites with moderate to high disturbance produce depositional features such as point-bars that have a successional vegetation cover, including willow and shrubs. These areas of the river channel attract bird species not commonly found within the forest system such as Song Sparrow and Mourning Warbler.

On other areas within restricted floodplains, the forest is more stable and the bird community is typical of the surrounding upland and face deciduous-interior species, including Red-eyed Vireo. There are species in this habitat which are not typical of upland forests but use the river system. These include Spotted Sandpiper, Belted Kingfisher and Wood Duck.

Riparian vegetation is typically unique within a valley landform as a result of the continuous and dynamic interactions among hydrologic, geomorphic, and biotic processes (Gregory et al., 1991; Sanders and Edge, 1998). Riparian areas often offer: (i) a juxtaposition of water, cover and food; (ii) a greater diversity of plant composition and structure; and (iii) more favorable microclimates because of increased humidity, higher rates of transpiration, and greater air movement (Oakley et al., 1985). The resulting streamside plant communities generally form an array of highly productive, biologically diverse, and structurally complex habitats that intuitively should support more species and numbers of birds than the relatively simple and less productive uplands. This has been supported in the literature, which has documented large aggregations of breeding birds and riparian-dependent bird species in stream corridors (Carothers and Johnson, 1975; Kauffman and Krueger, 1984; Strong and Bock, 1990; Sanders and Edge, 1998). However, many of these studies have been conducted in arid environments where gradients in microclimate and vegetation are more pronounced (McGarigal and McComb, 1992). For example, riparian zones in the southwest U.S. support a greater density and diversity of avian species than do adjacent uplands and may provide more habitat for nesting birds in North America than any other vegetation type (Carothers and Johnson, 1975).

These patterns do not apply to smaller, high-gradient mountain streams such as those found along the Escarpment. McGarigal and McComb (1992) found that riparian areas in mountain streams did not support a greater abundance and diversity of birds species compared to adjacent upland habitats. In these landscapes, streamside areas offered habitats for very few unique terrestrial bird species during the breeding season.

Both of these situations appear to exist in the valley units described in the valley system model for the Escarpment. The high-gradient streams did not have high abundance or diversity compared to the surrounding uplands and slopes. In contrast, the larger floodplains and low-gradient streams had higher values for abundance and diversity. This was especially true for areas where the forest cover has been altered, which leads to channels with a higher complexity of habitat patterns and a larger number of species.

6.9 Stress and Disturbance

In general, stress was considered as the response of the vegetation cover to limitations in micro-environmental variables that control plant growth, including energy, moisture and nutrients. In contrast, disturbance refers to the disruption of the equilibrium of the environment from processes such as fire or landslides. As described in Chapter Two, plant distribution theories propose the relationship between stress, disturbance and competition as the main control of plant selection.

6.9.1 Vegetation

This concept was applied to the vegetation associations following the model proposed by Southwood-Greenslade (Southwood, 1988) (Figure 2.2). Each transect was positioned on a graph that included increasing levels of stress along the X-axis and increasing disturbance down the Y-axis (Figure 6.9). The positioning of transects was based on a qualitative assessment of the relative levels of stress and disturbance at each site. To simplify the interpretation, transects that occupied similar space on the graph were combined into general categories such as upland deciduous forest on deep glacial

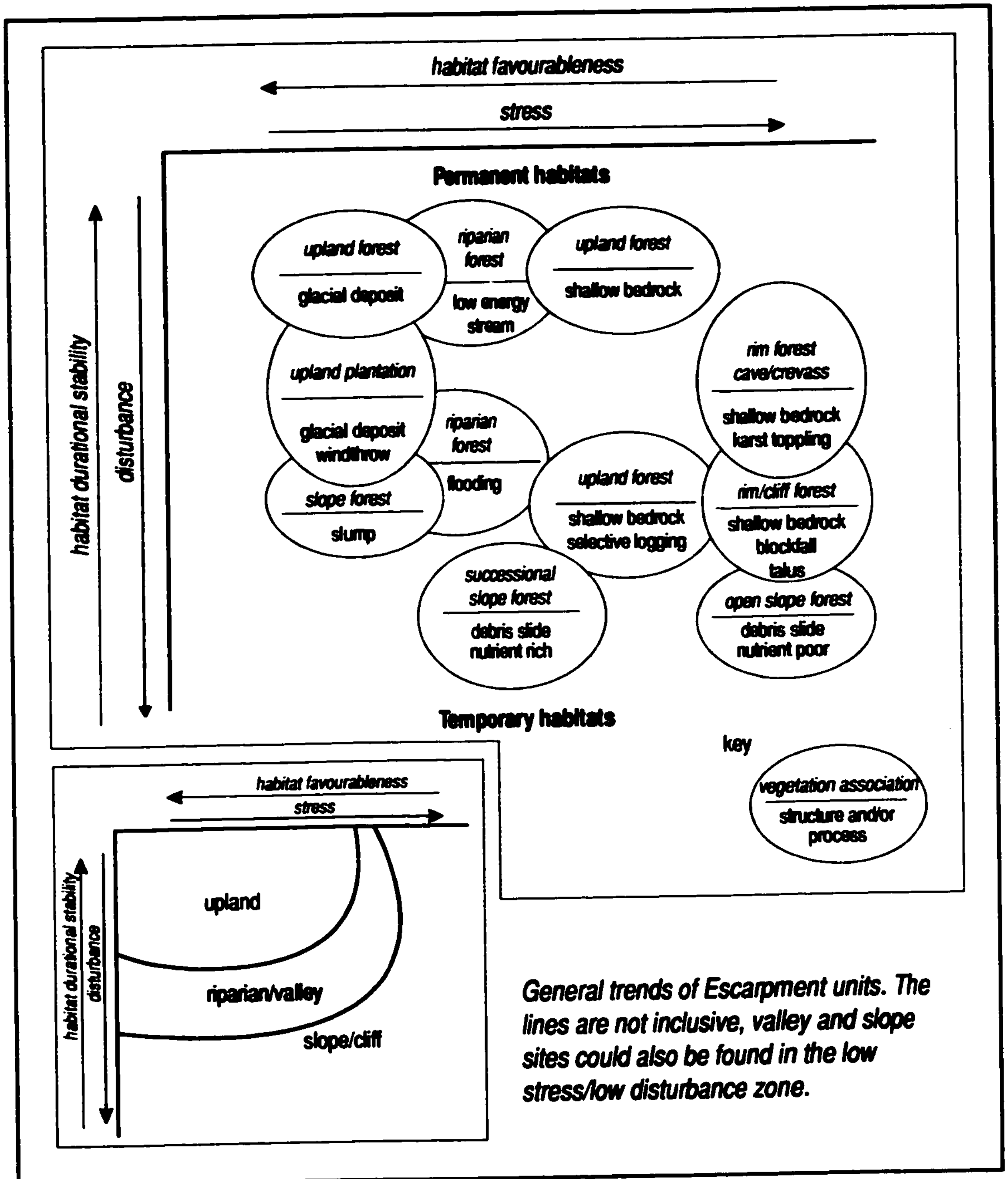


Figure 6.9 Relationship of forest communities to levels of stress and disturbance (developed from a concept illustrated in Southwood, 1978).

deposits. The results indicate several trends that support the general theories on plant distribution.

Low-stress and low-disturbance sites are represented by upland deciduous forests on deep glacial deposits. The upland forests on shallow bedrock plains experience a greater stress but low disturbance, while face forests followed a continuum of increasing disturbance along the disturbance axis. The more active faces occupied the lower portion of the graph. There were several levels of stress on these faces. High disturbance and moderate stress occurred at sites having debris slides with high levels of nutrients and moisture. At these sites, stress would be in the form of temperature fluctuations. Active faces can also have high disturbance and high stress, especially on steeper slopes of stratified drift or shale bedrock where erosion is high. These sites have very low or limited recovery. Sites on the type A and B slopes tend to be found at the right side of the graph, grading between moderate to high stress and moderate to high disturbance. This includes sites where there are bedrock exposures along the Escarpment ridge with small crevices or large cliff faces with extensive talus slopes. The higher disturbance occurs where there is active blockfall. Finally, the riparian communities are found in the centre of the graph, with low to moderate disturbance and moderate stress. The stress is primarily from moisture fluctuations while the disturbance is related to fluvial processes such as flooding or bank erosion.

These patterns reveal several aspects of these communities and their arrangement on the Escarpment. The overall pattern shows a general trend of the upland forests restricted to the upper left corner where disturbance and stress are lower. Valley sites have a more extensive range extending into higher levels of disturbance. The sites that experience the greatest range of variation in stress and disturbance is found on the Escarpment face, which experiences all ranges of stress and disturbance.

To this point only the natural environment has been considered. The response changes dramatically when human disturbance is added to the pattern. In the previous graph, plantations were included which are human constructs, but these were considered from a temporal perspective as an existing community. Current processes in plantations have low to moderate disturbance levels. There can be blowdowns which are likely more common in a plantation than in the undisturbed forests, although during this study there were windthrow events in both forest communities. These disturbances in the plantations created larger gaps, although these were not measured in detail. The process of creating a plantation involves a high level of disturbance over a long time-scale and similarly land clearance for agriculture is a major disturbance to the system. These processes would be located on the bottom left side of the graph but they would be dependent on the type of disruption to the forest and soil system.

The results of this classification support Southwood's interpretation of these factors on species patterns. At the top of the graph where disturbance is low, these sites are identified as permanent communities, which is verified in this study. This area is dominated by the upland forests where the main disturbance is treefall and gap replacement. There is a gradient of species types from left to right which represents an increase in stress-tolerant species. In this study, this represents the transition from forests dominated by sugar maple to those principally of white cedar. These can be considered as relatively stable systems that maintain a consistent pattern of species dominance.

At the bottom of the graph, the main community type is successional. This corresponds with communities that are establishing on the debris slides, talus slopes and to a lesser extent on smaller slumps and bank erosion. These communities are temporary as they shift toward more complex forest communities or are re-disturbed and cycle through the successional forests indefinitely. At the left side of the graph, high disturbance-low stress sites are dominated by r-strategists which take advantage of the resource base and reduced competition. On the right side, these environments favour stress-tolerant r-strategists, which severely restricts the potential colonizers of these sites. As shown, sites which experience these environments are usually low-diversity, resource-restricted sites.

The Southwood-Greenslade model also indicated that the third principal control, biological processes, especially competition, increases from the bottom right to the top left. Competition is the predominant factor in stable, less stressful forest communities typically found on the upland sites. Therefore, the physical controls of the micro-environment and geomorphic processes have increased importance for many of the Escarpment sites, especially those on the faces and in high-gradient stream channels. Away from the face, the dynamics of species interactions within the forest cover become the dominant control, which emphasizes the importance of treefall and gap replacement as a competition-reducing strategy.

6.9.2 Birds

A similar examination of the roles of disturbance and stress has been completed for the bird communities. To simplify the analysis, the groups established in the cluster analysis were used (Groups A-E). The five groups were positioned on the disturbance-stress axes of the Southwood-Greenslade model as presented in Figure 6.10. As expected, the patterns are somewhat similar to those of the vegetation associations (Figure 6.9). The deciduous forest-interior group is aligned along the stress axis, including many of the upland and less disturbed slope sites. The birds of the coniferous forests are found along the disturbance axis, which indicates the importance of small gap creation and successional change in the forest cover. Bird communities associated with the fluvial systems, the rivers and swamps, are located in the centre of the graph, indicating the change and stress these associations experience. Finally, Group B, which includes those sites with higher levels of disturbance as well as moderate stress is located at the bottom right. This group includes many bird species that are adapted to successional sites or gaps and edges found within the forest.

The results are comparable to the vegetation model, which indicated that sites along the top of the graph are permanent habitats. In this case, these are forest-interior species that are most susceptible to disturbance from habitat fragmentation, human encroachment and similar pressures. They have adjusted to moderate stress, as long as a high-canopy deciduous forest is maintained with varying levels of undergrowth. Similarly, the birds of the coniferous plantations have relative habitat stability and favourableness. These bird communities are lower in diversity and quite specific in the species that comprise them. Less is known about the relation of these species to disturbance or the size of plantations, although these sites can experience significant management pressures.

The species in the valleys, the riparian forests and related habitats span various levels of disturbance. The presence of water will override some of the other controls. This will attract species quite specific to the riverine system such as Great Blue Heron

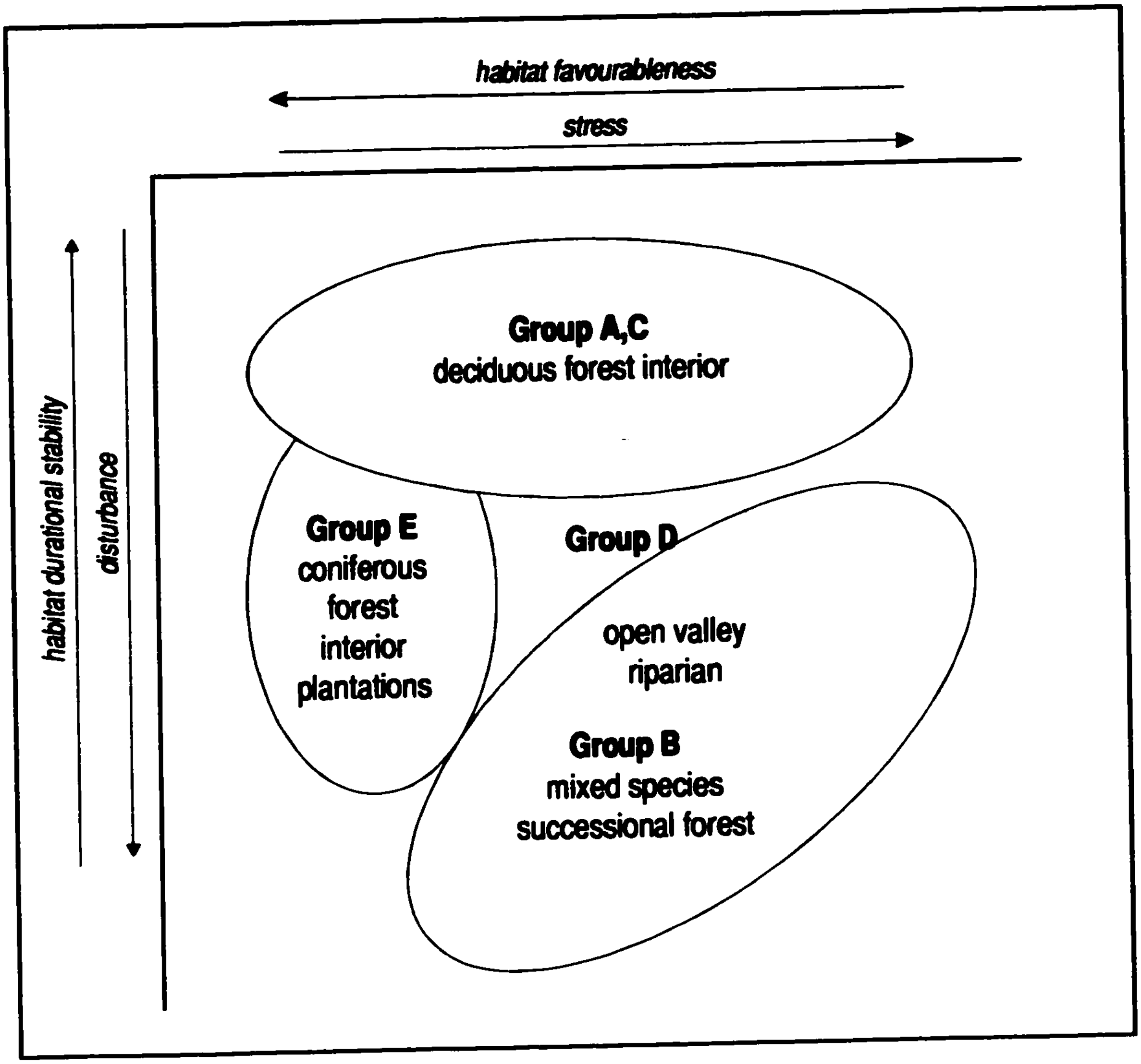


Figure 6.10 Relationship of bird groups to levels of disturbance and stress.

(*Ardea herodias*) or Wood Duck. Group B has a greater diversity of species which is often indicative of transitional habitats. The successional forests and gaps attract species that are adapted to edges and openings, which combined with the forest species that use the gaps for foraging, creates a high diversity of use in this habitat.

6.10 Space-Time Relationships

One of the general concepts of biophysical relationships is the representation of the structure and functions along axes of time and space. This provides a visual representation of the general effect of the processes, indicating the time frame over which they will have an impact as well as an estimate of the magnitude of the impact based on the affected area. When considered in context with stress, it does not provide evidence of the persistence of this impact. The impact of the disturbance and subsequent processes can act to prolong the effect of the disturbance indefinitely. Depending on the type of disturbance combined with environmental constraints such as slope bedrock and moisture flow, the resulting disturbed area such as a landslide scar will recover rapidly or very slowly (Milne and Moss, 1988). This can be a function of the type of disturbance or external factors such as climate. Therefore, the vegetation associations will be a response of the combined effect of disturbance and stress. This complements the work of Grime (1977) and Southwood (1988?).

The relationships between bird and vegetation associations and geomorphic processes are displayed in Figure 6.11. This figure presents the combined disturbance events based on their size or spatial range, a measure of intensity or magnitude, as well as the temporal range over which the event will take place. At the lower end of the scales, the smaller, lower-energy processes control the local environment. These involve singular

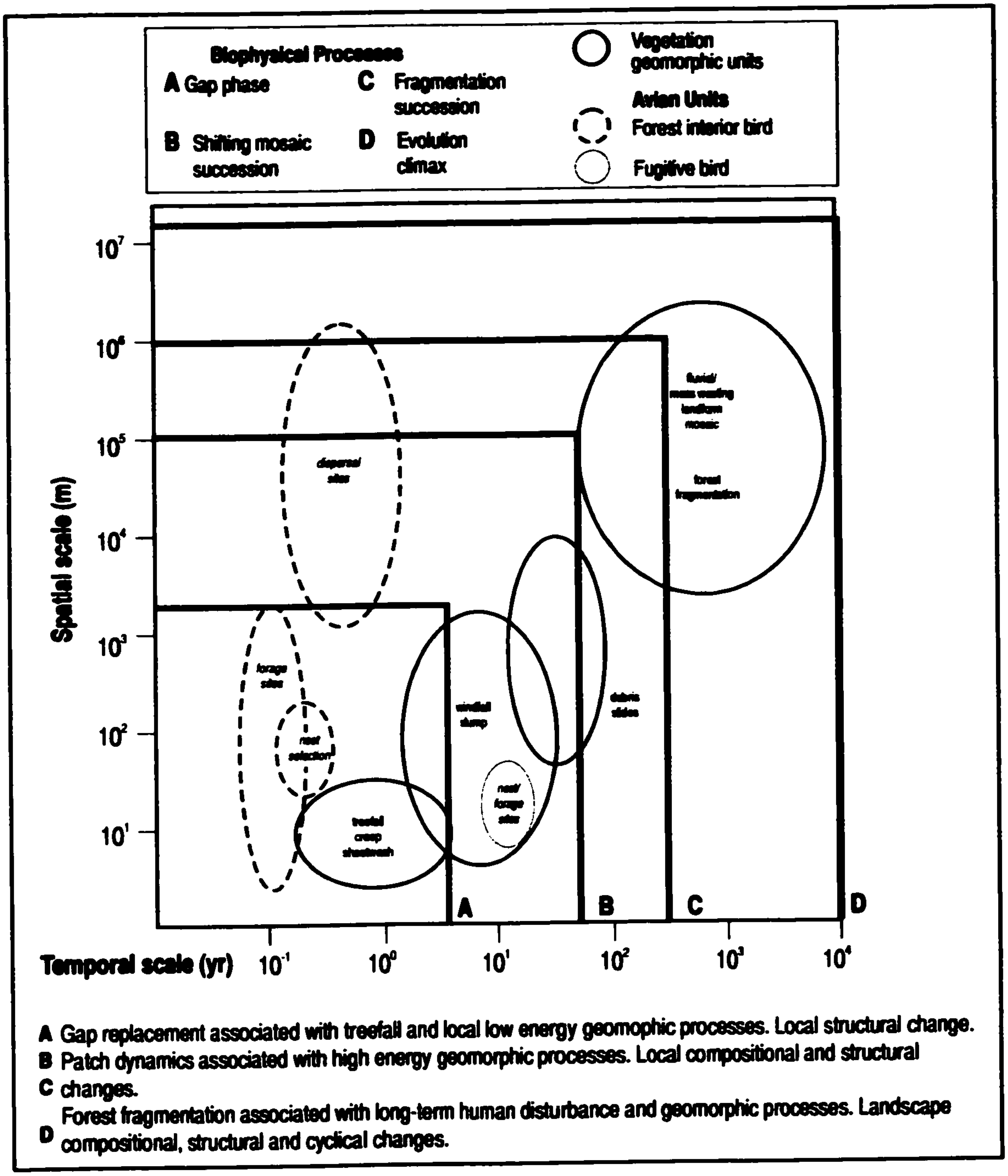


Figure 6.11 The organization of Escarpment land units and biophysical processes within a spatiotemporal hierarchy (adapted from a concept by Hughes, 1997).

cycling of forest trees by treefall. This has little disruption of the surface material although it frees up material and creates a small gap for light penetration. This acts along a yearly time frame, similar to the daily and seasonal pattern of bird species. The geomorphic processes progressively increase in size of impact on the land system as the temporal scale increases. The moderate-sized disturbances include processes such as windthrow and debris slides which are related to gap phase and shifting mosaic succession or patch patterns in forest cover. At the larger scale, impacts are from processes such as fire, or human modification from forest clearance and agriculture. These create larger directional changes in forest cover or traditional successional patterns. It is this group of processes that is of the greatest concern from a management viewpoint with respect to managing resources and land on the Niagara Escarpment. The time period between approximately 10 to 100 years involves critical land-shaping processes and vegetational response (Moss and Milne, 1998).

In this diagram (Figure 6.11), the relationship of birds to the geomorphic processes has also been plotted. The most obvious difference between vegetation and bird communities is that the spatial pattern of the birds is less restricted and consequently the movement of individuals is greater, which is reflected in the stretch of bird positions along the Y-axis. Daily foraging and seasonal dispersal extend into the range of 1000 m^2 to 100,000 m^2. Similarly, the pattern of habitat selection can be quite extensive based on habitat availability and competition. In contrast, the pattern for fugitive bird species was plotted for habitat selection to provide a comparison of the two types of species. The fugitive bird pattern is much more contained, reflecting the limited range of these species within forest sites.

These results emphasize the importance of considering different scales when combining information on wildlife and forest dynamics to develop management strategies for a site or region. The processes of the bird community extend much further than the trees, and therefore patterns of habitats or combinations of different forest types may have to be combined when developing a wildlife strategy. The scales to be considered for the forest-geomorphic relationships may have to be altered to properly understand the wildlife component.

6.11 Escarpment Landscape Model (ELM)

The individual systems of the geomorphic/vegetation/bird system, as described in the preceding sections, are combined in a model of the Niagara Escarpment landscape system. This builds on the concepts of the ESM to provide a more comprehensive model of the Niagara Escarpment landscape system. Where the ESM focused on the inter-relationships between geomorphic processes and forest dynamics on the different slope types, the Escarpment Landscape Model (ELM) has a broader spatial scope that includes other landscape components - the bedrock plains and glacial plains above the face as well as the stream valleys and lower plains within and below the scarp face. It is the complex of these landscape units that make up the greater Escarpment landscape system.

An Escarpment Landscape Model (ELM) for the central Niagara Escarpment is illustrated in Figure 6.12. The initial division is based on the position in the Escarpment landscape, either upland, face or valley. Divisions within these units are linked to the disturbance and stress levels. In general, from the left side of the chart to the right there is declining control and increased response within the systems. Proceeding to the right identifies the related forest types and the association of bird groups. These are combined

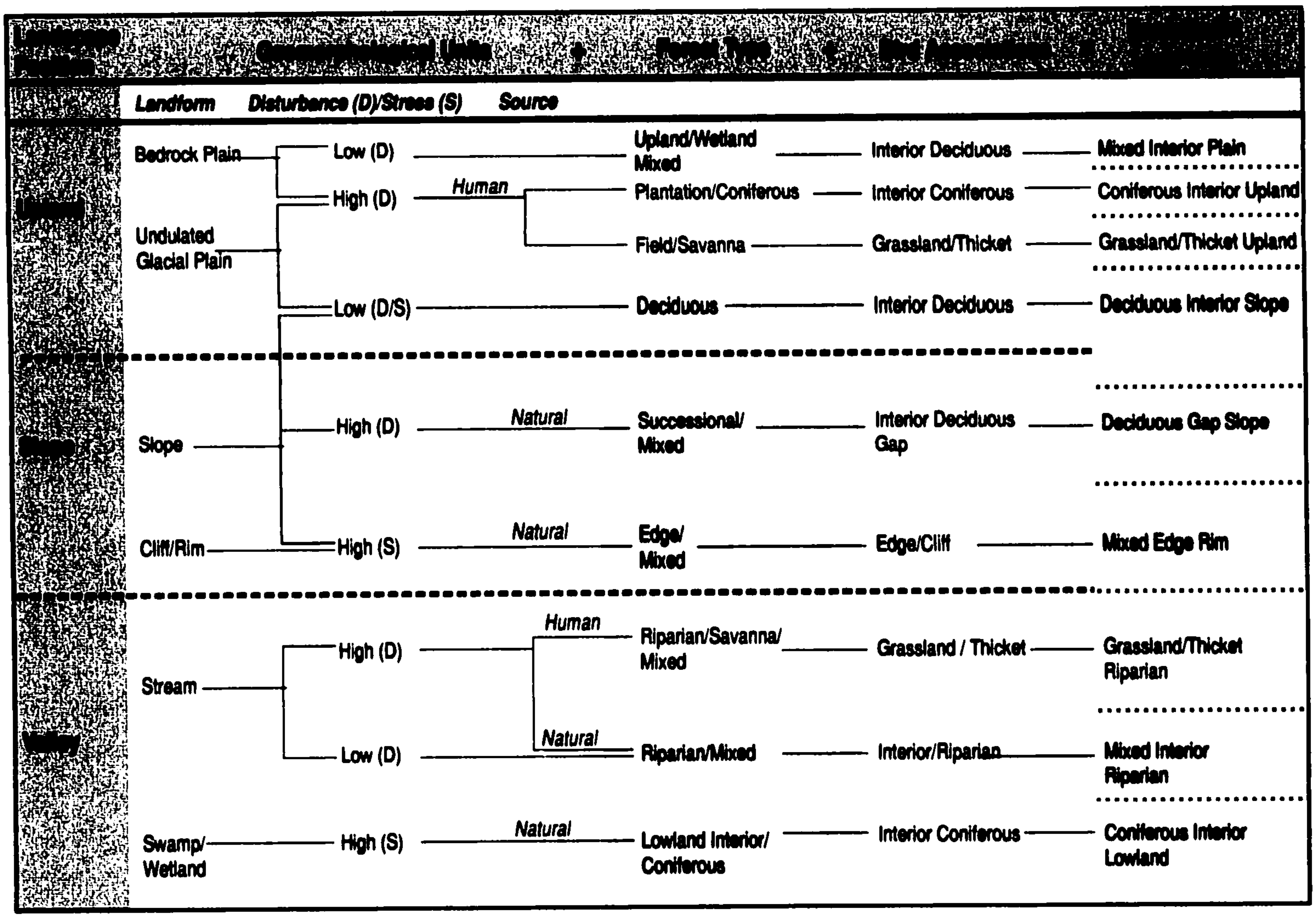


Figure 6.12 Escarpment landscape model (ELM). The land units build from the geomorphological unit on the left to the bird associations on the right, indicating the level of control and integration of landscape components.

on the right side of the diagram to produce nine Escarpment landscape units. These correspond to the units introduced in Figure 5.9. These are mappable units and are similar in scale to the 'land type' of the U.S. system (ECOMAP, 1993) or the 'ecosite' of the Ontario Ecological Land Classification system (Lee and others 1998).

One of the criticisms of many land classification schemes is that the approach is morphological, which limits the applicability to management. In some ways, it is the best approach and suits the ability of GIS to transform a large quantity of data such as soil types and elevation into a manageable or simplified presentation of information for interpretation. However, this approach will only portray a static system. It is limited temporally to the point of reference of data collection. It is static in the sense that it treats each land unit or habitat as the permanent condition. This is useful in short-term planning, for example the NEC's five-year plan, but it is limited in its ability to forecast conditions beyond that time frame - into 10-100 year periods which should be the time frame of ecosystem management strategies.

In the ESM, one of the distinguishing features of the land units are the processes that initiate change or control the structure of the system. One way to classify these processes is based on the level of disturbance and stress experienced at that site. At this scale of operation, the sources of disturbance are expanded from the ESM to include a differentiation between human and natural disturbances. For this model, these levels are simply identified as high or low disturbance. High levels of human disturbance include land clearance and forest replacement. For example, there is a number of pine and spruce plantations found along the Escarpment which alter the vegetation structure of the forest from deciduous to coniferous. There are also sites where the land has been cleared for agriculture but has subsequently been abandoned and is returning to a natural forested state. In earlier successional stages, these areas are a combination of fields, orchards and cedar stands. Areas in the uplands and valleys, rather than the face, often exhibit higher levels of human disturbance. By contrast, natural disturbances are greater where there are geomorphic events of high magnitude, more common on the Escarpment face.

6.11.1 Upland Landscape Units

The upland sites had four identifiable land units which varied based on the surface material and disturbance regimes. The broad difference was between sites on the bedrock plain in the southern section of the research area and those on the undulating till plains of the northern region. Within each of these, there are several further subdivisions based on levels of disturbance and stress.

Mixed Interior Plain

This land unit includes the upland sites on the bedrock plain. Typically this land unit is a relatively flat surface having shallow soil on bedrock outcrops, with karst topography as well as intermittent pondings and poorly drained sites.

This pattern creates a diversity of moisture and soil characteristics that is reflected in the vegetation and bird dynamics. Primarily the land unit is covered by upland deciduous forests, similar to the other upland sites and dominated by sugar maple, beech and white ash. However the seasonally flooded lowlands are covered by a mixture of deciduous and coniferous species including red and silver maple, American elm, eastern white cedar and balsam fir. The bird populations are also quite similar to the upland interior forests, dominated by Red-eyed Vireo, Eastern Wood Pewee and Ovenbird. The combination of small, seasonal wetlands and bedrock outcrops attracts a large variety of species. Wood Duck and Mallard were located in the ponds, and Northern Waterthrush and Winter Wren were located within this unit as well.

These sites can be described as a relatively stable system that experiences low disturbance and moderate stress depending on fluctuations in water levels. There are no obvious gaps in the forest cover, except for the wetland areas. However, there are likely higher levels of stress in this unit than in the Deciduous Interior Slope. The presence of water is often seasonal and will vary from year to year, setting up the potential for drought and change in the vegetation component. Similarly, the shallowness of the soil will make these sites more susceptible to low moisture levels. Consequently, there may be more mortality in the tree cover creating small gap disturbance and potential for blowdown and other small disturbances. This will increase the potential for cycling in the forest cover and will increase the diversity of habitat, which in turn increases bird diversity. It was evident at Speyside that the number of woodpeckers was high, which could be related to the number of snags in the forest. Overall, this leads to sites with higher levels of bird diversity than in similar forests on upland glacial deposits as found in the Deciduous Interior Slope.

Deciduous Interior Slope

The Deciduous Interior Slope unit includes sites that are found on uplands above the defined rim of the Escarpment and face units of the Escarpment mainly in the northern region at Glen Haffy and Hockley, sites associated with type C slopes. This landscape unit includes both upland and face sites, since the nature of the terrain is similar for the upland areas and the Escarpment face. The depth of glacial material in areas such as Hockley and Glen Haffy creates deep, rolling valleys above the Escarpment, similar in structure to the

Escarpment slopes. Similar geomorphic processes shape the slopes, especially soil creep and sheetwash as well as treefall.

In response, the vegetation cover is typically a mature, deciduous forest similar to many woodlots in southern Ontario. These forests are dominated by sugar maple, American beech and occasionally eastern hemlock. Where there has been previous human disturbance there are higher numbers of black cherry and white ash. The main forest dynamics are from individual treefall and blowdown. These create small openings in the forest cover that fill in with similar species. The bird populations are typical of southern Ontario deciduous forest interiors, with the highest concentrations of Red-eyed Vireo, Ovenbird, Wood Thrush and Eastern Wood-Pewee.

This unit experiences both low levels of stress and disturbance, and consequently can be considered a very static system. This landscape unit will have some of the most stable habitats which, when combined with a large forest interior, produce high densities of deciduous forest-interior birds. These sites are very important within the landscape as source areas for deciduous forest-interior species.

Coniferous Interior Upland

The Coniferous Interior Upland is a landscape unit that is a human construct. It is not a natural unit and is dependent on the management practice of creating monocultures of pine and spruce plantations on lighter or weaker soils in southern Ontario. These units are primarily found in the upland areas where there are large tracts of land suitable for planting, and consequently there was no evidence of plantations located on the steeper and active faces or in the stream valleys.

This landscape unit was located on both the bedrock plain and the northern glacial plain, although it appears to be more dominant on till plains where the soil is thicker. The plantations on the shallow soils were much smaller. These land units experience relatively low natural disturbance, although there were several records of blowdown during the study period. Plantations are more susceptible to this form of disturbance, with the regularly spacing and nature of the individual trees. The obvious disturbance is the human modification of this system with the replacement of a primarily deciduous or mixed cover with a total coniferous cover, and by reducing the variation in tree age, which creates an even-aged stand.

The status of this system will depend on the management practices. If management has ended and the forest is naturally regenerating, then the system can be considered to have low to moderate disturbance with low stress, although there could be circumstances where the moisture level would be low, especially on the sandier glacial deposits. When there is removal of stems, the system becomes quite dynamic, increasing the impact of disturbance to the system, especially if harvesting involves clearcutting. Over the long term this can be considered a dynamic system with cyclical or directional change depending on the management plans.

The vegetation cover reflects a mature coniferous cover dominated by red pine, white pine or white spruce. At the sites studied in this report, these land units occurred on public land where forest management had been significantly reduced or eliminated. Harvesting is occurring on similar landscape units in the region of the Escarpment, which creates different vegetation associations. At the sites in this study, various levels of regeneration were taking place, mainly the replacement of the coniferous cover with a mixed or primarily deciduous cover. As this occurs, the overall ecosystem structure changes, especially the wildlife component.

Grassland/Thicket Upland

The Grassland/Thicket Upland landscape unit is also dependent on human disturbance. These units are located primarily in areas of human activity, including the upland areas and in some cases the stream valley as described below. The upland sites were not studied as thoroughly as others in this study; there was only one site located in this land unit. However, this unit is prevalent throughout the Escarpment as farms are abandoned or land is placed on hold for development, aggregates or rural settlement. These are dynamic systems that are typically returning to a forest cover. They are at various stages of recovery and need to be investigated further to understand the complex system of natural processes overlain by the combined human disturbance from previous land management as well as present practices such as tree planting and other restoration projects.

The study site was located on bedrock plain and, like the Mixed Interior Plain, it experienced variations in the levels of moisture creating a mosaic of drier and wetter microsites. Natural disturbance was low although stress levels were likely moderate to high from moisture variations and exposure to sun, which would not be experienced in the forests of the Mixed Interior Plain.

The vegetation cover reflected this variation with patches of grasses, shrubs and a tree layer dominated by white ash and eastern white cedar. The dynamics of this system suggest fairly quick recovery to a deciduous forest cover on the drier areas and smaller mixed and coniferous cover where there were small streams or ponds. It is predicted that with time this unit would return to the Mixed Interior Plain. The bird populations also reflect this variation and include a mixture of grassland, thicket and early-forest species; these include Song Sparrow, Eastern Kingbird, Field Sparrow, and Blue-winged Warbler. Many of these species are recognized as species of conservation concern mainly because of declining habitat and populations (CVC, 1998; Askins, 2000).

These are transitional forests that are habitat for a number of neo-tropical migrants such as American Redstart. In eastern North America, many of these vegetation communities have already reverted back to forest cover (Hunt, 1996). To maintain these units on the Escarpment will require a management direction at odds with current strategies such as tree planting. Proper management will need to maintain the dynamic nature of these systems. As they currently exist, they are long-term dynamic systems, but are reverting back to static forest systems.

6.11.2 Face Landscape Units

Deciduous Gap Slope

The Deciduous Gap Slope landscape unit is found on the Escarpment face where high levels of natural disturbance exist, primarily from debris slides. These units have high disturbance but low stress which promotes a very dynamic system. Slides are frequent but recovery rates are relatively high. These sites occur on the steeper slopes where structural controls such as bedrock outcrops direct water to the surface and initiate debris slides. This process creates gaps in the forest cover. Within the range of this study, this unit occurs in combination with both the bedrock plain and the till plain; it is more locally a function of bedrock structural controls and the presence of water.

The vegetation response is a mixed cover or, less common, a deciduous cover. On the scars, a successional vegetation cover is dominant which varies over time as the scar recovers. In many cases these sites remain active as new scars are initiated at the same site or the adjacent edges.

Scars will have varying impacts on the bird populations. These sites can attract a high diversity of species by creating a natural 'edge effect'. This functions at two scales. At the smaller scale these scars attract species that nest in these gaps such as Indigo Bunting and Mourning Warbler. At the larger scale these scars provide food sources in the form of herbaceous plants, flowering shrubs and varying types of trees which may add to the overall productivity of this site. Therefore, species typical of the forest interior are also commonly found on the scar, including Scarlet Tanager, Yellow-bellied Sapsucker and Eastern Wood Pewee. Overall, the continued presence of these scars, either through re-initiation of the same scar area or through initiation of new scars, serves to create sites of higher species diversity. Consequently, these units could play an important role in the regional landscape as critical source areas of regional metapopulations. In managing these sites it is important that micro-climate and moisture sources are not disrupted. Local and regional changes to water tables could influence the dynamic nature of these slopes (Milne and Moss, 1996).

Mixed Edge Rim

The Mixed Edge Rim landscape unit is a restricted type found only along natural edges associated with the cliff face and, in some cases, extreme ridges of the face. The existence of a large dolomite cliff face will create a micro-environment with a high level of stress and sometimes natural disturbance where the face is actively weathering. These natural edges usually have little soil cover and low moisture. Where the face is quite large there is an extensive cliff face environment (Larson et al., 1988). Natural edges are not a common feature of landscapes in general, especially where the edge is relatively stable. Often natural edges are the result of disturbances such as fire or wind and therefore change over time. The scarp face, however, can be considered a dynamic system. Disturbance is moderate to large, ranging from a steady removal of rock and talus build-up to large blockfalls. However, blockfall is an infrequent phenomenon at a greater time scale than debris slides. The uniqueness of this landform associated with the high level of stress attracts a specific group of species adapted to this environment.

The vegetation cover is often a mixture of coniferous and deciduous species that have adapted to stressful environments. The dominant tree is often eastern white cedar and there are often very old individuals on the rim and cliff face which leads to the uniqueness and importance of this unit. The complexity of habitats at the base of the cliff produces a diverse community of trees including late successional species such as basswood and white ash as well as gap species such as mountain maple.

Several bird species unique to this habitat included Common Raven, Turkey Vulture and Rough-winged Swallow. The presence of Common Raven represents one of the most southern breeding records for this species in southern Ontario. The bird populations on the talus slopes also reflected the diversity of the unit, with a mixture of interior and edge species, including Red-eyed Vireo and Eastern Phoebe (*Sayornis phoebe*), similar to the Deciduous Gap Slope.

6.11.3 Valley Landscape Units

Grassland/Thicket Riparian

The Grassland/Thicket Riparian landscape unit is another feature that has resulted from human disturbance. Like the Grassland-Thicket Upland unit, this feature is a response to land clearance by humans, creating a mixed vegetation cover that includes small patches of trees and open clearings along river channels. This site is typical in the upland areas away from the Escarpment face or further downstream beyond the immediate Escarpment valley. Only one site for this type of unit was investigated in this study but it is similar in characteristics to other stream valleys with similar meadow/thickets in the Credit Valley watershed which overlaps the study area (Milne and Bennett, 2001).

This unit is considered a low-gradient system, as the stream channels do not exhibit a high disturbance factor and there is limited bank erosion. There is a wide floodplain so much of the area could experience moisture stress during wet years. This is a slow-flowing system compared to the Mixed Interior Riparian unit (see following section), where river systems drain over the Escarpment and have high-gradient stream channels. The grassland/thicket riparian unit can be a dynamic system where there is vegetation change as the open areas return to lowland forest.

The vegetation cover is considered riparian with patches of trees dominated by eastern white cedar and deciduous cover consisting of Manitoba maple and black ash. This cover is eventually replaced with the Mixed Interior Riparian forest. The Grassland/Thicket Riparian unit has a mixture of bird species that reflect the combination of open thicket habitat and the riparian system. There were high concentrations of Song

Sparrow, Indigo Bunting, and White-throated Sparrow, as well as riverine species such as Wood Duck, Mallard and Great Blue Heron.

This transitional forest is similar to the Upland Grassland/Thicket unit. There are very diverse habitats for birds which will eventually be replaced unless this system is treated as a dynamic system and disturbance is artificially sustained.

Mixed Interior Riparian

The Mixed Interior Riparian landscape unit is found primarily within the face segment of the Escarpment. It includes river systems that flow over the bedrock which can result in a waterfall. The river immediately below the knickpoint is a fast-flowing stream with a narrow or nonexistent floodplain that cuts through the bedrock and glacial material until it reaches a broader floodplain where the energy level is dissipated laterally. This land unit also occurs on the upper bedrock plain. It is related to the re-entrant valleys, the deep glacial valleys that have been cut back into the main edge of the Escarpment. These are high-gradient systems in which disturbance from high flood events reworks the stream channel, moving and shifting the cobble streambed. This will have an impact on the vegetation immediately adjacent to the floodplain. Where the channel broadens, small seasonal ponds develop when the stream overflows the banks and floods the plain.

The forest cover is a mixed cover with a wide diversity of species. The coniferous cover is predominantly eastern white cedar stands, which can be quite dense. There is a wide variety of deciduous species including sugar maple, balsam poplar, trembling aspen, and yellow birch. Despite the presence of water these landscape units have a lower diversity of bird species, especially in the extremely fast-flowing channels. The species most common along these channels include Black-capped Chickadee, Winter Wren, and Northern Waterthrush. Where the channel broadens or disturbance creates a pattern of point bars and openings in the forest cover, gap species can be found including Song Sparrow and Mourning Warbler. Riparian species recorded at these sites, although not within the breeding season, included Spotted Sandpiper, Mallard and Common Grackle.

Coniferous Interior Lowland

In this study, the Coniferous Interior Lowland landscape unit was limited to only one sample at Alton, not on the Escarpment. It was in a poorly-drained floodplain of the Credit River at the base of a small slope. This was a relatively stable system with low levels of disturbance, but could be considered to have higher levels of stress from the fluctuations in moisture content of the soils. Therefore, it represents a static system most affected by changing levels of moisture.

The forest cover is predominantly coniferous, primarily eastern white cedar, with balsam fir and white spruce. The trees form a dense forest cover with many snags and dead trees on the forest floor. The trees are often growing on small hummocks or islands that frequently blow over. The main dynamics of this system appear to be individual tree replacement from old age, wind, or disease. This unit had a quite unique bird population, comparable only to the Coniferous Upland Plantations. Birds in this unit are typical of coniferous forests and included Winter Wren, Nashville Warbler (*Vermivora ruficapilla*), Red-breasted Nuthatch, and Golden-crowned Kinglet (*Regulus satrapa*). Similar results were found for coniferous swamps within the Credit Valley watershed (Milne and Bennett, 2001).

6.12 Summary

In this chapter, descriptive models have been proposed to explain the relationships between vegetation and avian components, and landforms and geomorphic processes for each of the face, upland and valley units. These models have emphasized the differences in biophysical process and the resulting associations of the biological components. These relationships were then considered in combination with disturbance and stress to provide a better understanding of a system's organization both in time and space.

In the final section, the results of the classification and ordinations for both bird and vegetation data were combined to create a set of nine Escarpment landscape units. By determining these inter-relationships, it was possible to introduce a set of land units that were based on the geomorphic form and process related to the Escarpment land system. This process considered the roles of disturbance and stress in classifying these units, an important consideration for long-term management strategies. There were several identifiable units representing important components of the Escarpment and targeted for concern in land use planning. In the concluding chapter, the results of this work will be summarized followed by a brief discussion of possible applications of this information to land and wildlife management issues on the Niagara Escarpment.

Overall the complexity of the Escarpment presents a unique landscape for this area of Ontario. This creates concerns for the management of the Escarpment within the boundaries of the Plan as well as the role of the land system within the larger regions of southern Ontario. These concerns will be pursued in the concluding chapter as related to the findings of this work.

Chapter Seven
Summary, Applications and Recommendations

7.0 Introduction

A number of relationships between the geomorphic vegetation and avian components of the central Niagara Escarpment were identified in this study. There were patterns in the biological components related to landscape position. However, location on upland, face and valley sites was not the only factor; there were also patterns related to disturbance and stress from natural and human processes. In this chapter, the results of this study will be summarized and then followed with a discussion relating these results to environmental management issues on the Escarpment. The summaries will highlight the relationships between the geomorphic, vegetation and avian systems for each of the land units. This will be followed with a brief review of the landscape units and systems.

7.1 Vegetation and Geomorphic Relationships

There was a distinct pattern of vegetation associations between the upland, face and valley segments. This is directly related to the type of disturbance: human disturbance was more prevalent on the uplands and natural disturbance was greater on the slopes and valleys. At the landscape scale there were differences related to glacial deposits and bedrock structure. Between landscape units, the main differences were types of disturbance and presence of water systems while at the site level there were relationships between the levels of disturbance which could be related to bedrock structure and water flow.

Upland

1. On deeper deposits of glacial till and stratified drift, upland forests were primarily deciduous dominated by sugar maple. On the bedrock plateau, where there are shallow soils, a second forest association dominated by silver and red maple was found. In these forests, disturbance was not a dominant factor in tree replacement but moisture-induced stress likely caused compositional change in the plateau forests.
2. The major form of disturbance encountered on these units was human-initiated. One form of disturbance was the presence of red and white pine plantations. These forests are in a state of regeneration and are being replaced by a deciduous forest dominated in the early stage by black cherry and white ash. Forest clearance and land abandonment has also led to a dynamic system. The pattern of change in this forest was dependent on the composition of adjacent forests; this has created a mixed cover of white pine, white ash, and apple.
3. Geomorphic processes are primarily low-energy events, dominated by creep and sheetwash. Where there are deep glacial deposits, the terrain is more irregular and slope angles can be as steep as the main Escarpment slope, but there was no evidence of rapid mass movements. Forest cover was very similar between uplands and slopes in these landscapes units.
4. Gap-phase replacement was a dominant process in both the deciduous and coniferous forests. Small openings were created in the canopy cover from wind or ice damage; in these gaps the forest was replaced by combinations of canopy, successional and shrub species, depending on the level of disturbance. It appeared

these processes created larger openings in the older plantations but more investigation is required to develop a stronger relationship.

Face

1. There was greater variability in the vegetation composition of forested slopes on the Escarpment face. The vegetation forest associations ranged from a forest cover with a strong similarity to the upland deciduous sites on the deep glacial deposits to mixed stands or coniferous stands dominated by white cedar. Overall, there was a higher percentage of coniferous cover compared to the upland sites. The greater diversity of species can be related to the variety of microhabitats created from variations in natural disturbances and stresses related to the geomorphology of the site.
2. Vegetation response to debris slides followed two general paths. In some cases, the scars were quite dynamic and had a high diversity of vegetation cover. On more stressful sites recovery was more restricted and diversity was lower. The pathways could be related to the bedrock geology, glacial deposits and related moisture flow.
3. Talus slopes below cliff faces also displayed a high diversity of tree species. The sites were controlled by a combination of disturbance and stress from talus accumulation.
4. A diverse forest cover developed on buried cliff faces and associated talus slopes. Successional or gap species, such as basswood, white ash and ironwood are important members of the canopy. These is also a higher diversity of shrubs and undergrowth.

Valley

1. There was a higher concentration of coniferous species, primarily eastern white cedar, within the lowlands and stream valleys.
2. High-gradient channels had a higher diversity and density of tree cover. Riparian species were found in association with upland species such as sugar maple and white birch. Disturbance is initiated by high flood events and by bank erosion. Undercutting by fluvial action also initiates debris slides on adjacent slopes which promotes change in the forest cover.
3. The valley units had a strong moisture presence; in most cases there was a stream passing through the unit. In the low-gradient stream channels and valleys, moisture stress will likely control changes in forest composition. There appears to be a strong relationship between the vegetation component and moisture levels which should be examined in more detail.

7.2 Avian Populations and Biophysical Systems

The relationships between bird populations and the geomorphic/vegetation system were related to the type of vegetation cover and landscape position. The roles of disturbance and stress were not as obvious as found between the vegetation and geomorphology components. One of the reasons for this is the ability of birds to move throughout the complex of forest communities, especially where there has been limited habitat fragmentation or the creation of extensive edges. The overall effect is to increase the similarity between geographically-related sites.

Upland

1. Upland forests on deep glacial deposits had the highest densities of deciduous forest interior species such as Red-eyed Vireo and Wood Thrush. Where there were small pondings and bedrock outcrops, the diversity of the landscape unit was increased. At these sites, species such as Northern Waterthrush, Veery and Wood Duck were added to the populations.
2. Bird distribution was strongly related to the distribution of deciduous and coniferous cover. This was strongest in the upland areas where there were a number of plantations. Plantations provide a habitat for a number of coniferous forest species such as Red-breasted Nuthatch, Pine Warbler and Yellow-rumped Warbler. These habitats add to the overall diversity of the landscape and are an important component of the landscape mosaic
3. There were distinct bird associations where the land was regenerating to a natural cover following land abandonment. The field and thicket habitat was dominated by Song Sparrow and Indigo Bunting. These sites also provided unique habitats with a distinct avian component which increased the overall diversity of the Escarpment landscape.
4. There was some response by species to gap-phase replacement in the forest cover. There were records of species such as Winter Wren and American Robin utilizing treefall gaps, but the variability and density of species were not comparable to avian use of debris slides on the face units.

Face

1. The variations in levels of natural disturbance and stress created a mixture of vegetation types ranging from coniferous to deciduous stands. The related response in the avian species was a shift from groups dominated by Black-capped Chickadee to Red-eyed Vireo. Faces with little disturbance and a strong deciduous cover attracted species similar to those found on the undisturbed upland forests. Faces with a mixed forest cover had higher concentrations of species such as Black-throated Green Warbler and Black-and-white Warbler.
2. The diversity and abundance of species were high on scars of some debris slides; these were sites of increased shrub cover and greater food resources. These large gaps added to the overall diversity of the land unit. In comparison, bird diversity was lower where the slide scars exhibited high stress and limited recovery.
3. Cliff and talus complexes created an inherent edge that attracted a higher diversity of species. The cliff environment provides a unique nesting habitat for several species including Common Raven and Turkey Vulture. On the talus slopes there is increased shrub density which potentially increases food sources and cover.

Valley

1. Black-capped Chickadee dominated all valley units. Extensive stands of white cedar and associated conifers in the lowlands attracted a number of species similar to those found in the plantations such as Red-breasted Nuthatch and Yellow-rumped Warbler.

2. The low-gradient, wide floodplain sites had very high diversities and densities of some species, especially those adapted to riverine shrub communities such as Song Sparrow and White-throated Sparrow.
3. The high-gradient, small river channels that cut through the Escarpment face had a low diversity of species, a pattern that has been reported in mountainous stream systems (McGarigal and McComb, 1992). The high-energy streams did attract several species such as Northern Waterthrush and Winter Wren, but they were not restricted to these habitats.

7.3 Landscape Units and Systems

The relationships described in the preceding sections were used to create a series of landscape units for this region of the Niagara Escarpment. These units bring together the composition of the biophysical environment while also addressing the controlling processes that initiate change or maintain stability. These units show a general relationship to landscape position as well as the patterns of the biological components, but there are temporal and spatial variations from these parameters related to differences in natural and human processes. The key findings for this section are presented in the following list.

1. Nine landscape units were identified for this region of the Escarpment, with several units corresponding to each of the upland, face and valley units. These were combined to create a descriptive model of the landscape systems.
2. Differences in upland units are related to the depth of surficial material and bedrock formations as well as human disruptions to the vegetation cover. Face units were related to bedrock structure creating cliff faces as well as the level of

mass movements. Face units with low levels of disturbance are similar to related upland units. Valley units can be divided between gradient levels and related flow rates as well as human disturbance.

3. Two general landscape systems were identified for this region. They are primarily a response to the bedrock structure and surficial geology. Bedrock plateaus and small cliffs in the southern region were dominant while the northern region was shaped by the rolling topography of deep glacial deposits.

7.4 Landscape Units and Management Issues

There are several areas in which the results of this study are important to wildlife and land management including species and habitat management and land classification. In general, wildlife management is often directed at species or habitat conservation. Efforts towards species management in terms of time, economies and policies are often dictated by the level of rarity, or the Vulnerable, Threatened and Endangered species (VTE's) (e.g., Bocking, 2001).

Habitat is measured by its importance for a specific species or a suite of animals such as old growth forests or estuaries (Seymour, 1992). Habitat or habitat loss can also be determined by its extent or decline and can be measured by rarity (Gauthier and Wiken, 2001). The tools for establishing management strategies at the landscape or regional level that address the combination of species and habitat are dependent on overlays of relevant environmental measures that produce Geographic Information Systems (GIS) which identify habitats and/or species areas (e.g., habitat suitability). Often these overlays are based on biophysical parameters, such as vegetation, that are easily mapped (e.g., Lee et al., 1998) . As indicated in this study, overlays should also include measures of system processes, especially those that link the biophysical and human systems (e.g., DeGraaf and Miller, 1996; Clark and Pelton, 1999).

7.4.1 Species and Habitats

Often the focus of land management is on protecting a site for a plant or animal species with limited numbers. The focus will depend on the managing agency but is often directed at species with limited numbers such as an endangered species or the VTE's as identified by a specific agency such as COSEWIC (COSEWIC, 2000). This could also be at the local level such as a conservation authority, for example, Credit Valley Conservation (CVC) on the Niagara Escarpment (Milne et al., 2000a). Other approaches could include isolating important species that are indicators or regulators of ecosystems, such as indicator species or keystone species.

One of the difficulties in using rarity as the goal is that often there are too few rare species upon which to build a comprehensive strategy; this can weaken the perceived importance of a habitat. In this study there was only one VTE - limited to records of Red-shouldered Hawk at Hockley and Silver Creek. A more useful approach is to create a comprehensive list of species that target key conservation concerns, such as critical breeding habitat, staging grounds or declining population numbers (Faith and Walker, 1996; Flather et al., 1998; Milne et al., 2000a). This approach has been developed for a number of scales both federally (Dunn et al., 2000) and locally (Credit Valley Conservation, 1998). Several approaches have been applied to lands of the Escarpment including the Credit Valley watershed (CVC, 1998) and a broader mapping of the entire Escarpment (Couturier et al., 1998).

A large number of species considered to be of conservation concern by CVC were identified in this study of the Escarpment. In another study, these species were mapped by presence/absence at the scale of the Ontario Bird Atlas squares (Cadman et al., 1987), and it was apparent that the Escarpment region had a greater diversity of target species than the surrounding urbanizing landscapes (Milne et al., 2000b). This reinforces the importance of the Escarpment as a source of regional metapopulations of many forest-interior species (Wyatt et al., 1997).

One of the main reasons for this concentration of important species is the variety of habitat that occurs at several levels. At the regional scale, the combinations of different land uses, slope types and geological structures enhance diversity. At the landscape scale it is the combination of upland, slope and valley system with varying levels of human and natural disturbances that creates the diversity. Finally at the land unit level, areas on the Escarpment slope experience a diversity of processes resulting in a micro-pattern of habitats along the face, slope and cliffs. This creates a more diverse pattern of habitats than found in upland forests or the typical woodlot of the rural landscape. It is the subtlety yet complexity of these slope systems that attracts a large number of wildlife species from the surrounding land units.

It is important from a management perspective to identify which species are dependent on specific habitats. This will assist in protecting critical habitat or modifying existing habitat such as restoration of forest cover or eliminating exotics. There is considerable information on the relationship of species to general habitats but there is still a lack of detail on how species interact within their environment, especially the mosaic of the landscape. It is necessary that our knowledge extends beyond simply understanding the preferred breeding habitats or nest sites. It is necessary to understand the use of different habitat components during breeding, dispersal and migration seasons, such as the use of foraging sites during breeding season (Harpley and Milne, 1996). For instance Credit Valley Conservation (1999) developed a Habitat Utilization Model to identify the preferred and utilized habitats for species within the Credit Valley watershed. Information on the relationships between birds and habitat that were discovered for the Niagara Escarpment has assisted in refining CVC's understanding of wildlife/habitat relationships in the Credit Valley watershed.

7.4.2 Niagara Escarpment Commission and Protected Areas

One of the directives of the Niagara Escarpment Commission is to establish natural areas and protected lands to maintain ecosystem functions, composition and structure. To achieve this goal requires an understanding of how the system functions. It is necessary to understand more than simply the components of a system but also what are the processes and fluxes of energy and material (Moss, 1983). By comparison, the Ecological Land Classification (ELC) system for Southern Ontario, at the scales of land unit and landscape, is primarily focused on vegetation pattern and variation in the structure of the forest cover. With this focus, any variations in vegetation dynamics and patterns in habitat will be overlooked, which will have implications for land management. At the scale of the 'community series' of the ELC, an area may be mapped as deciduous forest cover. However, this will overlook the dynamics of the biophysical processes that are driving this system. For example, the ELM (Figure 7.12) indicates forest cover is deciduous for both the slope and upland units, but forest gap replacement occurs more frequently in the Deciduous Gap Slope unit than the Deciduous Interior Slope. In response, bird populations will have a greater diversity in the Deciduous Gap Slope units where landslides are a component of the biophysical system. Consequently, these units could play a more critical role in foraging and nest sites for many species than sites situated in the Deciduous Interior Slope units. In turn, land and resource planning decisions should take these differences into consideration when planning land use on the Escarpment. This could be achieved by establishing a classification scheme that includes landscape processes. Mappable units could be identified at the planning scale based on criteria related to the combination of landform and process.

This approach to establishing land units and understanding the ecosystem relationships can be applied to management policy within protected and natural areas of the Escarpment. One of the main issues in land management is the decision to preserve through natural processes, to allow landscapes to return to their natural states, or to renew the land by adding species and individuals through tree planting or wildlife re-introduction. There is often a conflict of uses that arises from these situations, between maintaining human-modified habitats and developing a 'natural' system or pre-settlement landscape. However, this may be at odds with other conservation directives such as maintaining biodiversity and functioning of the ecosystem.

Through this study, several land units have been identified that play a central role in the Escarpment system and are threatened by current land use and resource demands. These situations will be reviewed, followed by concluding recommendations for management. A number of these sites on the Escarpment are undergoing a change in land cover as forests are established both naturally and through human involvement. This is leading to a reduction in some habitats identified in this paper, such as the old field/orchards and plantations. Two groups of avian species are threatened by these changes. The plantation community, which as discussed earlier is more diverse than predicted, will be threatened from a regional viewpoint; many of the species found there are more northern in nature and range but have maintained populations in southern Ontario in extensive plantations that were established during the past century. With the removal of these land units and reduced replacement, this group of species could be at risk. This has implications at the regional level if agencies such as CVC have management goals directed at maintaining levels of biodiversity within a watershed.

Plantation

The roles of conifer plantations in wildlife management and fragmentation have not been studied extensively in southern Ontario, although exotic and native conifers are central in many afforestation programs (Izhaki, 1999; Shochat et al., 2001). Variations in bird diversity can be related to vegetation structure or limited quality habitat initiated in the plantation and the habitat strategies of the local bird population. The presence or absence of a shrub understory will enhance or deter species colonization of the plantation (Lopez and Moro, 1997; Diaz et al., 1998; Shochat et al., 2001). The habitat strategies of the regional bird populations will also have an effect on the successful colonization. Cody (1975) found South African plantations had very little diversity because the bird species were mostly specialists while pine forests in Chile had a higher richness since the species are more generalists.

It is important to understand the dynamics of these forests since many are in a state of transition by removal, abandonment or management as they mature. In some cases, these forests have been taken over by conservation authorities or have been purchased by private owners for potential development and conversion to housing developments. The argument has been that since these forests are primarily monocultures, they do not serve a strong functional role in the landscape and do not contribute significantly to ecosystem characteristics such as biodiversity.

This can be argued on several points. Biodiversity can be high in these forests, especially when there are management practices in place that enhance this feature. If areas in the forest floor are allowed to regenerate with shrubs and young saplings, several species will take advantage of the vertical complexity such as Winter Wren, Mourning Warbler, and Ovenbird. This structure, the result of natural regeneration, was observed at all of the sites. This type of complexity and species composition has been observed at other plantations in the same region (Milne and Bennett, 2001).

This complexity is also enhanced by natural disturbance. Over the study period, events occurred at Palgrave and Alton that created small gaps within the coniferous cover. Small bursts of strong wind, micro-bursts, can cause a domino effect and knock down several rows of pine. This created small gaps several 10 m^2. It was observed that species were quickly attracted to these openings for use as a foraging area, similar to the debris slides on the active slopes, although not of the scale at Silver Creek.

These plantations also have to be considered within the context of the larger landscape, as part of a regional forest and as part of the immediate forest mosaic. Within the forest mosaic, these areas represent small patches that are integrated with other forests of similar composition, other small plantations, of different ages and levels of management, and forests that are primarily deciduous. It has been observed that, in many of these managed forests, it is a common procedure to leave a portion of the continuous forest cover in a natural state. The result is a greater diversity of species that use both forest covers for a combination of functions including nesting and foraging. For instance, at Palgrave, adult Scarlet Tanagers were observed feeding juveniles within the plantation forest, although the only breeding records were from the adjacent upland deciduous forests.

Deciduous Upland Plains

These land units are the current sites of conflict over local land use. The bedrock plain with limited glacial cover and the proximity to major urban centres makes these sites prime locations for large quarry and extraction operations. Some of the largest pit operations on the Escarpment are located close to the research sites and current demands are only going to increase the number of sites that are targeted for extraction. From the results of this study, it is apparent that these sites are a unique landscape of the Escarpment. The Halton Hills area has some of the largest tracts of mature deciduous upland forests left on these bedrock plains. In comparison, there is little forest left in other areas on the Niagara Peninsula. The only similar areas of bedrock are found on the Bruce Peninsula but this is in a different zone, with different vegetation and wildlife.

These forests serve an important role as source areas to replenish the surrounding habitat with young birds of the forest interior, because of their size and percentage of interior habitat. These habitats produce a high proportion of young birds, such as Wood Thrush, that disperse to more depauperate woodlots in the landscape (Wyatt et al., 1998). These uplands are also important because of the diversity of the microhabitats. The combination of upland bedrock plains and outcrops combined with the small wetland depressions attracts a wide variety of species, such as Winter Wren, Northern Waterthrush and Wood Duck, more so than found in the Deciduous Interior Slope. A number of these species have been identified as species of regional concern and are targets for developing monitoring programs for conservation issues. (CVC, 1998). The clearance and eventual extraction of this bedrock will eliminate a very diverse and complex avian/vegetation system from this region. Quarry restoration does not target replacing this type of land unit. The direction of restoration is usually towards a series of wetland habitats combined with recreation opportunities that do not replace these diverse upland forests.

Cliff/Rim Forest

This unit is under considerable pressure from recreational use including extensive hiking along the upper rim as well as rock climbing on the cliff face (Kelly, 1996). These sites are under significant environmental stress and for the most part represent relatively static systems. The species that inhabit these sites are stress tolerant, possibly able to withstand an increase in stress levels from human activities, but increased trampling could push the stress level to intolerable and lead to the decline of some of these unique species. It is the uniqueness of the cliff habitat that promotes the rare growth form of white cedar, but it is also the cliff characteristics that attract human disturbance and stress. A thorough understanding of the functioning of these systems is required to develop a proper management strategy.

Regenerating Fields

Many landscapes at the scale of eastern North America are experiencing a loss in early successional species as agricultural land is abandoned and returns to a forested state. The clearing of the forests in eastern North America for European settlement allowed a diversity of successional habitats to coexist. However, the decline in anthropogenic disturbances, along with the elimination of natural habitat conditions, is leading to significant declines of many species with a trajectory leading toward local extirpations for many species (Askins, 2000; Hunter et al., 2001).

There are many areas with this type of cover on the Escarpment and therefore this region may be an important source area for these species. Proper land management could be critical in the preservation of a number of grassland and thicket species. As seen at Limehouse, these lands are reverting to a sugar maple-white ash forest cover. It is important for the manager to identify these landscape units and be aware of the expansion of forest and the rate of regrowth. An important recommendation for land management would be to consider managing these vegetation units to maintain their place within the landscape. This could require thinning invading tree species in the fields and plantations. By maintaining the open nature of these sites, the bird species adapted to field and edge habitats will remain in the landscape.

This has to be tempered with managing for natural processes that are maintaining the system and ensuring that they are allowed to continue to keep the natural areas functioning properly. For example, moisture is one of the main controls of vegetation and bird populations and is also responsible for many of the processes that shape the Escarpment slopes; therefore, a thorough understanding of the hydrology of the managed area is essential. Any change in surface and groundwater could lead to changes in the ecosystem processes and components. If processes that disturb the forest cover are altered, such as the elimination of natural edge maintenance, this will alter the system and reduce the biodiversity of these sites. This could include the loss of species dependent on these habitats for nesting, feeding, etc. or reduced productivity for those that use the site as a preferred foraging site within the greater forest cover.

7.5 Management Recommendations

In this final section, a number of recommendations will be presented based on the findings of this study, including suggestions for management and further research.

1. The combination of upland, face and valley systems of the Niagara Escarpment produces a high level of heterogeneity in geomorphic features and processes which is manifested in the pattern of vegetation and avian species. This variability is a key component of the larger Escarpment landscape providing important habitat and vegetation diversity. There is also a strong relationship between the type of system disturbance and landscape position. Management plans need to recognize these relationships and strive to maintain these systems by considering the entire Escarpment landscape - how individual systems function and integrate at the landscape scale.

2. The importance of disturbance and stress in the functioning of the Escarpment system needs to be translated into classification schemes and management strategies. Natural disturbance provides a mechanism for forest rejuvenation, and consequently provides local habitats for some bird species and food sources for many other forest-interior birds. In contrast, some levels of disturbance and stress create sites that are species poor. In future studies, magnitude, frequency and other important characteristics of disturbance need to be studied to develop a stronger understanding of these processes and their role in the Escarpment system.

3. This information should be incorporated into GIS to produce maps of management areas with units that best represent the landscape ecology of the region. This provides a measure of ecosystem processes and takes the information beyond simply identifying specific species or habitats.

4. Knowledge of these units can be applied to other regions of North America where the Escarpment is a prominent feature of the landscape, such as New York or Wisconsin. The general relationships are applicable to other regions where similar land systems exist. Specific species will differ but it is proposed that the general relationships between environmental disturbance and stress will be reflected in the pattern of vegetation and bird associations. Future research could compare the relationships to strengthen these relationships.

5. Similarly, a number of habitats have been investigated in this study that are common in other areas of southern Ontario. Findings from this study will assist management decisions in areas where habitats such as alvars, plantations and abandoned agricultural fields are part of the landscape mosaic.

6. This study has emphasized the importance of structuring research at several levels of investigation to understand the functioning of land systems. Patterns in the biophysical system were identified at scales of the landscape, land unit and site level. It is clear that different controls are predominant at different scales. Management decisions should be developed by considering the interaction between these levels and, more specifically, studies should investigate patterns and controls at levels above and below the target level.

7. There were a number of bird species of conservation concern identified within the Escarpment planning area. This highlights the importance of this region as a refuge for many species that are no longer prevalent following extensive land clearance in southern Ontario. Also it emphasizes the importance of these areas as sources of forest-interior species that restock surrounding agricultural and urbanizing landscapes. Efforts should be maintained to protect the extensive blocks of interior forest found on the Escarpment.

8. The general pattern of bird populations is strongly related to vegetation composition, especially the ratio of deciduous/coniferous cover. This relationship could be useful for a rapid site assessment to identify important habitat/species relationships.

9. The upland forest in the southern region of the study provided a unique habitat that is under threat from quarry development. The limestone plains with shallow surface material and poor drainage create a mosaic of microhabitats that attract a diverse group of birds, much greater than the associations found in upland forests on well-drained glacial deposits. Restoration of quarries should focus on returning these landscapes to natural systems that maintain the functions and diversity of these habitats.

10. Plantations have an important functional position in the Escarpment landscape. There are unique and diverse species, uncommon in southern Ontario, dependent on these habitats. As well, the combination of plantations and natural forests creates a forest mosaic that increases the overall extent of the forest interior, which benefits deciduous forest-interior birds.

11. Rejuvenating fields are also an important and unique land unit in a state of transition. A number of species are dependent on the combination of shrub, field and young forest; as these habitats are regenerating to forests, these species are threatened.

12. Plantation and field habitats have to be considered as desirable habitats, with strategies to maintain their presence in these landscapes. In management units such as parks or the NEP, management strategies should consider practices to regenerate these habitats. Recent human disturbance plays an important role in the functioning of many of these natural and protected areas and should be considered within the framework of the biophysical system. Management strategies will need to consider preserving processes that create and maintain these habitats.

APPENDIX A

STUDY SITE INVESTIGATIONS

A.0 Introduction

A description of the results of the field work are presented in this Appendix. This includes the raw field data as well as a description of the site and observations of the biophysical relationships within the landscape systems. This information provided an additional data source for the interpretation of the analyses in Chapter Five. It also provides an opportunity to present qualitative descriptions of the sites since some aspects of natural communities are sometimes missed in statistical analyses. This information will assist in identifying the landscape units and the landscape system completed in Chapter Six.

An overview of the 29 transects is presented, including a general description of the landforms, vegetation and bird populations. It is beyond the scope of this work to examine the situation at each of the 113 sample points or stops, but it is pertinent to discuss the pattern that occurs across transects where the processes are quite dynamic (e.g. landslides). Each of the 11 sites, identified in Figure 4.1, will be discussed with respect to the combination of transects at the sites; this will include a description of landform characteristics, vegetation composition and structure and avian populations and spatial distribution across the site.

A.1 Speyside

This site is located at the southern end of the study area on a small plot of public land, surrounded by private lands. A good example of the bedrock plains of the Caledon Hills section, it borders the Halton Escarpment unit. It can be considered part of the type B slope complex although this plain is not immediately adjacent to the Escarpment slope. This site has two transects both within habitat typical of the bedrock plain. Transect 2 follows the Bruce Trail through this property from the access road. Seven stops run parallel to a moderate-sized pond from stops A-D and then cross the stream at stop E before finishing along the trail near Transect 1 (Figure A.1). Transect 1 is situated away from the trail, perpendicular to Transect 2, and follows a rise in elevation to a small upland of exposed bedrock. There are three stops on this transect, the last stop on this transect was at a small seasonal pond.

A.1.1 Speyside Transect 1 - Upland One (swamp)

Geomorphology

This transect is on the bedrock, upland plain with no discernable slope angle and related azimuth at the three stops. There is a small rise at stop B with various bedrock outcrops which create small convex-concave slopes. The natural disturbance is low; only weathering of the exposed bedrock and moisture stress from seasonal variations in water levels. Depending on the levels of rainfall, the small pondings remain wetter or dryer longer. Human disturbance is greater as there is evidence of past and present selective logging. Stop A appears to have been heavily logged in the past while near stop C logging was taking place during the study period.

Vegetation - Species

This transect, through the back of the property, did not display the same diversity as did the transect along the trail. This may be related to the number of samples, as there are only three stops along transect B. Despite the lower numbers, there is a variation in species between the three stops (Figure A.1). Stop A is in an area that appears to have been logged; there are many individual trees, a number of snags and a variety of shrub and herbaceous cover, but the tree cover is relatively sparse. Only two species, sugar maple

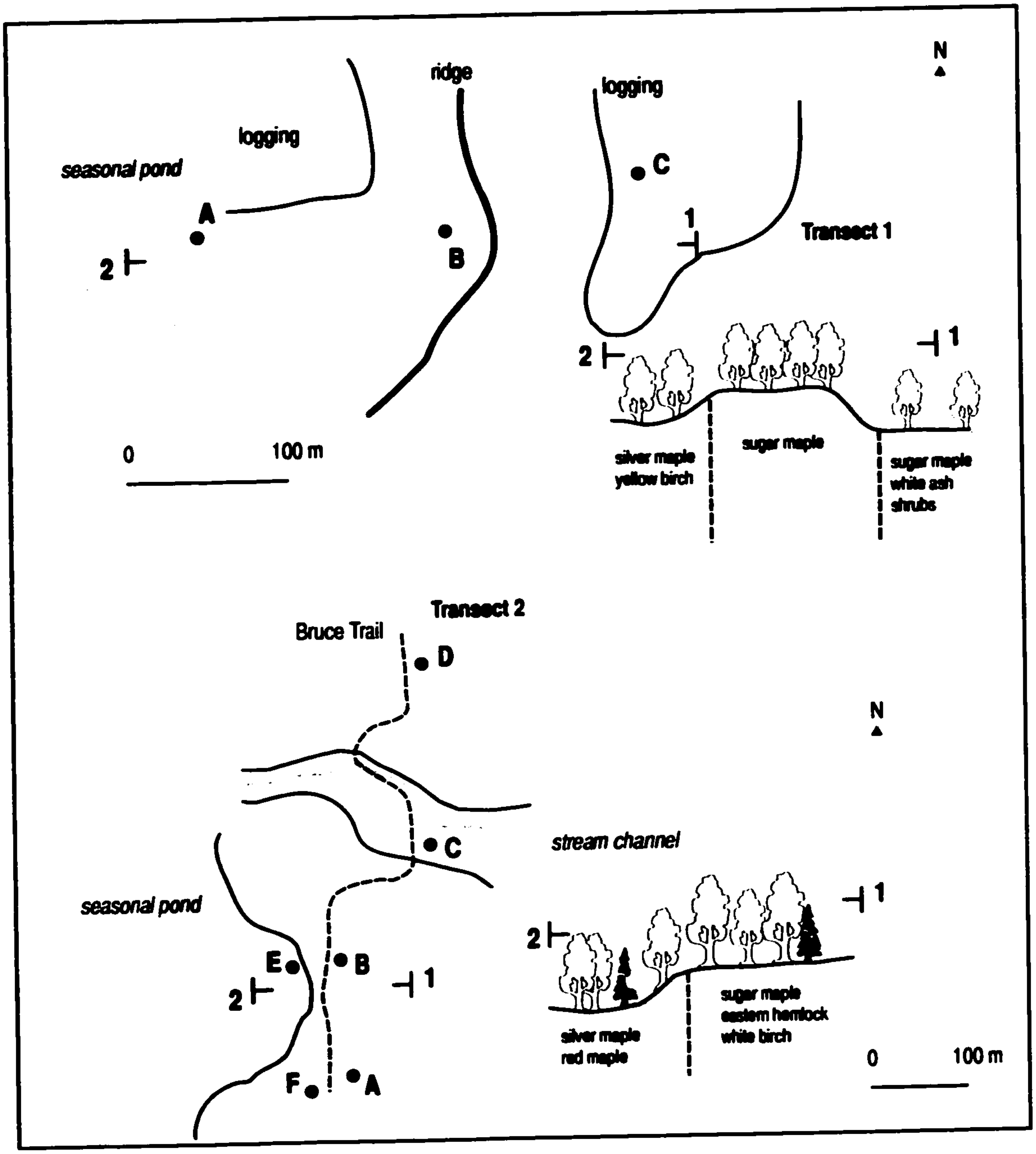


Figure A.1 Geomorphic processes, vegetation profiles and survey transects and stops at Speyside.

and white ash are present in the tree layer. The second stop is located on a ridge of bedrock outcrop or plain. This area has a complete forest cover dominated by sugar maple, IV 152 (see Appendix C). The third stop is in a different habitat, a small ponding that fluctuated annually, with a forest cover primarily of silver maple and yellow birch.

Vegetation - Structure

The forest structure of the swamp transect is similar to the trail transect. The age ratio is low but higher than Transect 2. There are similar scores for the deciduous ratio with 100 and 88 respectively for the old and young groups. There is quite a variation in forest structural characteristics between stops. For example, there is a very young, open forest cover at stop A. Stop B has a closed canopy with much older trees and very little undergrowth. Most of the other characteristics including the number of snags, stem density and saplings are in the mid-range of scores for all the transects.

Bird Populations

The bird population on this transect had an average species richness of 27. However, this was a very diverse group of species representing the variety of habitats found within this site. Forest interior birds had the highest scores especially Eastern Wood-Pewee, Red-eyed Vireo and Ovenbird. Great Crested Flycatcher also had a high score, one of the highest for this species throughout the study. Resident species were lower but still had significant scores, such as Black-capped Chickadee, Blue Jay and American Robin. Other high scores recorded for species of lowland deciduous forests include Veery and Northern Waterthrush. In comparison, there were also records for Gray Catbird (*Dumetella carolinensis*), Common Grackle, Red-winged Blackbird

(*Agelaius phoeniceus*) and Wood Duck. Of particular note, this site had one of the few records for Broad-winged Hawk for the study area.

The bird populations were distributed along the profile. The first stop has poor drainage with some standing water and has been selectively logged. This open area attracted species such as Common Grackle, Red-winged Blackbird and woodpecker species such as Downy Woodpecker and Hairy Woodpecker. There was also one record of Red-bellied Woodpecker (*Melanerpes carolimus*) for this site during the spring of 1999; subsequently, this species has been recorded as a breeding bird at this site (McIllveen, 2001). At the second stop the forest is typical of an older deciduous stand on the shallow bedrock upland and had greater records of forest interior species. The third stop is often inundated with seasonal ponding which sometimes remains through the breeding season; this habitat attracted species such as Wood Duck.

A.1.2 Speyside Transect 2 - Upland Two (trail)

Geomorphology

Most of the stops along this transect have a minimal angle, only stop F has a slight grade at 8° with an azimuth of 87. The landscape location varies between stops, as some are located in low-lying, poorly drained sites while others are on the small uplands that surrounded the wetland. Human disturbance is primarily from use of the access trail which is part of the Bruce Trail system. Natural disturbance is minimal although there is seasonal moisture stress in the lowland areas as these ponds dry up during most summers.

Vegetation - Species

The variability of soil and water drainage in this area of the Escarpment creates a diverse pattern of vegetation but there are two general groups similar to those found at

Inglewood and Terra Cotta. The drier areas of this transect are dominated by a combination of eastern hemlock and sugar maple. Other trees forming the canopy include white ash, yellow birch, basswood, and American elm. Where there is seasonal ponding the main tree cover includes silver maple and red maple with some American elm. Along the stream channel there is a mix of eastern white cedar, yellow birch, silver maple, and American elm.

Vegetation - Structure

This transect had one of the younger stem ratios of the study sites with a score of 47. For most of the stops this forest is primarily deciduous although stop A had a low ratio and would be considered a mixed forest. This forest had a low number of snags, and an average density for both old and new stems. However, the number of saplings was above average for this transect. Despite the younger nature of this forest, it still had one of the higher canopy covers at 90.

Bird Populations

The trail transect at Speyside had a high score for richness, which was 30. No species recorded an Importance Value (IV) over 10 but there were many between 3 and 10. Some of the forest interior birds with higher IV included Red-eyed Vireo, Ovenbird and Rose-breasted Grosbeak. There were also several species that are more common in the wetland deciduous habitats including Northern Waterthrush and Veery. The most dominant resident was Black-capped Chickadee and to a lesser degree American Robin and White-breasted Nuthatch. Of note, Common Grackle scored relatively high, the result of a large number of birds recorded late in the breeding season. This record was at the end of the breeding season and the birds were beginning to flock prior to migration. A similar phenomenon was recorded at the Alton site during surveys in mid-August.

The diversity of the habitats at the stops account for the variety of species recorded. The first two stops were along the edge of a seasonal ponding area. In these areas, the dominant birds are Northern Waterthrush, Common Grackle as well as the forest interior and residents mentioned above. At the third stop the forest opens up along a small drainage channel that is dominated by shrubs, herbaceous plants and scattered trees. Song Sparrow, Winter Wren (*Troglodytes troglodytes*), Baltimore Oriole (*Icterus galbula*), Mourning Warbler, Magnolia Warbler (*Dendroica magnolia*) and Broad-winged Hawk were observed in this area. The Broad-winged Hawk was only recorded once and was not likely a paired adult. Similarly, the Magnolia Warbler was only observed once and was also likely an unpaired male. Both species were south of their range as identified in Cadman et al. (1987).

A.2 Limehouse

The site of Limehouse is situated within the Limehouse Conservation Area, public land in the Credit Valley Watershed (Figure 4.2). Four transects are situated within this study area and include the rims of two slopes, a bedrock plain and a stream valley associated with a slope type B system (Figure A.2). Transect 1 is located along the rim of the bedrock ridge, skirting the edge between the mature forest and an abandoned field and orchard. Transect 2 runs parallel to the ridge through an old field that is currently regenerating. Transect 3 is situated along the ridge of the stream valley of the Black River which cuts a deep valley draining to the southeast off the Escarpment. The last transect, 4, is located along the river channel. This site is representative of the slope type B system.

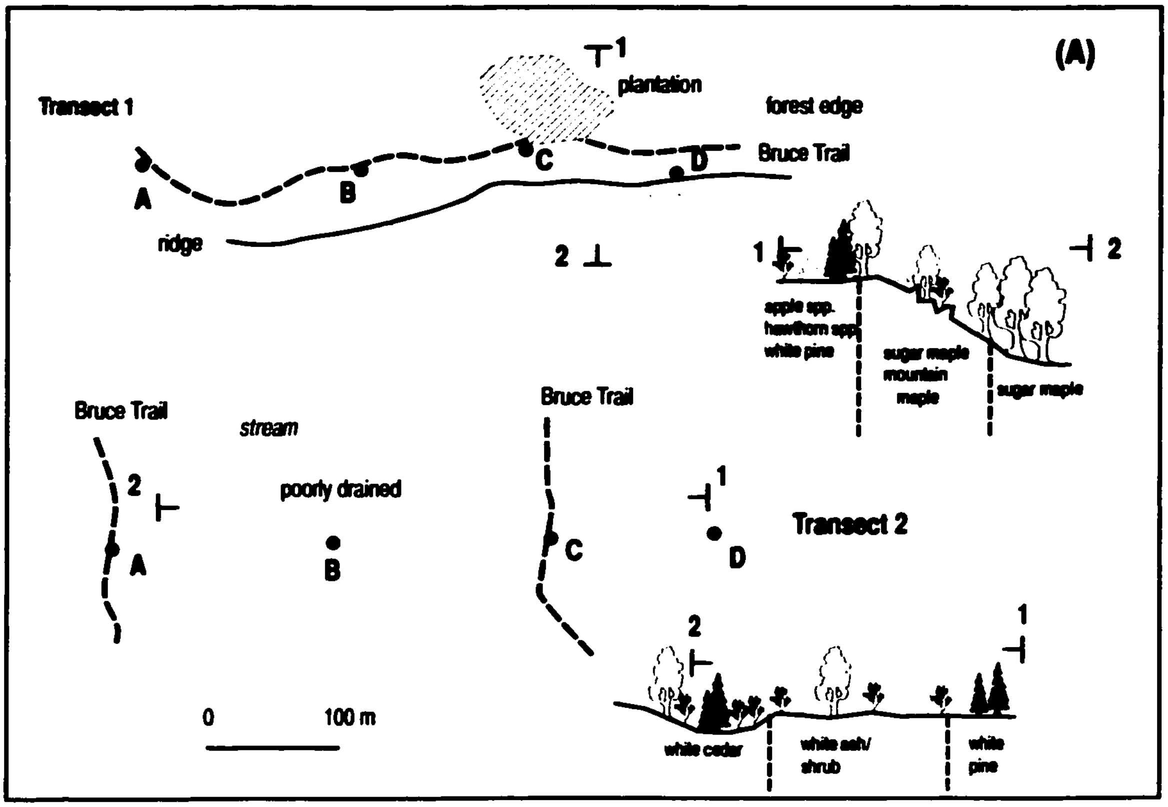
A.2.1 Limehouse Transect 1 - Upper Ridge

Geomorphology

The upland Transect, 1, follows the rim of a small outcrop of bedrock that forms small faces and crevasses. At its steepest location the slope angle is 17° but above the exposed bedrock where several of the surveys were conducted the slope has a minimal angle of only 2 - 4°. The general aspect of the slope is to the east-northeast as is the case for Transect 3 (Figure A.2). The azimuth ranges from 39° to 100° but is generally around 55°. The slope shape varied between stops, but most were convex although there was concavity at stop D. Human disturbance includes the Bruce Trail and there is considerable modification of the vegetation cover just west of the transect where it borders an old field and small pine plantation. The old field has the greatest influence at stop 1 where the vegetation cover is currently shifting from an orchard to natural forest cover. At stop D, a small planting of pines influences the natural system. Natural disturbance is mainly from karst weathering of the exposed bedrock, creating a distinctive crevice pattern to the upper slope. This includes the toppling of blocks downslope as they became unstable from the release of basal support by weathering.

Vegetation - Species

The forest here is quite diverse because the transect is situated at the edge of an abandoned field on the Escarpment slope. Several of the stops are situated within the edge and plantation while others are located at the slope sites where the small crevices are prominent from karst weathering. Therefore, there is a higher diversity of trees at this site than similar sites within the forest interior (Appendix D). The small plantation is dominated by white pine while the slope is covered by a mature forest of sugar maple with



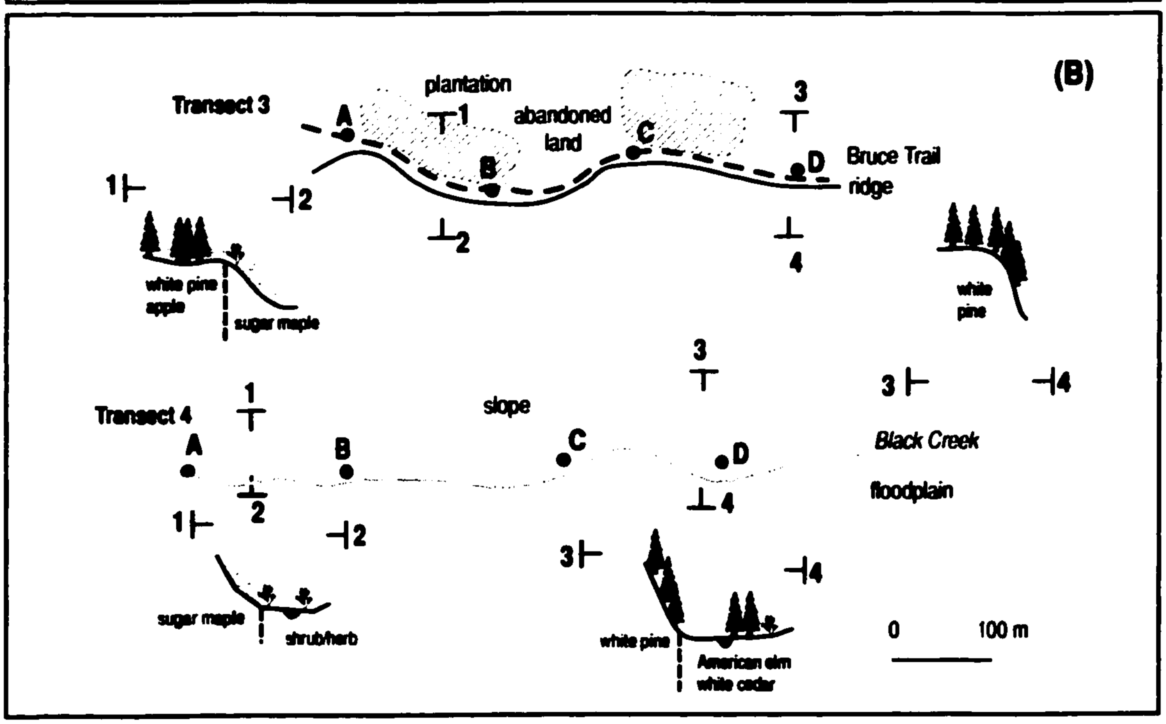


Figure A.2 Geomorphic processes, vegetation profiles and survey transects and stops at Limehouse. (A) Upper ridge and field unit (B) Lower ridge and stream unit.

a few American beech and bitternut hickory. The edge forest is a mix of white ash, European buckthorn, downy hawthorn and white birch. Many of these species are important components of the pine stand as this stop is in the process of returning to a natural state.

Vegetation - Structure

The forest structure is quite varied for this transect due to its location along the edge of old field and forest. The age ratio, despite an average score of 61 was quite high within the forest proper and quite low (30) along the edge of the forest. This pattern is also evident in young stem and sapling densities with very high scores on the edge and quite low scores within the mature forest. This transect had fairly high scores for the multistems which could be related to field species such as apple and hawthorn species found on the edge. The forest is predominantly deciduous with very high ratios for both old and young stems. Old stem density and snag scores were relatively low.

Bird Populations

The bird populations are a combination of resident and edge species with some forest interior birds. The highest IV was recorded for Red-eyed Vireo. Other high scores for interior birds included Eastern Wood-Pewee and Ovenbird. Other interior species included Wood Thrush, Great Crested Flycatcher and Rose-breasted Grosbeak. Resident and related edge species were also quite high including Black-capped Chickadee, American Goldfinch, American Crow, Blue Jay, and White-breasted Nuthatch. Species that are associated with the edge and abandoned field included Indigo Bunting, Eastern Towhee, Northern Cardinal, Common Yellowthroat and Field Sparrow. Some of these species were found within the forest as they foraged along the edge of the two habitats.

A.2.2 Limehouse Transect 2 - Field

Geomorphology

This transect is situated along an extensive bedrock plain with minimal slope angle. The slope shape for each stop was considered as a plain although the slope position is midslope (see Figure A.2). There is minimal natural disturbance although a small drainage channel crosses the transect between stops C and D. The main disturbance has been human modification of the transect through land clearance; this area is currently a combination of old field and successional forest that is regenerating. There are also several side trails of the Bruce Trail that cross the transect.

Vegetation - Species

Tree cover is not dominant along Transect 2. The area is in a period of revegetation following field abandonment which is evident in the mixture of successional species and introduced species that cover this transect. This site has lower diversity than the other edge Transects, 1 and 3 (Appendix D). The most common tree is white ash; it had very high scores in comparison to the other species, with an IV almost three times as high as the next species. Other common species are apple and sugar maple which emphasizes the contrast between the abandoned field and the regenerating forest. The only other species that were recorded included American elm, narrow-leaved hawthorn and white pine. Absent from this list but significant is a narrow corridor of eastern white cedar that follows a small drainage channel flowing from the upper slope to the lower stream channel (see Figure A.2). This added a stronger coniferous presence to this section of the transect.

Vegetation - Structure

The early state of succession is evident in the age ratio which was only 9 and three of the stops were even lower. The forest is primarily deciduous although there are some older eastern white cedar at stop D. Not surprisingly there is a very low density of old stems (7) but there was also the highest density of new stems (52) for the study and one of the highest densities of saplings. This site also had the highest score for ground cover at 93%. Canopy cover was quite low but did vary across the transect depending on the degree of succession. It ranged from 10 to 70%.

Bird Populations

This transect had a high diversity of species, a result of the combination of field and successional forest situated near the mature forest interior. The highest IVs were for species associated with fields and meadows. This included Indigo Bunting (IV 11), Song Sparrow, Field Sparrow, Gray Catbird, Common Yellowthroat and of note, Blue-winged Warbler and Golden-winged Warbler (*Vermivora chrysoptera*). These were the only records for these two species in the study. Other species associated with this habitat but in lower numbers were Eastern Towhee, Bobolink (*Spiza americana*), Eastern Kingbird, Mourning Warbler, and Red-winged Blackbird. As expected, many resident and edge species were also common at this site, including Black-capped Chickadee, American Robin, American Crow, and Northern Cardinal.

A.2.3 Limehouse Transect 3 - Lower Ridge

Geomorphology

Transect 3 has four stops. This transect is located along the rim of a deep valley of the Black River that has cut steeply into glacial material. The upper portion of the rim has minimal slope angle and is considered a plain. Below the rim the slope drops to a small stream channel at a steep grade of 31°. This slope faces to the east-northeast with the azimuth ranging between 54° and 65° for three of the stops. Stop C had an azimuth of 354°. The steepness of the slopes promotes strong sheetwash and creep, but there was no evidence of larger mass movements. On the rim there was also little evidence of mass movement and natural disturbance was considered negligible. Human disturbance includes a trail and several small pine plantations at stops A and B. The transect follows the Bruce Trail for the entire length of the transect (Figure A.2).

Vegetation - Species

This transect has a mixture of natural and introduced species as seen in Appendix D. The influence of cleared land is evident with the presence of apple, hawthorn, and European buckthorn. As well there are small pockets of white pine plantations that are not currently being managed and are naturalizing. The dominant trees are white pine, apple and downy hawthorn. This site is in transition, in the sapling layer there is a strong presence of white ash, and to a lesser extent sugar maple and black cherry.

Vegetation - Structure

The age ratio of the forest was in the mid-range of results and was quite consistent between sites. The forest could be classified as a mixed forest but this includes small but very dense pine plantations. The young deciduous ratio for new stems was much higher at 76 than for old stems. This could indicate a direction of change in the composition of the forest over time. There was a high score for snags but most of these were within the small plantations where the trees were planted very closely and had not been thinned. The plantations accounted for the high density of old and new stems and similarly the very low score for saplings. This may suggest limited change in the forest cover in the near future. The density of the plantings is also evident in the very low score for groundcover (15).

Bird Populations

Species diversity was low for this transect, only a small portion of the birds were frequently recorded and only six species were observed more than three times. Of these, four were resident species. The species with the highest IV was Black-capped Chickadee (20). American Robin and Blue Jay had the next two highest values; numbers of Northern Cardinal and American Crow were also significant. This transect also had several groups of birds that were related to the small pine plantations and open fields above the rim. Pine Warbler had a high value; it is a common nester in pine plantations and naturally occurring pine stands in this region (Milne and Bennett, 2001). There were also several open field species including Indigo Bunting and Common Yellowthroat.

A.2.4 Limehouse Transect 4 - Valley

Geomorphology

The fourth transect follows the stream channel of the Black Creek, which is located in a steep valley with small floodplains. This is a low-energy stream that meanders through a narrow floodplain. The first two stops are actually on the edge of the valley where there is little floodplain. Consequently, stops A and B were on steep valley slopes at angles of 30°. This valley slope faces to the east-northeast with an average azimuth of 60°. There is a rudimentary trail along the stream valley in places and at stop B there is a small shelter for hikers which resulted in considerable trampling in the vicinity. There is little evidence of mass movement on the slopes although because of the steepness and lack of groundcover, sheetwash and creep would be important processes. The stream has some evidence of bank erosion but this is not as obvious as high-energy streams flowing over the Escarpment at Forks of the Credit and Hockley Valley.

Vegetation - Species

In the floodplain, the dominant trees are the stands of eastern white cedar and smaller clusters of American elm. On the slopes, the dominant trees are white pine and sugar maple at stops A and B respectively. There are also some extremely large white pines on the slope and rim of this narrow river channel on the south side of the valley. There is a high diversity of trees in the river channel including small numbers of downy hawthorn, white pine, black cherry, apple, eastern hemlock, white birch and ironwood. The stops on the steep slopes have less variety, especially stop B which was purely sugar maple (Appendix D).

Vegetation - Structure

The forest has a relatively high ratio of older stems (70) which is consistent for all four stops. It is a mixed forest with a deciduous ratio of 57 for the old stems. However, there was considerable variability between stops, ranging from 16 to 100, the result of several large stands of eastern white cedar along the stream channel. This transect has an average number of old stems but a lower density of young stems and saplings. There are also a low number of snags. The open areas of the channel allow for a higher average of ground cover and alternatively a lower canopy cover (65%).

Bird Populations

This stream valley had a relatively low number of species (22) compared to the diversity of the other channels. Of these, only a small number that had high scores and many species had only one occurrence. Black-capped Chickadee had the highest IV (20) and several other resident species were also important, Blue Jay and American Robin. The other dominant species included several forest interior and riparian species. The interior species include Red-eyed Vireo (IV 12), Eastern Wood-Pewee and Rose-breasted Grosbeak. In the stream valley, field-related species included Indigo Bunting and, in lower numbers, Common Yellowthroat and Song Sparrow. The records of Pine Warbler (IV 10) and Chipping Sparrow (*Spizella passerina*) emphasized the strong presence of white pine on the adjacent ridge.

A.3 Silver Creek

The Silver Creek site is situated entirely on public land within the Silver Creek Conservation Area in the Credit Valley watershed. This area is within the Caledon Hills Escarpment unit, in an area with extensive bedrock plains with little glacial deposits on the rim of the Escarpment. The Silver Creek valley is a deep channel that has been cut between cliffs of dolostone bedrock creating cliff faces similar to the Type B slope types (Moss and Milne, 1998). For the most part they are smaller cliffs with some crevice development. The slopes below the face and rim are some of the most active found in this study area with several active scars. There are four transects located at Silver Creek. They were established in a parallel pattern and include the upper interior forest (Transect 1), the exposed cliff and rim (Transect 2), the Escarpment slope (Transect 3), and the lower slope and stream channel (Transect 4) (Figure A.3). All transects have four stops except Transect 2. There were several more vegetation survey sites added for a total of 6 to gain a better understanding of the variation between the immediate face/rim and the forest set back from the rim.

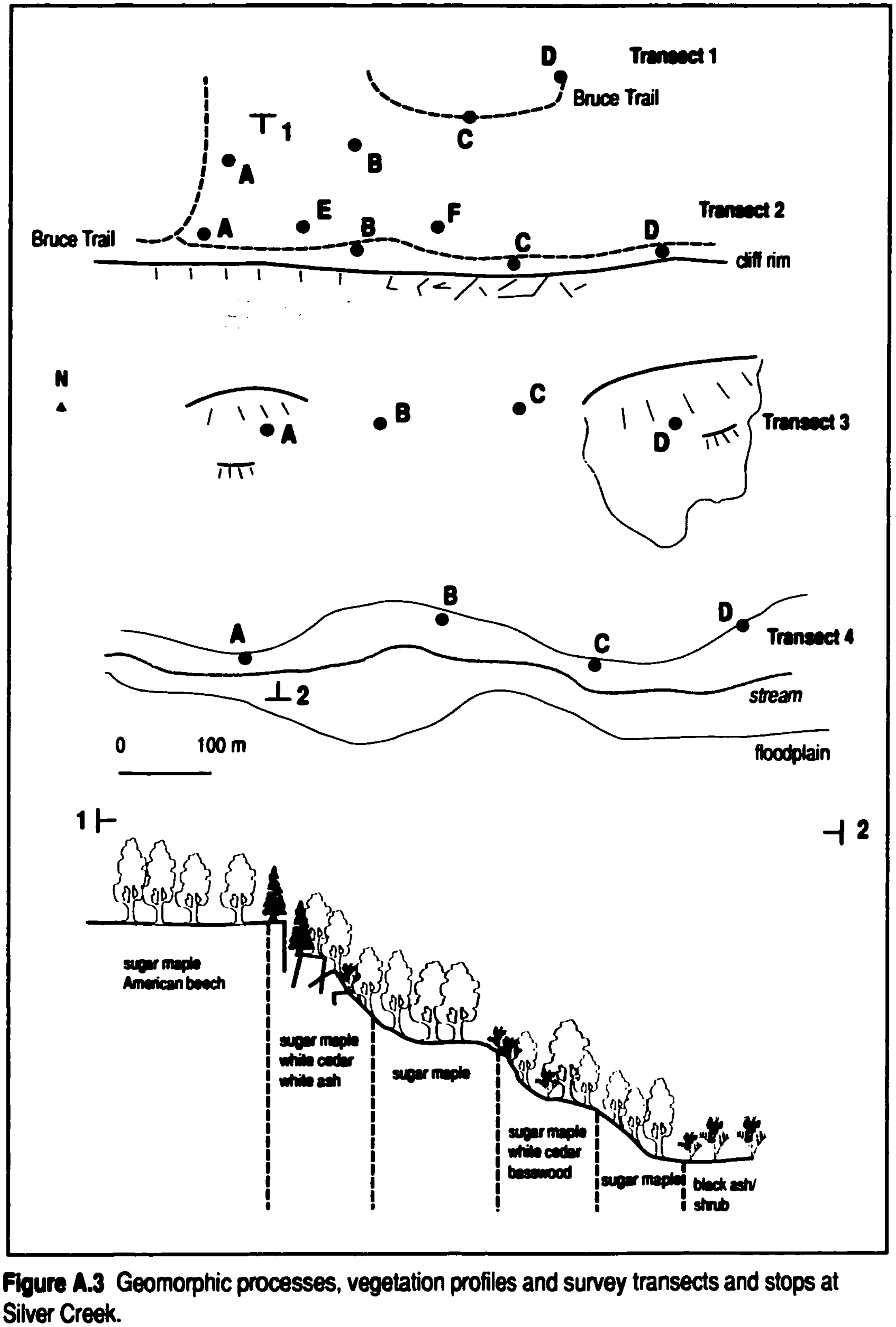


Figure A.3 Geomorphic processes, vegetation profiles and survey transects and stops at Silver Creek.

A.3.1 Silver Creek Transect 1 - Upland

Geomorphology

This transect crosses an upland bedrock plain where the slope angle is minimal and consequently the azimuth was not recorded. There is little natural disturbance along this transect - each stop was on weathered bedrock that displayed evidence of karst weathering. Human disturbance was quite low as well, in spite of several stops being located on the Bruce Trail and adjacent to stop A was a side trail of the Bruce Trail that was near to an area that appeared to be experiencing regeneration.

Vegetation Species

The Silver Creek Upland site had a relatively high diversity of tree species compared to some of the other upland sites such as at Hockley. The vegetation pattern is somewhat uniform across the deciduous forest, dominated by sugar maple, which had IVs ranging from 90 to 160 (Appendix E). At stops B-D, several species are important sub-dominants. These include bitternut hickory, red oak, white ash and black cherry. Only stop 1 had a variation in cover. This stop is located on the edge of an area that has been cleared and is in a mid-successional stage, with a young tree cover of a variety of successional species. The stop is just beyond this area but the presence of eastern white cedar is evidence of its influence.

Vegetation - structure

The forest structure on the upland transect is predominantly an older forest with an old stem ratio of 71 and a cover that is primarily deciduous. The density of the stems is average at 22 per plot for old stems and 10 for new stems. The sapling density is quite low. The canopy cover was almost complete at 93%. The number of snags is slightly higher than average.

Bird Populations

This transect was dominated by a combination of forest interior birds and residents. The overall richness was low at 20 species. The largest scores were recorded for Red-eyed Vireo, with very high abundance scores (28). The IV for Eastern Wood-Pewee had a high frequency score but lower abundance score. Other interior species included Ovenbird. Several resident species had high scores although there frequency was lower, these included American Robin, Black-capped Chickadee and White-breasted Nuthatch. Also of note was the high score for Great Crested Flycatcher.

There were a number of species that scored low but are of note since they appear to be out of their usual habitat. These included species such as Red-winged Blackbird, Common Yellowthroat and Black-and-white Warbler. The presence of a small wetland area and a disturbed site to the north and east of the transect, especially close to stop A, attracted species more related to these habitats.

A.3.2 Silver Creek Transect 2 - Rim

Geomorphology

This transect is located on plain with minimal slope angle and azimuth. Along the transect the cliff face is gradually reduced to very little exposure and so grades to a Type C slope by the last stop. However, this site also includes the steep cliffs of the Escarpment near stop A. Human disturbance is limited along this transect except for the well-established Bruce trail which receives a considerable amount of traffic because of the proximity of an outdoor education centre. Human disturbance was also high at the first stop where the forest has been cleared and is naturally regenerating. There has also been natural disturbance along the face of the cliff which creates crevices and talus slopes. This is also a stressful site, with shallow bedrock and an exposed upper face.

Vegetation - Species

This transect has a diverse cover of trees with no strong dominant species. Sugar maple had the highest IV but this was based on its strong presence at stop D, where the survey circle was established back from the rim. The rim forest is a combination of eastern white cedar, sugar maple, basswood, ironwood and mountain maple, which is most evident at stops B and C (Appendix E). In the forest just beyond the edge of the cliff, the forest is typical of the upland forest described in Transect 1, with a dominant sugar maple and lesser numbers of basswood, white ash and red oak. The first stop, an area just beyond the edge that has been cleared and is at a successional stage, is more diverse. This is evident from the variety of species including eastern white cedar, white birch, white ash and sugar maple. There are also basswood, ironwood, and large-toothed aspen. This forest presents a combination of disturbance and stress. There has been some human disturbance along the trail, especially at stop A. The natural edge of the cliff favours species such as eastern white cedar (Figure A.4).

Vegetation - Structure

The forest of the rim transect can be characterized as an older forest. It has one of the higher old stem ratios, and it is predominantly deciduous, especially younger stems of the forest (see Appendix E). There are, however, several stops where the forest has a greater mixture of deciduous and coniferous stems. These stops are at the edge of the cliff face. Many of the other characteristics were average for the study including the number of

Figure A.4 Cliff face at Silver Creek Conservation Area.

Figure A.5 Debris slide on slope segment, Transect 3, Silver Creek Conservation Area. These slides experience periodic events that maintain the open surface.

multistems, saplings, old stems and snags. The density of new stems was low, overall although higher at the stops near the Escarpment rim.

Bird Populations

The rim transect had an average score for species richness (25) but that value included a variety of species that use different habitats. The highest scores were related to the surrounding forests and included a high number of interior species. This included Red-eyed Vireo, Eastern Wood-Pewee, Rose-breasted Grosbeak and Great Crested Flycatcher. Resident species were also quite high especially Black-capped Chickadee and White-breasted Nuthatch as well as American Goldfinch and American Robin. The other high score was recorded for Veery which occurs at many sites with wet lowlands. Of note is the presence of edge species such as Northern Cardinal, Eastern Towhee and Indigo Bunting. The pattern of the species along this transect relate to the presence of the edge of the cliff face. The edge species were more likely to be found immediately along the cliff face where there is a higher presence of eastern white cedar and mountain maple. Away from the edge forest, interior species such as Red-eyed Vireo, are more likely to be encountered.

A.3.3 Silver Creek Transect 3 - Slope

Geomorphology

The slope transect is situated along the mid-slope below the main cliff face and above the main bench (Figure A.3). This slope has an average angle of 21° but ranges from 10° to 27°. The main aspect of this slope is to the east-southeast with azimuth readings between 102° and 119°. The specific slope shape varied depending on the stop, ranging from concave to convex, which was related to the position of the bench and the shape of the scars. There was no evidence of human disturbance on this transect although a rudimentary trail runs between the two scars, stops A and D, although this was likely a wildlife trail. This transect has two major slide areas which makes it one of the most active slopes in the study. The scars of the debris slides were extensive each measuring 500^{+} m^2 in size (Figure A.5). Sites of water entry to the slope surface were at the contact of the thick clay bedrock and upper layers of weather-resistant bedrock. They are initiated primarily above the mid-slope bench and at the base of the cliff segment where there is another strong bench. The slides were quite active with new portions of the slide being initiated during and after the study period. The two stops between the scars were less active but there was some localized movement where there were seeps. This initiated treefall that created small gaps in the forest cover.

Vegetation - Species

This transect was dominated by sugar maple, with the highest IV at each stop, ranging from 60-130 (Appendix E). However, there was also a strong diversity of species in the forest cover, the result of the two landslide scars. This is especially evident at stop A, where there was a broad mix of species with no dominant one. Sugar maple shares the scar with white ash, basswood, ironwood and trembling aspen. There are also numerous stems of willow *spp*., American elm, and red oak. Some revegetation is taking place on the scar, but the recurrence of landslides keep this transect quite active. There are various states of cover on the scars with large mats of tree, root and slope material at the base and on benches of the scar. At the other scar, stop D, there are several different species such as blue beech *(Carpinus caroliniana)* and bitternut hickory. Blue beech is a Carolinean species which was not found in any of the research sites north of this site. At the other stops, where there was no obvious disturbance, some of the same species were found but the diversity of each stop was not as great. Sugar maple was the dominant tree along with ironwood, American elm, basswood and white ash. There were also small numbers of bitternut hickory and blue beech.

Vegetation - Structure

This transect had a lower age ratio percentage at 44. However, there was a strong variation between the forested stops and those on the scars. The average on the scars was 29 while it was 59 on the less disturbed sites. In contrast, there was no difference in deciduous ratio; it was 100 for both new and old stems on scars and forest stops. It is somewhat surprising that this site had low scores for snags and multistems. There were only a few records of snags on the scar areas but this could be related to the location of the plots, which are situated in the mid-section of the scar where most of the removal takes place. If they were in the depositional areas, the numbers may be different. Less surprising was the lower score of old stems especially on the scars. This is also evident in the low score for canopy cover. However, the average scores for new stems and saplings suggest that there is some regeneration taking place. The number of saplings was especially high at stop A.

Bird Populations

The slope transect of Silver Creek had one of the highest richness scores at 34 species (Appendix E). This included a wide range of species including forest interior, resident as well as a number of species that are typical of edge and gaps. There were no dominant species at this site and the IVs were quite similar for a number of species. The higher scores included Black-capped Chickadee, White-breasted Nuthatch and Downy

Woodpecker. Forest interior species also had high numbers including Red-eyed Vireo, Eastern Wood-Pewee, Great Crested Flycatcher and Rose-breasted Grosbeak. Also with high scores were Veery, more typical of lowland, wet habitats and, surprisingly, Turkey Vulture. This species was common throughout Silver Creek and individuals were commonly found resting early in the morning on snags on the cliff face or on the slopes, especially on the scars.

The majority of species were observed at the two stops on the scars. At these stops, the diversity was quite high and included a mix of the forest interior species which were observed feeding and foraging across the scar. This included most of the forest interior species as identified earlier as well as other species that were taking advantage of the open edge and food sources. These scars provided nesting sites for these species such as Mourning Warbler and House Wren. A number of species not typically found in mature deciduous forests were found, including species such as Canada Warbler, Mourning Warbler, House Wren, Indigo Bunting, Nashville Warbler, and Baltimore Oriole. The two stops in the forest interior had similar species to other mature forest habitats, dominated by Red-eyed Vireo, Eastern Wood-Pewee and other related species.

A.3.4 Silver Creek Transect 4 - Valley

Geomorphology

The valley transect follows the edge of a small floodplain that has recently been controlled by a beaver dam that is no longer functioning. There is now a small stream that drains through the floodplain. The stops were situated primarily on the edge of the channel and included the lower concavity of the slope. The slope angle and azimuth were measured in the lower concavity. The average slope angle was 15° and ranged from 9° to

19°. The slope aspect was southeast with azimuth measurements ranging from 102° to 126°. The general slope shape was concave, although for several stops the micro-relief was straight and even convex. There was no evidence of human disturbance along the transect and similarly little natural disturbance on the lower slope, although at stop D there was some weathering of the exposed rock deposited on the lower slope. The main disturbance is from fluctuating water levels, the result of infrequent flooding of the floodplain. The high number of snags in the floodplain and lack of woody vegetation suggest this area has undergone disturbance in the recent past (Figure A.6).

Vegetation - Species

As mentioned, the stops on this transect included samples that were primarily on the edge of the stream channel. The channel itself is mainly an open wet meadow with many snags and only a few trees that were almost exclusively black ash. The forest edge and lower slope of the Escarpment were dominated by sugar maple which had a very high IV (Appendix E). Other trees in the canopy included white ash, basswood, and ironwood. Less important were eastern hemlock, yellow birch, white birch and black ash. This last group of species was found nearest to the edge of the channel and was not as common upslope.

Vegetation - Structure

The forest in this slope valley was primarily deciduous for both the older and younger stems. The age ratio was moderate and both the densities were slightly below average but the density of saplings was quite high. The density of snags was low for the forests on the lower slope but considerable higher within the floodplain. The number of

Figure A.6 Transect 4, Silver Creek Valley. This valley has been flooded from beaver activity.

multistems and multistem cover was also average for this transect. The canopy cover was high at 81%.

Bird Populations

Transect 4 had a high diversity of birds, one of the highest for the study, as well as high abundance for some breeding species. This transect straddles two habitats between the deciduous slope that extends to the base of the slope and then becomes a flooded valley that is mainly shrub, grasses, and snags. The highest IV scores were recorded for Black-capped Chickadee and Song Sparrow. Aside from the Chickadee, other important resident species were American Robin, Blue Jay, Brown Creeper and White-breasted Nuthatch. Because of the presence of the deciduous forest, many forest interior birds were presentl; the more important ones were Red-eyed Vireo, Wood Thrush, Scarlet Tanager and Eastern Wood-Pewee. There was a group of species, such as Song Sparrow, Mourning Warbler, House Wren, and Common Yellowthroat, that are typical of the wet meadow habitats. Also included on this list but not as common were Yellow Warbler (*Dendroica petechia*), Alder Flycatcher and Ruby-throated Hummingbird (*Archilochus colubris*). Other birds of interest because of their limited representation at other sites were Yellow-bellied Sapsucker, which was more frequently seen on the slopes of Silver Creek at transect 3, and Red-shouldered Hawk, which has been identified as a Vulnerable species (COSEWIC, 2000). It is typically found in southern Ontario forests where there are extensive forest tracts with a mix of upland and wet lowlands (Bosakowski et al., 1992; Howell and Chapman, 1997).

A.4 Terra Cotta

This site is situated on public land near the Terra Cotta Conservation Area which is managed by Credit Valley Conservation. It is located on the upland bedrock plain, typical of the slope type B systems. There are a number of irregular outcrops so that the land is somewhat irregular. There is also a major ponding area over which the transect crosses. It is a low-lying area and has seasonal pools. There is one transect at this site that follows the Bruce Trail through the upland forest and includes five stops. There were seven additional stops added to the vegetation survey (stops 6-12, see Figure A.7).

A.4.1 Terra Cotta Transect 1 - Upland

Geomorphology

The Terra Cotta transect is on an upland bedrock plain. Most of the stops were on flat surfaces although several sites were on gradual slopes that graded down to lowland areas. These stops had angles ranging from 5 to 17°. These were on the convex crest of the slope and below a small bedrock outcrop (stop 11). There was some irregularity in the microrelief and the site shape varied between concave to convex. Natural disturbance was low along the transect. Several stops were located in the lowland areas, which would experience moisture stress during certain periods of the season, especially during the summer breeding season. There was a low level of human disturbance, just foot traffic on the Bruce Trail (see Figure A.7).

Vegetation - Species

The main tree in this forest was sugar maple, especially in the upland stops. The IV for this species ranged from 110 - 185 (Appendix F). Also in the canopy were American beech, white ash, basswood, white birch and a few black cherry. In the low-

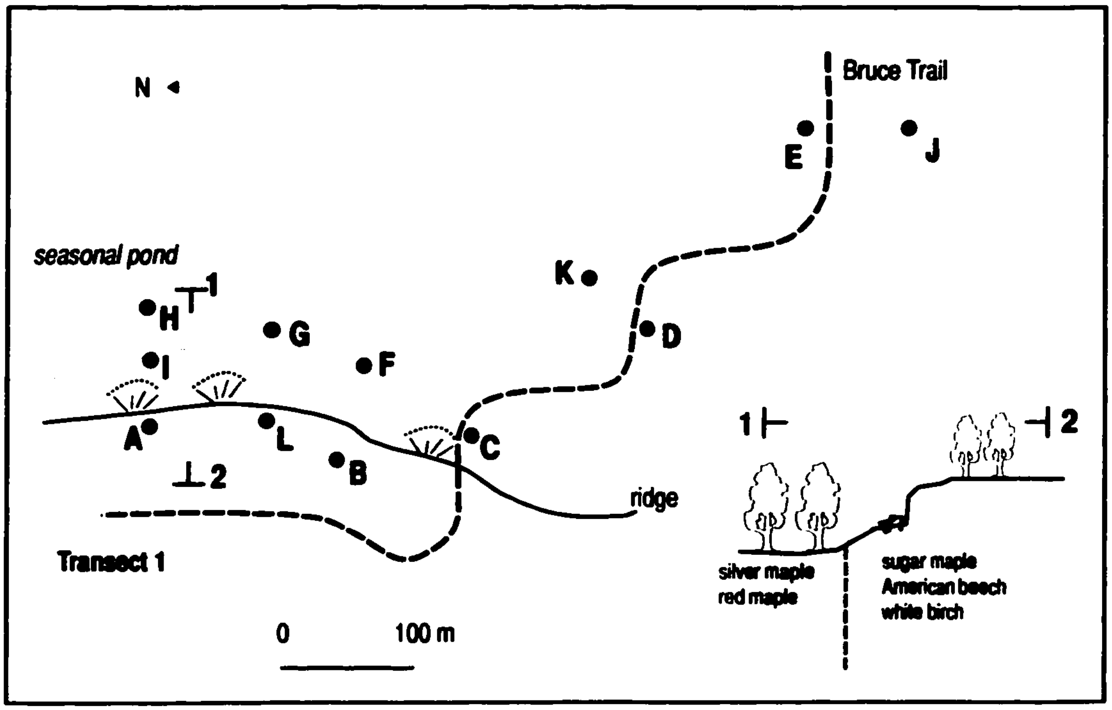


Figure A.7 Geomorphic processes, vegetation profiles and survey transects and stops at Terra Cotta.

lying wet areas, the species composition is quite different. The main trees in the canopy were red maple and silver maple with sub-dominants of yellow birch and American elm. The upland areas within this transect are quite stable, the mature sugar maple forest is dominant at all levels of the canopy and there is no evidence of disturbance. The low-lying areas also seem stable but are under stress from varying water levels.

Vegetation - Structure

The forest cover along this transect had one of the older average of trees among the transects with an old ratio of 81. The vegetation is predominantly deciduous with very high ratios for both older and younger stems. This forest had a higher average of multistem trees but a lower number of snags. In contrast, the density of young stems was low while the sapling number was more in the middle range of scores. The density of older stems was relatively high which is reflected in the very high average for the canopy cover (98%).

Bird Populations

The species on this transect were dominated by birds of the deciduous forest interior. The highest score was recorded for Red-eyed Vireo (17) followed by Eastern Wood-Pewee, Ovenbird and Scarlet Tanager (see Appendix F). Other species of the forest interior that were present included Wood Thrush and Rose-breasted Grosbeak. Resident species that scored high included Black-capped Chickadee, Brown Creeper and White-breasted Nuthatch. Species of note included Red-shouldered Hawk, as mentioned earlier - a species identified as Vulnerable (COSEWIC, 2000). A number of species are associated with the lowland areas but they are not dominant members of the wildlife population. These species include Northern Waterthrush, Veery, Winter Wren, and

Mourning Warbler. There were also records of Black-throated Green Warbler and Black-and-white Warbler.

A.5 Forks of the Credit

The study area for the Forks site was located on public land at the Forks of the Credit Provincial Park. This area of the Escarpment is a typical Type C slope unit of the Caledon Hills unit (Figure A.8). This Escarpment slope has extensive layers of Wentworth till and stratified drift that overlie a layer of sandstone of the Whirlpool formation (Tovell, 1992). The lower layer of Queenston shale is directly exposed to the Credit River at the Forks which leads to undercutting of the resistant layer and eventual block failure (Figure A.9). This site has extensive abandoned agricultural fields adjacent to large gravel pits. The Credit River flows through the site cutting a deep stream channel through the glacial material. There were two transects at this study area - Transect 1, which is located along the upper half of the Escarpment slope and Transect 2, which is located along the Credit River channel below the falls and running parallel to Transect 1.

A.5.1 Forks Transect 1 - Valley

Geomorphology

The stops along the stream channel were considered as a plain with no obvious slope angle. The transect occupied a position within a steep stream valley. The main natural disturbance along the transect was from the fluvial action of the stream. At several of the stops there was bank erosion and the formation of channel bars. Stop A is on an elevated deposit above the channel which is relatively stable, likely the result of an earlier geomorphic period (Figure H).

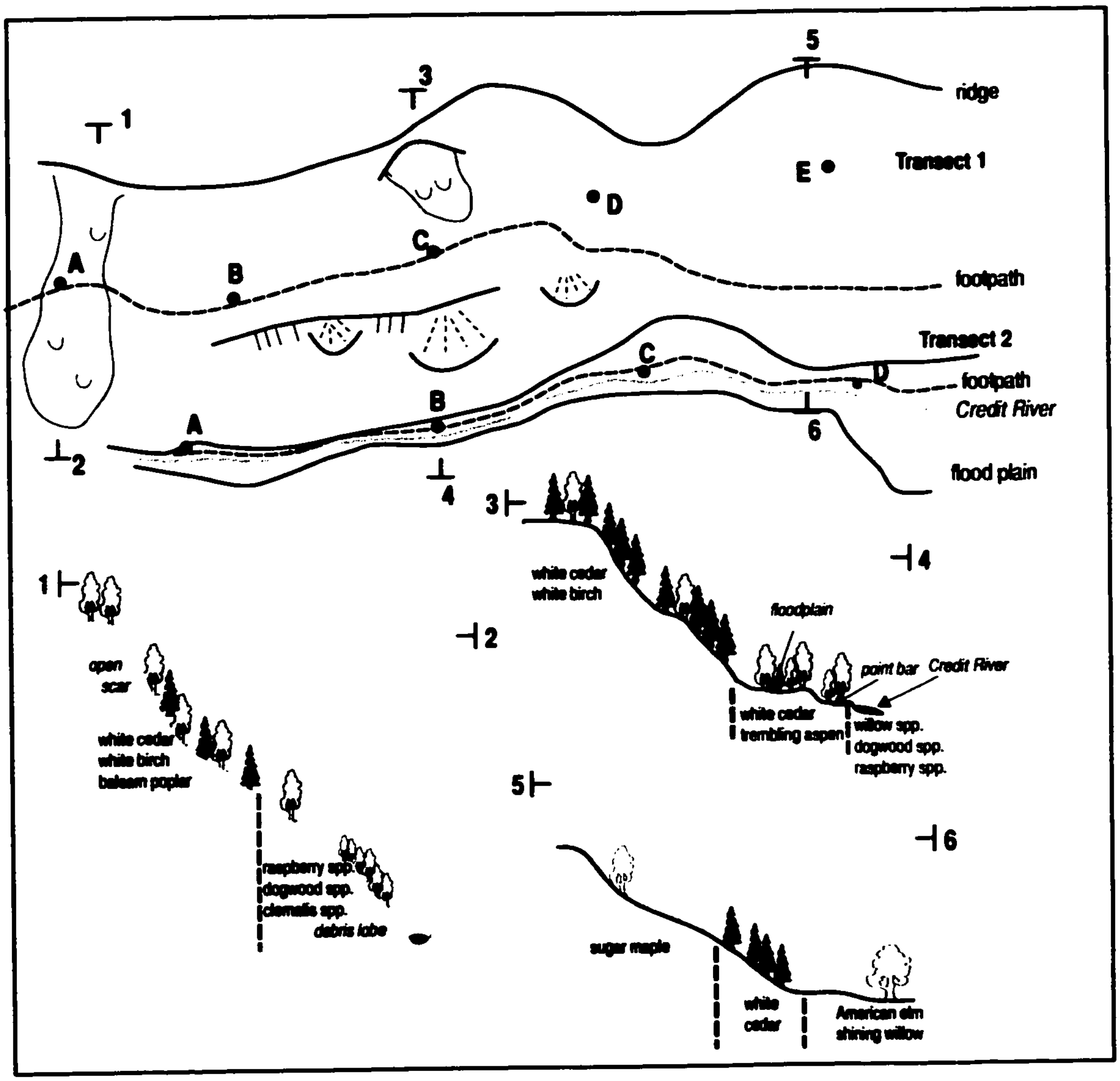


Figure A.8 Geomorphic processes, vegetation profiles and survey transects and stops at Forks of the Credit.

Figure A.9 Large blockfall from undercutting by the Credit River, Transect 1, Forks of the Credit Provincial Park.

The other three stops are on the edge of the stream on channel deposits and experience periodic flooding, especially during spring melt. Human disturbance was limited to a small footpath used by fishers.

Vegetation - Species

This stream transect is similar to other stream channels that are high energy and flow below the falls, in the high-energy river segments. Where the floodplain broadens a dense but young forest cover has developed while in narrow segments of the channel, tree cover is limited to several large trees, such as shining willow *(Salix lucida)*, along the river edge. Common species along the channel were predominantly eastern white cedar and American elm. American elm is common at three of the stops (Appendix G). White birch had high scores at stop B which had the most extensive floodplain. White ash was more dominant at stop A which was on a raised slope deposit sculpted by bank erosion. The species at this stop were more typical of the adjacent slope forest. In general, most of the trees were young with only a few larger individuals that were primarily shining willow and eastern white cedar. This reflects the dynamic nature of forests along these high energy stream channels.

Vegetation - Structure

This forest had a higher percentage of younger stems compared to many of the transects. The ratio of old/new stems was on the average 43%, although this varied along the transect; stop B had a particularly large number of smaller stems (see Appendix G). The forest could be considered mixed, but there was a stronger concentration of deciduous to coniferous, averaging 72%. The density of saplings was average at 16/plot for the transect. Canopy cover was not complete, averaging 71% with moderate variation between stops.

Bird Populations

This transect had a lower diversity of bird species compared to some of the other transects, especially other stream transects. The higher IV scores were divided between resident species and riparian species. The most common bird was Black-capped Chickadee with an IV of 18. Other resident birds that were important were Blue Jay, American Robin and Northern Cardinal. This last species had few other records in which it had relatively high scores. Riparian species were dominated by Song Sparrow (IV 11) but also included Northern Waterthrush, Winter Wren and Cedar Waxwing. Other riparian species present but not frequent or abundant were Mourning Warbler, Mallard, Spotted Sandpiper, Northern Rough-winged Swallow, Tree Swallow (*Tachycineta bicolor*), Ruby-throated Hummingbird and Common Grackle. Another two species associated with water and coniferous forest were Black-throated Green Warbler and Black-and-white Warbler.

A.5.2 Forks Transect 2 - Slope

Geomorphology

This transect is located along the steep slope of the Escarpment carved by post-glacial flow in the current Credit River channel. The average slope angle was 26°. The bedrock outcrops at several locations especially closer to the falls at stops A - C. The slope is quite irregular in shape as it cuts into the upper till plain with deep depressions that forms secondary ridges that extend downslope perpendicular to the main rim. Consequently, the readings for the azimuth varied considerably between stops, ranging from 146° to 315° depending on the position in the bowl. The overall slope aspect is to the south-southwest. Most of the stops are located where the slope shape is relatively straight, in the middle of the slope. Stop A was in the bowl of the debris slide and was more concave in shape (Figures 3.8 and 3.9).

Human disturbance was limited to some rudimentary trails that run from the slide to stop C. The last two stops had no evidence of human disturbance. In contrast, this transect had strong evidence of natural disturbance. The most western stop (Figure A.8) was located on a major slide that had removed the vegetation cover from the top of the slope to the base of the stream channel (Figure 3.8). This material was deposited over the lower half of the slope in a jumbled mass of soil, drift, and vegetation. Stops B and C showed evidence of mass movement, mainly below the outcropping of bedrock at midslope, although this was at a smaller scale than at stop A. There was also evidence of strong sheetwash and creep; the slopes were quite steep and bare underneath the tree cover. Stops D and E exhibited little evidence of geomorphic processes although the steep slopes showed some signs of extensive sheetwash or even channeled flow.

Vegetation - Species

This transect had a varied pattern of vegetation. Overall, the slope had distinctive patches of deciduous and coniferous cover, dominated by sugar maple and eastern white cedar respectively (Figure A.8). Sugar maple had a high score at stop D; stop E had some records of sugar maple but there was also a high score for ironwood (Appendix G). This is somewhat surprising since ironwood usually occupies a subordinate role in most forests in the study. The larger trees in the canopy were sugar maple, black cherry and white ash. In contrast, stop B was strongly covered by cedar, although on the upper portion of the slope, where the survey sample was completed, there was a mix of deciduous and coniferous as is evident with the presence of sugar maple, white birch and eastern hemlock. Further downslope towards Transect 2, where the slope steepens, the forest consists of almost pure cedar stands. Stop C represents the transition point along the transect between the two forest covers, and consequently it has a mix of cedar and sugar maple. Again ironwood is a dominant tree in the lower canopy. Stop A is on a recovering scar, located in the upper, drier reaches of the landslide scar. The recovering vegetation is dominated by eastern white cedar and balsam poplar.

There are sections of this slope that are in transition, where there have been major disturbances or ongoing minor disturbance and stress, and other sections, as found at sites D and E, where the forest cover appears to be somewhat stable. On the scar, eastern white cedar is the dominant tree with some stems of balsam poplar. The surrounding vegetation is primarily eastern white cedar from the top of the slope to the river with some large specimens of balsam poplar and white birch that rise above the cedar cover.

Vegetation - Structure

The transect along the slope had a relatively low ratio of old/new stems suggesting this is a forest in transition. The very different ratios between the stops ranged from 9 on the scar to 88 at stop B. Stop 1 is a mixed forest with similar values for both old and new stems, although the average is higher for deciduous. Again this reflects variations between the stops, ranging from 33 at stops A and B to 100 at stops D and E. The densities for old and new stems was average but the sapling numbers were quite low in comparison to the other transects. This may be a combination of the mature forest cover and the stress at some of the stops. In comparison, this transect had one of the higher records for multistem area. This may be a result of both the impact of the slide disturbance on stems as well as high concentrations of eastern white cedar, which can be extensively multistemmed.

Bird Populations

This transect had a low diversity despite the variety of habitats. Seven species were encountered regularly during the surveys. These can be divided into three groups- resident species, forest interior species, and disturbance site species. The resident species had the highest scores (Appendix G), especially American Robin (IV 18) and Black-capped Chickadee (IV 17). Blue Jay was also important. The portion of the forest dominated by deciduous forest attracted forest interior species, including Red-eyed Vireo, Ovenbird, Eastern Wood-Pewee, Great Crested Flycatcher and Wood Thrush. Another group of species tended to favour the more stressful and disturbed sites where there is a mixed cover; these included Black-throated Green Warbler, Black-and-white Warbler and Cedar Waxwing. Also present on the disturbed sections of the transect were Indigo Bunting and Nashville Warbler.

A.6 Inglewood

The Inglewood site is situated on private land in the central region of the study area near the community of Inglewood (Figure 4.2). This site is covered by a younger forest on a slope segment typical of slope type B, although at this site there is an extensive bench or bedrock plain situated on the midslope. There is only one transect at this site, located along this midslope plain. The transect was aligned along a main trail that runs through the centre of the site (Figure A.10).

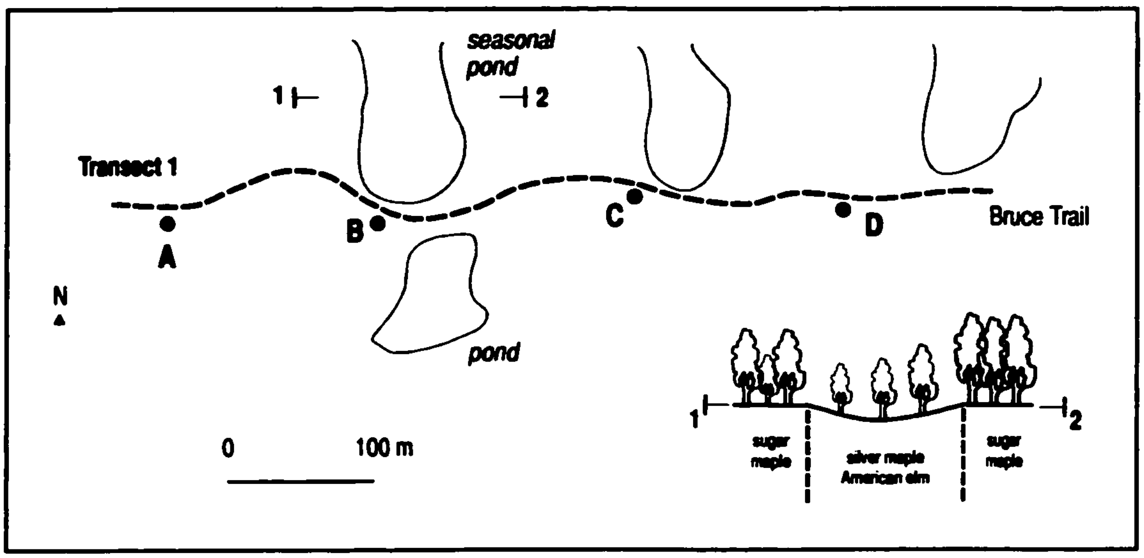


Figure A.10 Geomorphic processes, vegetation profiles and survey transects and stops at Inglewood.

A.6.1 Inglewood Transect 1 - Upland

Geomorphology

This site is located on the bedrock plain where the slope angle was <5° across the transect and no azimuth was recorded. The slope shape was considered as plain. Human disturbance was primarily along the trail which could accomodate motorized traffic and was used extensively for hiking and horseback riding. There was evidence of forest clearance and disruption to the bedrock throughout the forest and a quarry operation was located nearby on the bedrock plain. Natural disturbance was minimal. This transect had a number of permanent and seasonal small pondings. Fluctuating moisture levels throughout the year may lead to stressful situations.

Vegetation - Species

The forest cover of this site was a combination of sugar maple and white ash. It is apparent from Appendix H that this varied between sites with each species dominating at one sites. The IV ranged from 30 and 140 for each species. The diversity of secondary species indicates the presence of poorly-drained sites throughout the forest. These species included silver maple, red maple, American elm, and basswood. Black cherry and ironwood were also present in the understory.

Vegetation - Structure

The forest is relatively young, with a high young to old ratio at around 50%. The forest is primarily deciduous with percentages at almost 100%. It is a very dense forest with a high density of old and young stems at approximately 41/plot for each age group. This site had a high average of snags and only an average number of saplings, which suggests a stressful environment for seed establishment and sapling survival. The canopy cover is fairly complete at 87%.

Bird Populations

There were 26 species recorded at this site, primarily species of deciduous forest interior as well as those associated with wetland area, such as Veery and Northern Waterthrush. Mallard and Canada Goose were observed using the ponds at other times of the year outside of the summer study period. The most common species at this site was Red-eyed Vireo, with almost 20% of the combined relative abundance and frequency scores (Appendix H). Across the transect were an average of 5-10 breeding pairs. Other deciduous interior species common at this site included Eastern Wood-Pewee and Ovenbird, although their numbers were considerably lower 6-8 for importance value (6-8). Common edge species were American Robin, Black-capped Chickadee, Cedar Waxwing, American Crow and American Goldfinch, which ranged from 3 to 10. Also of note were the relatively high numbers of Northern Waterthrush and Scarlet Tanager.

A.7 Glen Haffy

The Glen Haffy site is located on public land in Glen Haffy Provincial Park, within the Caledon Hills land unit (Figure 3.15) on an area of the Escarpment dominated by rolling hills and deep glacial deposits. The slopes here are type C with little evidence of bedrock exposure. There are two transects located within this site, both situated on the Escarpment slope. Transect 1 is located on the upper slope below the ridge while Transect 2 is closer to the base of the slope near a cleared field. Both transects are bisected by a deep stream channel that flows perpendicular to the transects (Figure A.11). There are four stops on each transect.

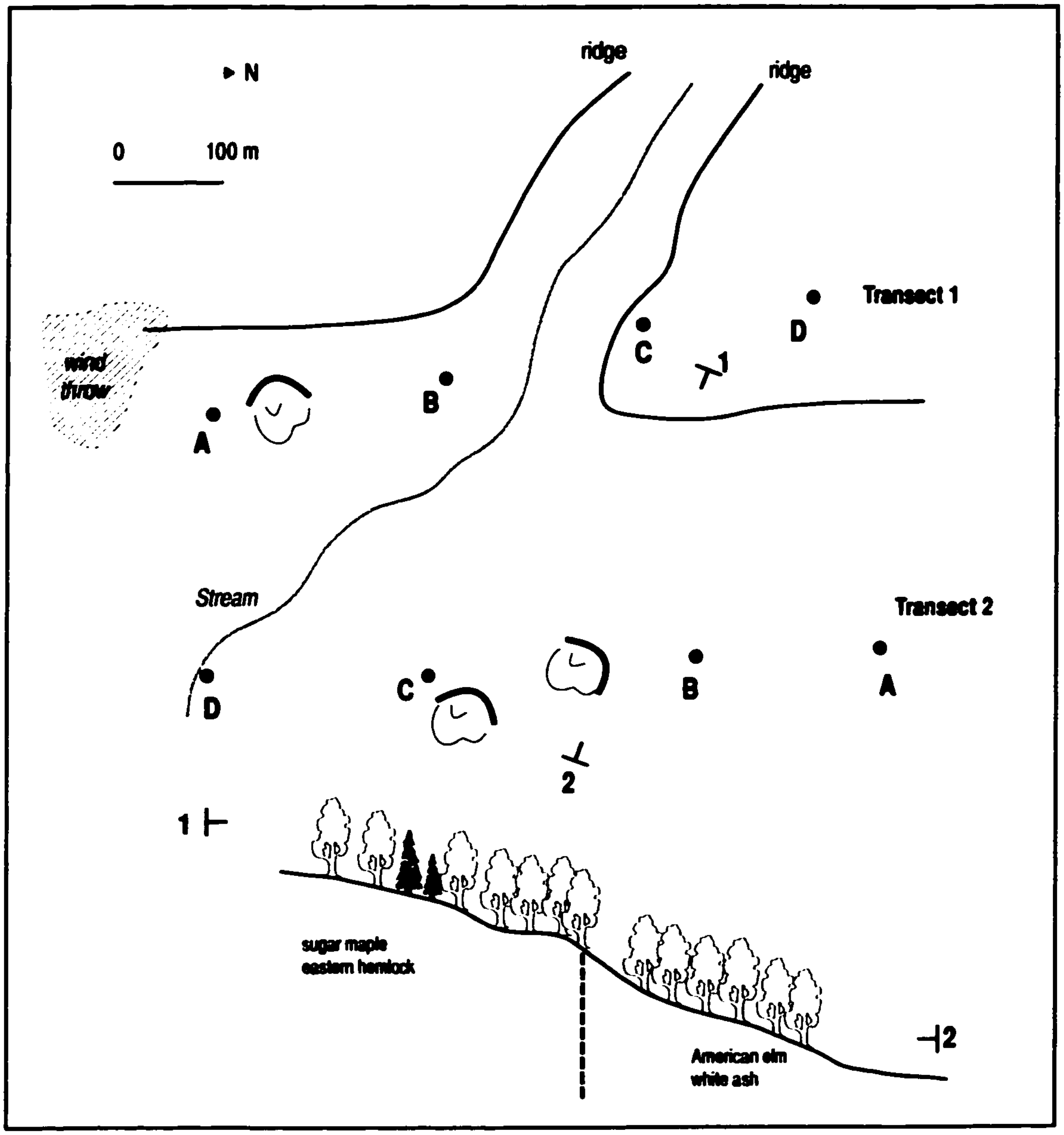


Figure A.11 Geomorphic processes, vegetation profiles and survey transects and stops at Glen Haffy.

A.7.1 Glen Haffy Transect 1 - Upper Slope

Geomorphology

Transect 1 runs along the upper slope, crossing a moderate re-entrant valley and then following the crest of the ridge to the north. Consequently, the slope angle varies between the steep slopes of the two southern stops and a minimal slope at the two northern stops. The slope angle averages 29° for stops A and B. The aspect of the slope is to the north-northeast with azimuth readings of 8° and 40°. The slope shape varies depending on the stop; those on the slope are on the straight portion of the slope while those on the crest are on convex and plain surfaces. Human impact is mainly in the form of a series of hiking trails; stops B and C are located on these trails, while stops A and D are within 30m of them. Despite the steep slopes there is little evidence of mass movement events, although sheetwash is evident. There was a major disturbance from an ice and wind storm that leveled an area of the slope forest immediately to the south of stop A (Figure A.11). This did not have a direct effect on this stop but did affect the bird species within the area of study.

Vegetation - Species

Since this transect is located along a less disturbed portion of the forest compared to the lower slope, the forest cover is more representative of the stable deciduous forest. The diversity is quite low; there were only five species recorded and of these, two had only one record and one had only two records. The most dominant tree was sugar maple. This species had a very high IV compared to the other species, in the range of 80 - 180. The lowest score was at stop B2 where eastern hemlock was predominant on the steep northeast-facing slope. There were records of hemlock at each of the other stops but at this site it had a greater density than sugar maple (Appendix I). The other species found on the slope were ironwood, butternut (*Juglans cineria*) and a large specimen of American beech. The forest appears to be in a stable state with sugar maple dominating all levels of the canopy. During the course of the study, an area just to the south of the transect was affected substantially by an ice storm and many trees were felled. This created a large gap in the slope forest but did not directly impact on the forest cover.

Vegetation - Structure

The forest cover had a moderate ratio of old stems but overall this transect had a very low density of old and young stems. However, the sapling density was quite high at 31. This transect also had the lowest scores for multistems and multistem cover as well as the lowest density of snags at less than one per stop. The forest can be considered mixed for the older stems but this is primarily from the low ratio at stop B where the northern slope had a high concentration of eastern hemlock. The other three stops had ratios greater than 75. The younger stems had a very high percentage of deciduous trees (99).

Bird Populations

The dominant bird on this transect was Red-eyed Vireo. It had the highest abundance, with more than twice as many individuals as any other species and was encountered on every visit. Other forest interior species were also common including Eastern Wood-Pewee, Ovenbird, Wood Thrush, Scarlet Tanager and Black-throated Blue Warbler. This last species was encountered on a number of transects but Glen Haffy had the greatest concentration and frequency of birds. There were at least two breeding pairs within the transect and several other records throughout the park. Many of the transects where Black-throated Blue Warbler were recorded were south of the range identified in the breeding atlas of Ontario (Cadman et al., 1987), which suggests a significant change in the breeding status or habitat requirements of this species.

Resident species were also common at this transect. There were high IVs for Black-capped Chickadee and Blue Jay (Appendix I). Also present were American Robin, Downy Woodpecker, Pileated Woodpecker and White-breasted Nuthatch. Although they did not score high IVs, there were several other species of note. Yellow-bellied Sapsucker was fairly common at this site, especially along the upper transect. There were also good scores for Black-throated Green Warbler and Winter Wren which were frequently observed along the Escarpment, especially in the moderately disturbed sites. This transect also had one of the few records for Broad-winged Hawk. The range of this species is further to the north and is more common in large forest tracts (Cadman et al., 1987).

A.7.2 Glen Haffy Transect 2 - Lower Slope

Geomorphology

This transect is located along the lower slope in the concave section of the slope. Itt had several stops located along stream channels that had heightened slopes. The slope angles varied from 3.5° to 20° with an overall average of 10°. Stop A had the steepest angle; it was situated on the edge of a remnant channel. The aspect of the slope varied between stops since some were on stream channels. Overall the azimuth ranged from 92° to 134° but there was a value of 345° on the side channel at stop A. As with the upper slope, the slope in general was facing to the east. Individual slope shapes varied between straight and concave, but overall the stops were in the concavity of the slope profile. As with the upper slope, several stops were located on or near the trail system (Figure A.11).

An area near stops C and D was covered with a small planting of spruce and pine which could affect local bird populations. Natural disturbance was limited, this area of the slope was mainly impacted by the release of water to the lower slope. There were natural springs near stop B and C. There may also be some impact from fluvial action during spring runoff at stop D, although this is a small-stream channel.

Vegetation - Species

This transect displayed a relatively high level of diversity as the site crossed several stream channels, slope seeps and drier ridges. A diverse pattern of vegetation cover was created, with several dominant species at different stops. The first stop (A) is on the edge of a stream valley, a stable slope covered by a mature forest of sugar maple, American beech and eastern hemlock. There is a similar forest cover at the second stop (B) but there were also a number of yellow birch in the forest cover. The last two stops were wetter, with a diverse cover of white ash, American elm, sugar maple, white spruce (*Picea glauca*), and in the stream channel eastern white cedar and an assortment of individual stems that included butternut, trembling aspen, narrow-leaved hawthorn, and apple (Appendix I). The last two species suggest this site is in the process of regenerating from land clearance. There were several small plantations and a cleared field near the transect. The last two stops seemed to be in transition with few larger trees and many small sugar maple and white ash. The first two stops were more static with mainly older trees dominating the forest cover.

Vegetation - Structure

This transect had a higher ratio of old to new stems than the upper transect. This was somewhat surprising since overall it appears to be a younger forest especially at stops

C and D, but there are a number of old, large trees that dominate stops A and B which affected this average. The forest can be considered mixed with a ratio of 59 although this varied between stops ranging in value from 28 to 87. The ratio was much higher for the smaller stems at an average of 87. This transect had a much higher number of multistems and multistem cover than Transect 1. As well there was a moderate number of snags. Old and young stem densities were higher but the sapling density was considerably lower. This transect had the highest canopy cover at 98%, although this is not entirely accurate given there are a number of openings along the transect especially where the springs reach the slope surface.

Bird Populations

There are several groups of dominant birds on this transect, including common species such as Black-capped Chickadee, Blue Jay and White-breasted Nuthatch (see Appendix I). Deciduous forest interior birds, such as Red-eyed Vireo, Eastern Wood-Pewee, Ovenbird, and Scarlet Tanager, were also an important component of the bird community. Each of these species were frequently observed, occurring in more than half of the surveys. Of lower importance are Black-throated Green Warbler, Winter Wren and resident species, American Robin, Brown Creeper, Downy Woodpecker and Hairy Woodpecker.

A.8 Hockley Valley

The Hockley Valley site is located on public lands within Hockley Provincial Park near the western edge of the park. There are three transects situated in this site, including examples of each Escarpment unit - stream channel, slope, and upland. Transect 1 is located along the stream channel, Transect 2 runs parallel to the channel along the adjacent slope, and Transect 3 is located in a north-south direction through the uplands to the south of the stream (see Figure A.12). This site is typical of the type C slope. There is no forest cover above the slope but there is an extensive upland forest to the southeast of the slope.

A.8.1 Hockley Transect 1 - Valley

Geomorphology

Transect 1 is located along the stream channel that flows over Canning Falls and enters the Nottawasaga River downstream. This is a high-energy stream with peak flows during spring runoff and high rainfall events. At stop A there is little floodplain, just a moderate slope of surface material from the slope and channel that grades to the stream at an angle of 10° and an aspect of 78°. The floodplain widens below stop A and there are only minimal angles at the other three stops. Similarly, the slope shape is mainly plain for these stops. There is no evidence of human disturbance along this transect, although after the research period a motorized vehicle was driven upstream for several hundred metres which created substantial disturbance to the streambed and herbaceous vegetation. This is a high-energy stream and there can be strong bank erosion and reworking of the cobble channel bed. It was evident that the small floodplain was frequently covered during periods of spring melt and high flow.

Vegetation - Species

The stream channel had a high diversity of tree species and no stop was dominated by one species (Appendix J). The two most common species were white cedar and sugar maple; other common species included American elm, basswood, white ash, ironwood, yellow birch, white birch, balsam poplar and black ash. There is no apparent change or

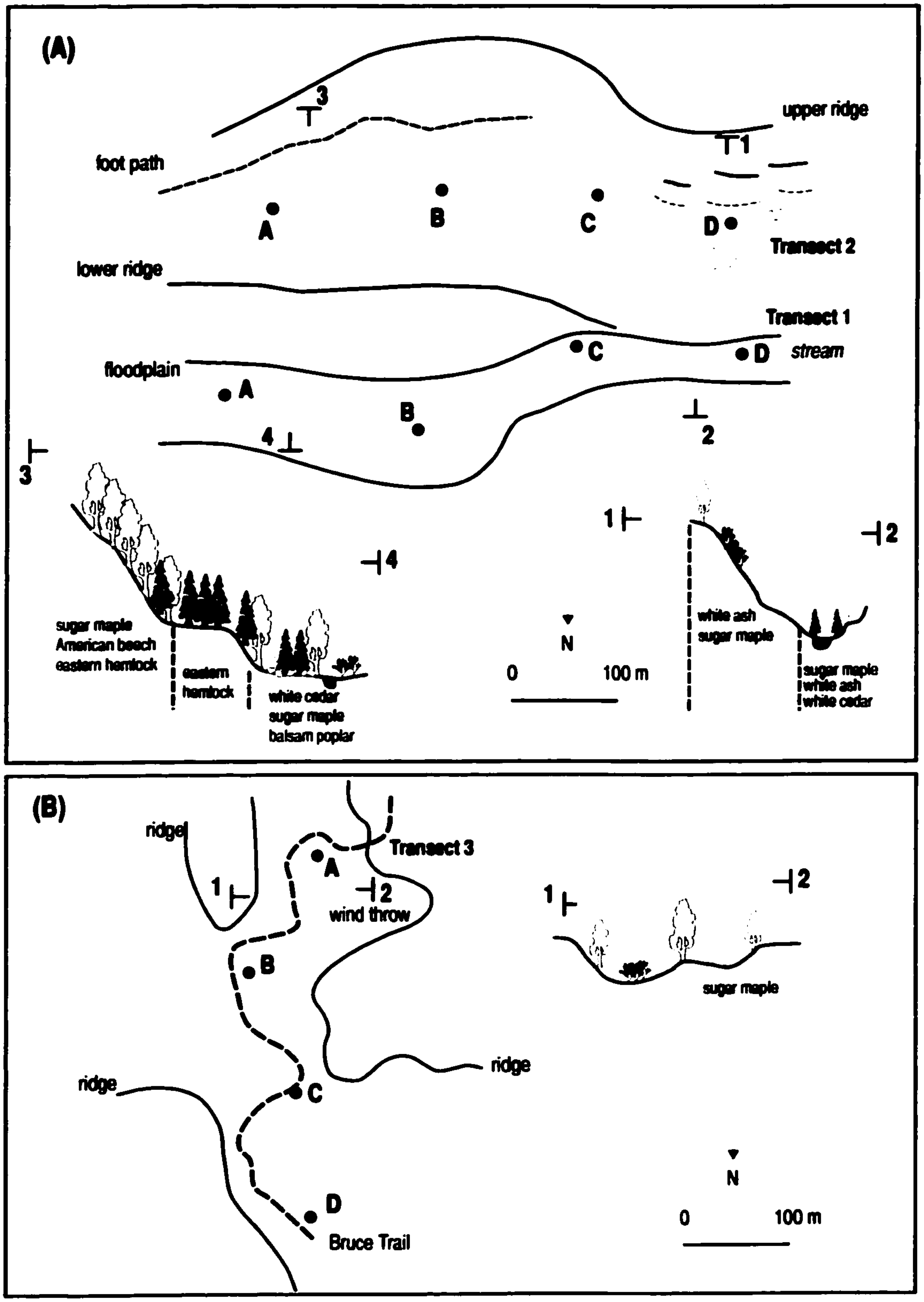


Figure A.12 Geomorphic processes, vegetation profiles and survey transects and stops at Hockley Valley (A) Slope and valley (B) Upland.

pattern to the forest dynamics, with older trees also represented in the understory. Larger trees were typically white cedar, sugar maple and balsam poplar. The width of the floodplain varied along the channel and the white cedar stands were more dominant in the broader channels at stops C and D. The spring floods created disturbance to the forest cover through bank erosion. In the active channels there was evidence of fallen trees and open shrub communities on the small point bars.

Vegetation - Structure

This forest had a high density of old and new stems. The composition was on the border of a mixed forest with a deciduous ratio of 75 for old stems and 77 for new stems. In contrast to the high density of tree stems there was a relatively low density of saplings. This transect also had a lower score for multistem and multistem cover. The canopy cover was moderate at 63%.

Bird Populations

The resident species were quite dominant at this site. Black-capped Chickadee had the greatest value at 14 and White-breasted Nuthatch and Blue Jay were also high in the range of 7-11. Short-distance migrant, American Robin, was also in this range (Appendix J). The only deciduous forest interior species to score relatively high was Red-eyed Vireo, although there were also records of Ovenbird, Scarlet Tanager, Wood Thrush and Eastern Wood-Pewee. Typical species of the mixed, riparian forest included Northern Waterthrush, Black-and-white Warbler and Black-throated Green Warbler. At least three individuals of each species were recorded during at least one survey and were observed in at least 50% of the surveys.

A.8.2 Hockley Transect 2 - Slope

Geomorphology

The average slope angle for this transect is 23° but was steepest at stop D (31°) (Appendix J). The slope aspect is mainly northeast with an average azimuth reading of 40° and a range from 9° to 57°. This slope is a combination of bedrock, glacial till and stratified drift (Braid, 1997). The bedrock surfaces only at stop D where several large layers of dolostone are exposed. The slope shape is mainly straight for all stops although variations in micro-relief created some convex and concave patterns. There is little human disturbance at this site. A rudimentary path is situated near stops A and B and a similar path is located at the base of the slope which ends near stop A. Natural disturbance was limited to creep and sheetwash at stops A and B. At stop C, there were some instances where water travelled over the slope from the midslope area. Only at stop D does the influence of a buried bedrock bench affect the hydrology and create an unstable slope which impacts on the forest cover. At stop 4, there were some bedrock exposures and further water flows over the slope (Figure A.12). A few small blocks had glided downslope and caused moderate damage to the vegetation cover.

Vegetation - Species

This forest is similar to Transect 3 located in the interior upland forest. There is a moderate level of diversity but the forest is dominated by a cover of sugar maple. At several sites, sugar maple forms the main canopy while at the first site it shares the cover with American beech and at stop D its IV is similar to white ash (Appendix J). A few other species have a minor position in the forest cover. These include yellow birch, basswood, eastern hemlock, butternut and American elm. Directly below the transect, the lower slope at the edge of the river channel is dominated by eastern hemlock which extends upslope in several locations, especially near stop A. The forest dynamics suggest a shift to a more stable forest of sugar maple, beech and hemlock. Records of white ash, basswood and butternut were only individual, older trees in the canopy while the sapling layer was mainly sugar maple with some American beech and eastern hemlock. Stop D likely experiences more flux in the cover; there is evidence of block glide on wet areas of clay which disrupts small pockets of the forest cover but does not appear to create large gaps and therefore has the same effect as individual tree replacement.

Vegetation - Structure

This forest transect had a relatively high ratio of old to young stems (78). The forest was primarily deciduous - the old stem deciduous ratio was 100 while the new stem ratio was slightly lower (90) because of the presence of eastern hemlock at stop A. As was found in other deciduous upland forests, this transect had low values of multistem, multistem cover and snags. It had quite low densities of old stem (14) and new stem (4), which was second lowest only to the adjacent Hockley upland transect. The sapling density was also quite low. There was a relatively full canopy cover at 82%.

Bird Populations

This transect was dominated by only a few species, although the total diversity for the site was comparable to many sites with a richness score of 25. Of these only a few species were found in high numbers or in more than half of the surveys,. The highest score was recorded for Red-eyed Vireo, both for abundance and frequency. Eastern Wood-Pewee had a high score but had lower abundance. Other forest interior birds with comparable scores were Ovenbird and Scarlet Tanager, although the tanager score was based on only a few observations and a higher abundance score. Resident species had high scores, particularly American Robin and Black-capped Chickadee. Also of note in this group were the relatively high scores for Brown Creeper and Hairy Woodpecker. These species were recorded in many transects, but were seen frequently and in relatively high numbers along this transect. Another important record was the high score for Black-throated Green Warbler, which was most frequently observed at the lower end of the slope in an area dominated by eastern hemlock. This forest also had records for Black-throated Blue Warbler which was south of its estimated range (Cadman et al., 1987).

A.8.3 Hockley Transect 3 - Upland

Geomorphic

The upland transect at Hockley is across deep deposits of till and stratified drift resting on top of buried layers of bedrock. This forms undulating hills with moderately steep micro-relief. The average slope angle along this transect was 12°. The variability of the slope aspect is apparent in the variety of azimuth records ranging from 4° to 90°. However, the general trend of the land was a moderate grade towards the northeast stream channel. The micro-relief varied between stops from convex to concave shapes with no real pattern. The transect follows the main portion of the Bruce Trail through the Hockley Provincial Park but there was no other evidence of recent human disturbance (Figure A.12). Natural disturbance was evident in a series of small gaps created from windthrow. A number of trees were uprooted during a major storm event during the course of the study. The steep micro-slopes experience sheetwash and soil creep, especially where there is little ground cover. Overall, the land exhibits a hummocky pattern from the process of treefall down the short slopes.

Vegetation - Species

The upland forest at Hockley Valley is dominated by sugar maple. The IV for sugar maple was very high at each stop, with high densities of stems dominating all layers of the canopy. The sub-dominant species are typical for these types of interior forests, with a few records of white ash and one record of American beech. As mentioned, maple dominates all levels in the forest which suggests this is a stable system. At stop A, black cherry was an important component of the canopy which suggests this area has experienced some disturbance in the past. It was at this stop where a wind storm knocked down a number of stems, creating small gaps in the cover.

Vegetation - Structure

This forest had a very high ratio of old stems. The old stems had a moderate density but new stems had the lowest score of the study with an average of only two stems per plot. This forest was entirely deciduous in the survey plots, with very low numbers of multistems, multistem area and snags. Ground cover was also low while canopy cover was quite extensive (88%). This is a mature deciduous forest that is slowly replacing itself with little change in species composition.

Bird Populations

The bird populations of this transect were a mixture of deciduous forest interior and resident species. The dominant bird was Red-eyed Vireo with an extremely high score for abundance at 29 (Appendix J). The next highest IV, with only half of this score, was American Robin. Other forest interior species included Eastern Wood-Pewee, Rose-breasted Grosbeak, and Ovenbird. Slightly lower were Scarlet Tanager and Wood Thrush. Other resident species with good scores were Brown Creeper and Black-capped

Chickadee. Also of note - this transect had reliable records for Black-throated Blue Warbler and Yellow-bellied Sapsucker. There were also several raptor records including Sharp-shinned Hawk and Red-shouldered Hawk. There was no evident pattern of birds along the transect. A few small gaps in the canopy cover from windthrow might attract species such as House Wren, but there were no consistent patterns identified.

A.9 Mono Cliffs

This site is located on public land within the Mono Cliffs Provincial Park, the most northern site in the study area. This region is somewhat unusual; there is a large outlier that creates a canyon-type environment with slope type A cliffs facing east and west. This creates a unique microclimate on both cliff faces. This is the only site that has type A slopes. There were three transects established at this site which are situated in the southcentral section of the park. Transect 1 is located on the top of the outlier, running north-south (Figure A.13). Both Transect 2s and 3 run parallel to 1 and are situated in the valley. Transect 2 is on a section of the Bruce Trail on the east side of the valley and runs along a small stream channel. Transect 3 is situated on the western slope at about mid-slope. Transects 1 and 3 had four stops; Transect 2 had four stops for the bird point counts and three more surveys were added to capture the variation in vegetation between the lower slope and stream valley (Figure A.13).

A.9.1 Mono Cliffs Transect 1 - Upland

Geomorphology

This transect is situated on the upper portion of the outlier, although unlike the other sites further south on bedrock plains, there is a thicker layer of glacial material on this upland. There is a slight slope to this transect which slowly grades to the east. The

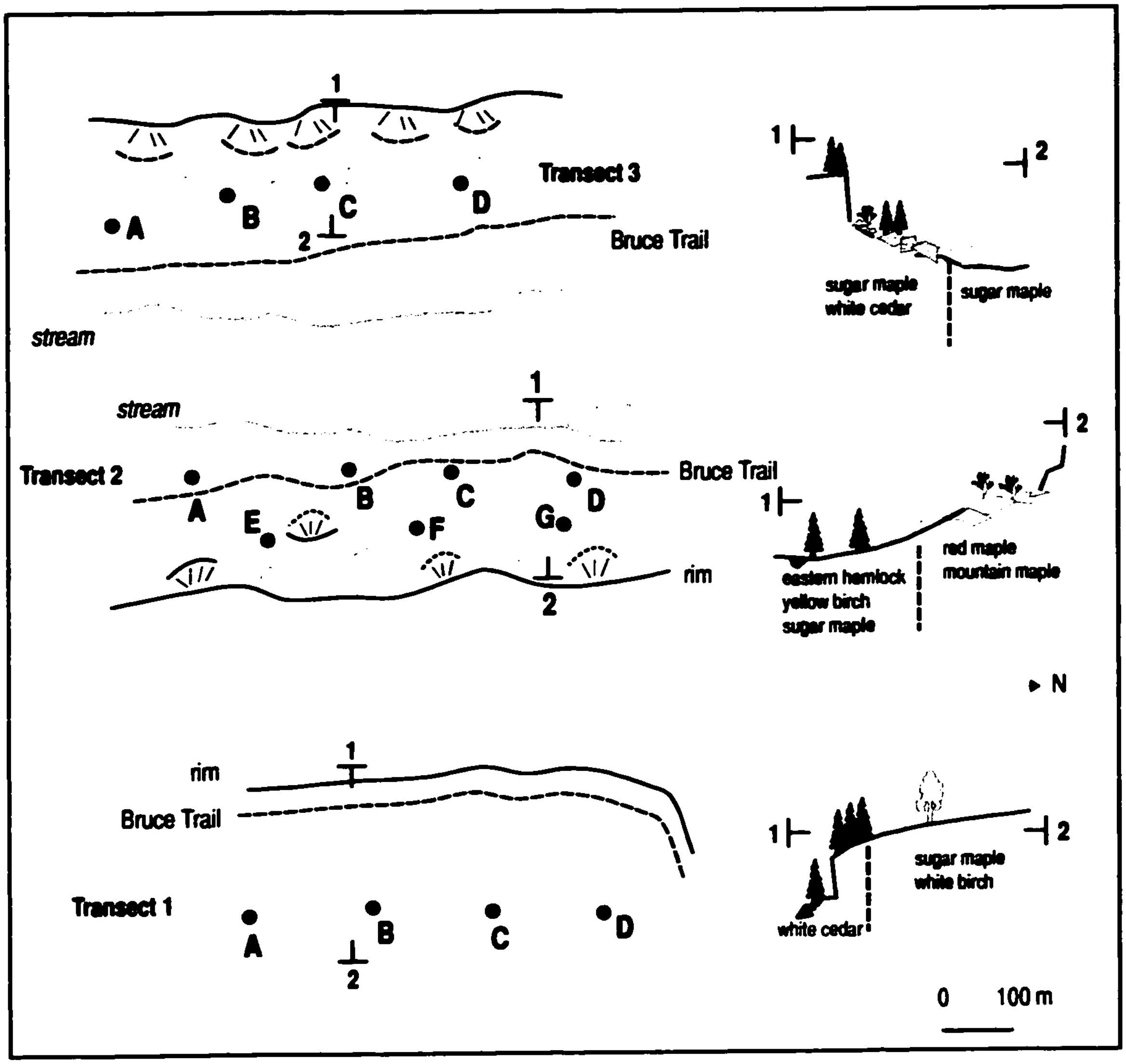


Figure A.13 Geomorphic processes, vegetation profiles and survey transects and stops at Mono Cliff.

average slope angle is 6° and the azimuth ranges from 62° to 100°. The slope shape varies between stops but it is primarily convex as the slope joins the larger slope segment of the eastern face of the outlier. There is little evidence of natural disturbance. At stop D, a gap has been created by several treefalls possibly from windthrow. Human disturbance is minimal - the transect runs parallel to two sections of the Bruce Trail which skirts the rim of the outlier, but there was no evidence of human activity on the transect.

Vegetation Species

Sugar maple dominates this upland forest in all layers of the forest levels. The IVs varied between 100-180 (Appendix K). There was a small variety of sub-dominant species. Most of these stems were found at stop D where white ash and white birch had scores of 51 and 36 respectively. Other species included basswood and American beech.

Vegetation - Structure

This transect had one of the largest age ratios with 89% old stems. The forest is entirely deciduous for both the old and young stems. There were very low scores for multistems and snags. The density of old stems was average but the young stems were quite low at 5. The sapling density was moderate but was concentrated in the gap at stop D where the number of saplings reached 60. There was very little ground cover and an extensive canopy cover (84%).

Bird Populations

The upland transect was dominated by forest interior species. The highest IVs were recorded for Red-eyed Vireo and Ovenbird (see Appendix K). These species had both highest abundance and highest frequencies. Other significant interior species included Eastern Wood-Pewee and Scarlet Tanager. Resident species were not as important at this site as at some other transects. The most common was the short-distance migrant, American Robin. Black-capped Chickadee scored similarly but this species was limited to several records, each with a large number of birds. Another species of significance was Black-throated Green Warbler, which was common along the edges of this upland and was associated with the eastern slope and cliff complex (Figure A.13). There were also several predominant woodpecker species including Downy Woodpecker, Yellow-bellied Sapsucker and Pileated Woodpecker. Also of note was the presence of Black-throated Blue Warbler which was found at a number of transects. Common Raven was recorded on this transect but it was associated more with the cliff faces of the western slope (Transect 3). This species record is also south of its range as identified by Cadman et al. (1987).

A.9.2 Mono Cliffs Transect 2 - Valley

Geomorphology

This transect is located along the lower slope of the bedrock outlier (Figure A.13). It includes the talus/block slope as well as the drainage area at the base of the slope where a small, permanent stream flowed north between the main Escarpment and the outlier. This cliff face is not as dominant as on the east-facing slope but there is some delivery of talus to the slope. The slope angle varied between stops depending on the location of the survey (8° to 25°) but in general the average slope was about 15°. The aspect was quite consistent as was found on the opposite slope. This slope faced almost due west with the azimuth ranging from 270° to 280°. The stops in the stream valley had a minimal angle and azimuth was not recorded. The slope shape varied between stops, ranging from straight to concave on the slope to plain in the stream channel. The only human disturbance on this transect was the presence of the Bruce Trail. The slopes have similar natural disturbance as found on the west side, which includes large blockfall events and talus accumulation, although the magnitude is not as extensive. There is little disturbance on the stops in the stream valley; there could be periodic flooding but there was no evidence of any major events during the research period.

Vegetation - Species

This side of the canyon had an even greater diversity than the west side. This, however, may be a function of the location of the transect and the sample points. This transect followed the edge of a small stream channel as well as the lower slope of the west-facing talus slope of the outlier (Figure A.13). Therefore, this transect included seven stops in several habitats which tends to increase the number of species due to habitat diversity and a larger sample size.

Despite this variation, the dominant tree is sugar maple (Appendix K). For stops on the slope, sugar maple shares the canopy with large-toothed aspen, white ash, white birch and red maple. The most diverse site is stop G, which was situated at the edge of a blockfall. The other stops were on slopes below the face but where there was little recent disturbance compared to the slopes on the west side. In the valley the vegetation was somewhat different with a diverse number of species. At stop B there was a high density of eastern hemlock and yellow birch.

Vegetation - Structure

Overall the average age ratio was moderate at 59%, placing it in the middle of the scores. There was, however, considerable variation between the stops with the ratio ranging from 38 to 87. The results of the deciduous ratio were more consistent, with an average of 88 and 89 respectively for old and new stems. This was not the case at stop B, which was situated in a stand of eastern hemlock in the stream valley. Of note this transect had above-average scores for number of snags and high densities of both old and new stems. In contrast, it site had very low numbers of saplings with an average density of 2.

Bird Populations

This transect had a variety of species with many scoring relatively high IVs. The highest values were several warbler species - Black-throated Green Warbler and Ovenbird. Aside from Ovenbird, other important deciduous forest interior species were Red-eyed Vireo and Wood Thrush and to a lesser degree Scarlet Tanager. Other birds with high values and common in this type of habitat included Black-and-white Warbler and Winter Wren. Resident species included Black-capped Chickadee. Of note along this transect is the record for Common Raven. This species frequented all sites at Mono Cliffs but is primarily associated with the cliff face. Also of interest is the presence of Black-throated Blue Warbler.

A.9.3 Mono Cliffs Transect 3 - Slope

Geomorphology

This transect has the most extensive cliff complex of all the transects in the study. The dolomite cliffs are at least 25m high, situated above a layer of talus, as well as a lower level of large blocks. The transect was situated below the cliff face among the talus and boulder deposits of the upper slope. The slope angle was quite constant for stops B-D at 24°. Only stop A had a lower angle, 6°, but this stop was located further downslope below the talus deposits. The slope faced almost due east with the azimuth ranging from

90 to 100°. There was little human disturbance at this site although several rudimentary trails led upslope to the cliff face and the Bruce Trail runs parallel to the base of the slope about 20m from the transect (Figure A.13). The main disturbance and stress were from the delivery of talus to the upper slope from weathering of the cliff face. Large boulders were deposited on the slope but there was no evidence of recent movements from the face. The majority of material was smaller blocks released from the cliff face by weathering processes. There was little soil development on the upper talus but the depth increased downslope.

Vegetation - Species

The stress and disturbance on this slope has promoted the establishment of a variety of species of varying age and size. The diversity was high on this transect with 14 tree species (Appendix K). Only at stop C was there a strong dominance of sugar maple. Stops A and B were quite diverse - at stop A alone there were 11 species. Overall this site has a number of species more typical of stressful and successional environments. Eastern white cedar had high scores at stop B which was in an area of large blocks. Another important species that is restricted to this type of habitat was mountain maple. This species was restricted to the more disturbed portion of the slopes, closer to the talus deposits. This area is not in transition, except that there are local sites where the species will be replaced following disturbance. It is more likely that the pattern on the slope is reflecting long-term stress environments, for example, areas where there had been extensive blockfall in the past.

Vegetation - Structure

The forest cover along this transect was a mixture of young and old stems that were predominantly deciduous although the old stem ratio was very close to mixed forest status (75%). This ratio varied considerably from 50 to 100 between stops which highlights the pockets of eastern white cedar across the transect. Overall, this forest had fewer stems, both old and new, compared to the other transects and had a low number of saplings. This suggests that tree establishment and survival is more difficult on this transect, which is supported by the high number of snags here. However, there was evidence of ice storm damage that occurred during the winter before the vegetation survey was completed, which may account for these results. Despite the lower number of stems, this forest had one of the higher canopy cover scores at 91% cover. It had above- average values for multistems which is likely the result of the disturbance and stress regime.

Bird Populations

This transect had one of the highest diversity scores for the study. A total of 37 species were identified during the summer breeding season. The highest IV score was for Red-eyed Vireo (10) but there were good representation of other deciduous forest interior species. These included Scarlet Tanager, Rose-breasted Grosbeak, Ovenbird, Eastern Wood-Pewee, and Great Crested Flycatcher. Resident species were also important including American Robin, Black-capped Chickadee, and Blue Jay. One group of species was commonly observed in more stressful or disturbed habitats - Black-throated Green Warbler, Black-and-White Warbler, Veery and Winter Wren. As mentioned previously, the cliff area was favoured by Common Raven which nested on the face. Mono Cliffs was the only site of record for this species in the study and it is one of the most southern breeding records for this species in Ontario (Cadman et al., 1987). Similarly, Northern Rough-winged Swallow used the cliff face for nest sites and Turkey Vulture frequently used the cliff face for roosting in the early morning. Hermit Thrush was observed throughout the canyon region but there were only a few records, suggesting this bird may not have bred in the region during the study period. Other birds of interest, because of their limited records in this study, were Blue-headed Vireo and Yellow-throated Vireo (*Vireo flavifrons*).

A.10 Alton

The Alton property is located to the west of the Escarpment in the upland drainage area of the Credit Valley watershed (Figure 4.2). This site is one of the two control sites, and is situated on public land administered by Credit Valley Conservation. It is primarily a low-lying area with the Credit River draining through the centre of the property. The river is surrounded by an extensive floodplain. In the upland areas, adjacent to the lowlands, there has been extensive reforestation with pine plantations. There are three transects: Transect 1 runs along the Credit River, following the stream channel (Figure A.14); Transect 2 is parallel to 1 and is located within the floodplain in an extensive eastern white cedar swamp; and Transect 3 is on the upper slope, also parallel to the river, and runs through a pine plantation. This site is situated beyond the Escarpment and was not part of the slope type complexes, however it could be considered as most similar to slope type C.

A.10.1 Alton Transect 1 - Valley

Geomorphology

This transect is situated along a low-energy stream channel. The slope angle was minimal, the transect was within the floodplain of the river, and consequently azimuth was

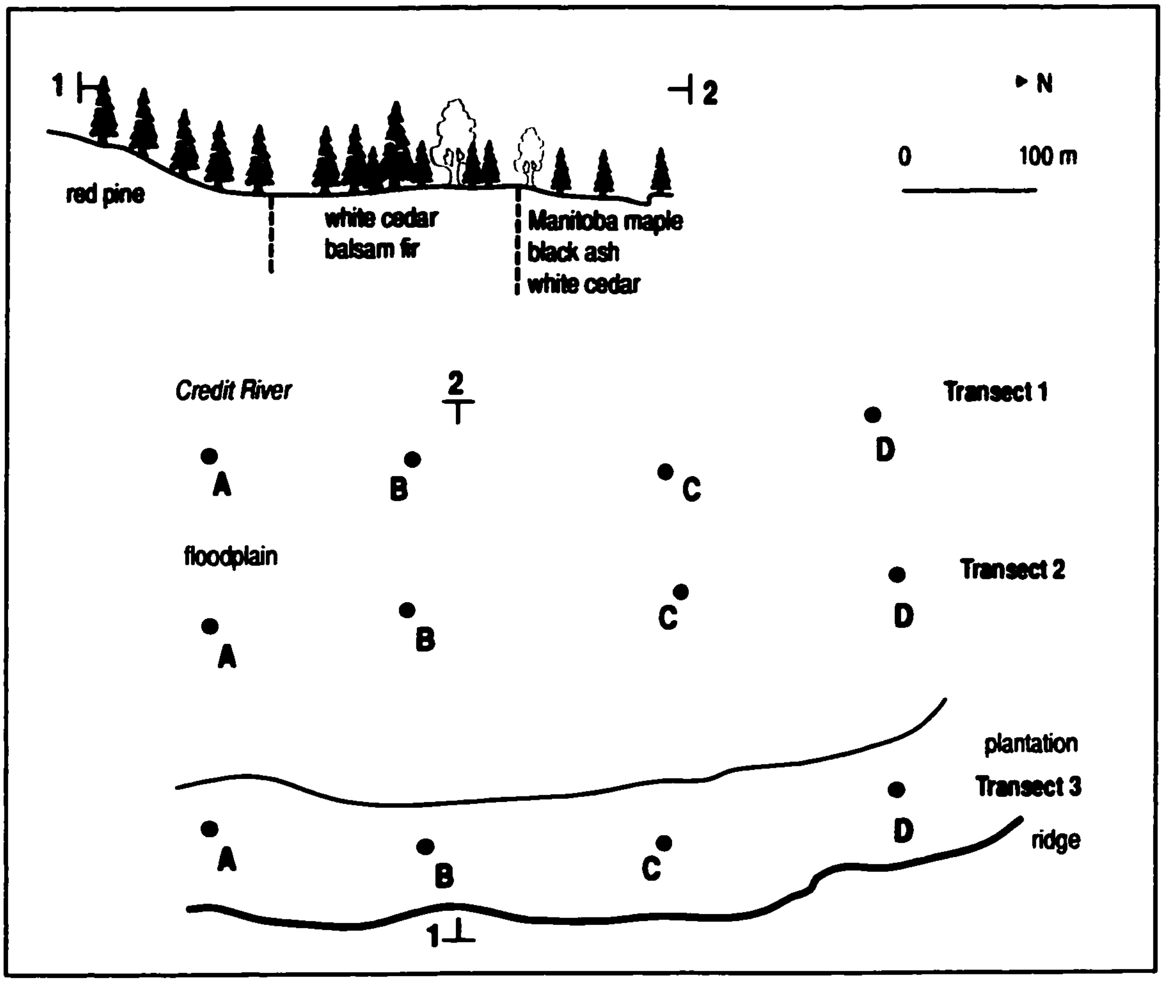


Figure A.14 Geomorphic processes, vegetation profiles and survey transects and stops at Alton.

not measured. The slope shape at each stop was considered as a plain. There was little evidence of current human disturbance; at stop A there was a rudimentary trail used by fishers but it was only sporadic at best through the transect. There was likely forest clearance in the past, as there are a number of open, savanna-like or wet meadow areas along the river channel which is becoming reforested (Figure A.15). Similar land units have been identified along the Credit River within the study area (Milne and Bennett, 2001). Natural disturbance was from periodic flooding. This was a low-energy stream compared to the channels draining off the Escarpment and there was minimal bank erosion and point bar development over the length of the transect. There is some meandering of the channel and bank erosion but this is not as great as in the Escarpment valleys. There was some evidence of bank overflow with small pondings, but this may be related to spring melt. There were no major flooding events during the research period.

Vegetation - Species

This transect passes through several different types of vegetation cover. At stops A and D, there were only a few isolated trees of black ash and Manitoba maple, located within an open meadow. These were relatively mature trees and there is little evidence that these sites are quickly filling in with other species. There was also an extensive cover of eastern white cedar and a combination of all three species at stop C. Several other species - balsam fir, American elm, and black cherry - had a minor role in the vegetation cover. In the lower, wetter areas of the floodplain the areas are filled in with a dense cedar canopy. The stream is lower-energy compared to some of the streams draining directly off the Escarpment and there is little evidence that there is much impact on the vegetation from fluvial processes.

Figure A.15 Credit River valley unit, Transect 1, Alton

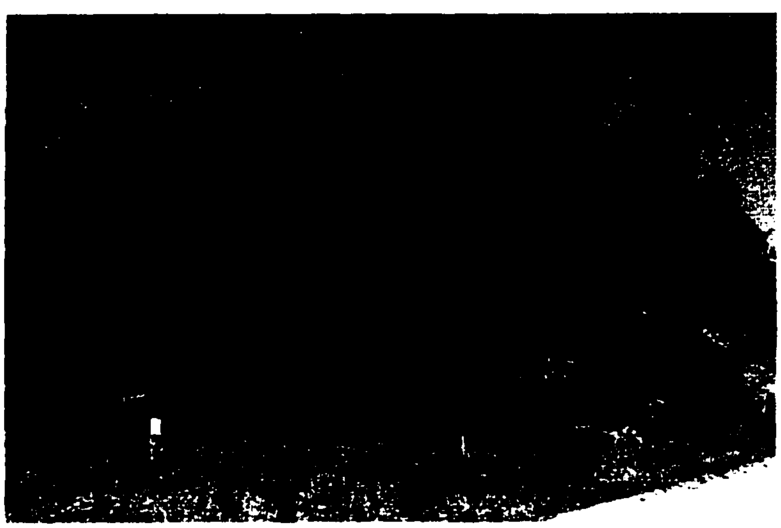


Figure A.16 Red pine (*Pinus rugosa*) plantation and small gap created by wind action, Transect 3, Alton.

Vegetation - Structure

This transect had a distinct forest structure because of the combination of species types and the previous disturbance regime. The age ratio was high for this transect at 70 and was fairly consistent between stops (Appendix L). The forest cover is close to a mixed forest with the ratio of old stems at 75. The new stems were slightly higher at 82. There were very few snags in this forest which is in keeping with the low density of trees and saplings. Stem density records were very low with some of the lowest scores recorded - old stems were 11, new stems were 5 and saplings were 2. This is also evident in the very low score for canopy cover at 14%. Of note is the high score for multistems and multistem area. These were some of the highest scores for all the transects, which is reflected in the concentration of eastern white cedar especially at stops B and C.

Bird Populations

This transect had one of the highest diversity and abundance of species records for the entire study. The higher IV scores were distributed between the resident and riparian species. Resident species included Black-capped Chickadee, which had high abundance scores and was observed during each site visit. Other residents included American Goldfinch, American Robin and Blue Jay. The riparian species with the highest score was Song Sparrow which also had high abundance scores and was observed during every survey period (Appendix L). Other important riparian species included House Wren, White-throated Sparrow, Northern Waterthrush, Mourning Warbler, Indigo Bunting, Common Yellowthroat and Winter Wren. Other important species were Black-throated Green Warbler and Cedar Waxwing. Of note for this site was the presence of several species directly dependent on the river course. These included Belted Kingfisher (*Ceryle* *alcyon*), Wood Duck, Spotted Sandpiper, Mallard and Great Blue Heron *(Ardea herodias*). Other species observed on this transect but not common during this study were Least Flycatcher, Mourning Dove (*Zenaida macroura*), Eastern Phoebe and Black-billed Cuckoo.

A.10.2 Alton Transect 2 - Swamp

Geomorphology

As with the river transect, Transect 2 is situated in the floodplain of the Credit River. It is primarily located on organic material and is poorly drained. There is minimal slope angle and no azimuth recordings were made. The site position at each stop was considered as a plain. There was no evidence of human disturbance along this transect, although the first stop (A) was in a clearing within the forest which may be related to previous land practices. There were several other areas near this stop that appeared to have been altered. Natural disturbance was related to moisture levels and to occasional windthrow. The rooting substrate was very poor, creating an unstable environment and increasing the chance for blowdown.

Vegetation - Species

This is a unique transect to this study. It is the only transect that runs through a lowland, poorly-drained coniferous swamp. The forest had a good diversity of tree species. The greatest variety of species is found at stop A. This is located in a small gap in the forest cover, in a wetter area where there was standing water in the summer. There was no dominant species but the site had trembling aspen, balsam fir, alder (*Alnus rugosa*), balsam poplar (Appendix L). Other species with more than one stem included white birch, black ash, and American elm. Over the rest of the transect the forest cover was more complete. The swamp is dominated by eastern white cedar which had IV values between 90 and 120 for stops B-D. Also important in this cover was balsam fir, with IVs between 50 - 70. Other species along the transect included tamarack and white spruce. Deciduous species included black ash, white birch, and trembling aspen. The upper canopy is made up of these less dominant trees which grow above the tops of the cedar and fir. This forest appears to be stable but there is individual tree replacement occurring from tree mortality and blowdown. There was one wind event, in the year following the study, which caused a certain amount of disruption to the tree cover, although this was more evident in the pine plantation (Transect 3).

Vegetation - Structure

The forest cover had an average age ratio at 55, however if stop A is removed from the calculation, however, the ratio rises to 70 which is similar to the river transect (Appendix L). This forest was a mixed forest but the deciduous ratio was quite low at 29 and 30 for the old and new stems respectively, and was dominated by eastern white cedar and other associated conifers. This transect had the highest number of snags for the study as well as one of the highest densities of old stems and relatively high densities of new stems and saplings. The old stem densities were higher in the closed portion of the transect while the sapling score was much higher in the open area at stop A. The low score for multistems was somewhat surprising given the concentration of cedar in this transect.

Bird Populations

This transect had an average value for richness (24), but was dominated by only a few species specific to the coniferous habitat. These included Red-breasted Nuthatch, Winter Wren, White-throated Sparrow and Yellow-rumped Warbler. The dominant species, however, was the resident Black-capped Chickadee which had a large IV, especially the abundance number (37). Other common residents included American Robin, Blue Jay and Brown Creeper. Scores for Ovenbird, which is usually considered a species of the deciduous forest-interior, were also high. Stop D was near to the western edge of the small plantation on Transect 3. Ovenbird was reliably recorded at this stop but these sightings may relate to the birds inhabiting the adjacent plantation. There were several other species not commonly found at many of the other transects. These included Blackburnian Warbler, Golden-crowned Kinglet, Nashville Warbler, Pine Warbler and Chipping Sparrow. Most of the forest cover on the transect was relatively homogeneous although the first stop was in a more open area of the swamp which accounted for some of the diversity of species. Species recorded in the opening included Canada Warbler, House Wren and Common Yellowthroat.

A.10.3 Alton Transect 3 - Plantation

Geomorphology

The plantation transect (3) was situated on a slope that graded to the lowland swamp and river with a slope angle of roughly 13° and an azimuth of 230° (Figure A.16). The slope material is primarily sandy till with no evidence of bedrock. The slope was approximately 40 m in length and the stops were nearer the upper slope where the shape was convex to straight. There was no strong natural disturbance although following the study period there was evidence of wind damage following a major storm event. Human disturbance is quite high since the forest cover was replaced with a plantation. It is apparent this area is not being managed and the forest is naturally regenerating, reducing the impact of human modification.

Vegetation - Species

This is an older red pine plantation that is not being managed. The dominant tree is red pine, with an IV ranging from 110-185 for the four stops. At stop 4 there were also a smaller number of white pine and green ash planted with the red pine and creating a more diverse canopy. There was also a high diversity in the understory as new species are replaced by older pines. The dominant understory tree was balsam fir, with a high density of small stems at each site. Stop A had the greatest mixture of species with Manitoba maple, white ash and many black cherry. This stop is in a small transition zone between a plantation on the slope and the lowland forest described for Transect 2. This forest is in a state of change, adjusting to the introduction of the plantation species and subsequent naturalization. As this forest matures and the trees are logged, of which there is past evidencet, or natural disturbance eliminates the canopy trees, the plantation species will be replaced by a mixture of balsam fir, black cherry and white ash.

Vegetation - structure

The process of natural regeneration is evident by the low age ratio of this forest (50%). Not surprisingly, this forest is predominantly coniferous, however, there were also some green ash, and therefore the ratio is slightly higher for the older stems than the other plantations in the study. This is not the case for the younger stems which had a ratio (27) which was much lower than the plantations at Palgrave. This is the due to a high concentration of balsam fir in the undergrowth, likely a result of the close proximity to the swamp where this species was a dominant component of the forest system. As with the other plantations there was a very low number of multistems as well as snags in this forest. However, there was higher density of old and new stems. Overall the irregular pattern of plantings and mixture of species created an open forest as evident from the 56% canopy cover.

Bird Populations

The plantation transect had an average score for richness (24). As with the swamp transect, this transect was dominated by Black-capped Chickadee with an abundance score of 31 and an overall IV of 21 (Appendix L). The bird population had a strong component of resident species including American Robin, Blue Jay, Brown Creeper, and American Crow. There were also several species, specific to the coniferous forests, including Red-breasted Nuthatch, Chipping Sparrow and Pine Warbler. As found in the swamp transect, Ovenbird was also important here. Several other species important in this habitat included Yellow-rumped Warbler and Winter Wren. This plantation is in a state of abandonment and naturalization which could account for the variety in species. This created a diverse mixture of tree species at some of the stops which attracted a variety of bird species. Of note, one season the large pines at stop D were used by a pair of Red-tailed Hawks for a nest site. Windthrow has created some gaps and growth of shrubs has attracted a variety of species. For example, at stop A there were records of Northern Cardinal, Red-winged Blackbird, Indigo Bunting and House Finch (*Carpodacus mexicanus*). This stop also had the greatest diversity of tree species and forest structure.

A.11 Palgrave

The site at Palgrave was located within a public forest managed by the Metro Toronto Conservation Authority. This is one of two sites that were used as controls for the study since it had a combination of upland forest and plantations. This site is located to the east and below the Escarpment slopes in an area of rolling topography and glacial deposits similar to the sites in the northern section of the study or to type C slope land units. There are four transects at this site. Transect 1 is located in an upland deciduous forest, while Transect 2 is located in a small lowland situated between two uplands. Transects 3 and 4 are located in upland coniferous plantations (Figure A.17). Only Transect 1 had four stops. The other three transects had only three stops because of the limited size of land cover for these habitats.

A.11.1 Palgrave Transect 1 - Upland

Geomorphology

This transect is in an area of glacial moraine in an undulating landscape which creates locally steep slopes. The slope angle varied considerably between stops and ranged from 6° to 24° with an average of 14° (Appendix M). The irregularity of the slopes is also evident in the aspect, which varied from northwest to southeast. Natural disturbance was limited to movement of soil downslope by creep and sheetwash. There was evidence of small gaps created from windthrow, and one major storm knocked down a number of trees during the research period. A portion of the transect was situated on a path that could be used by small motorized vehicles although there was little evidence of use during the study period. It is also likely the forest at stop D had been selectively logged in the past.

Vegetation - Species

This transect is situated within a mature upland deciduous forest. The results of the survey identify the dominance of sugar maple in this forest, with the highest value in

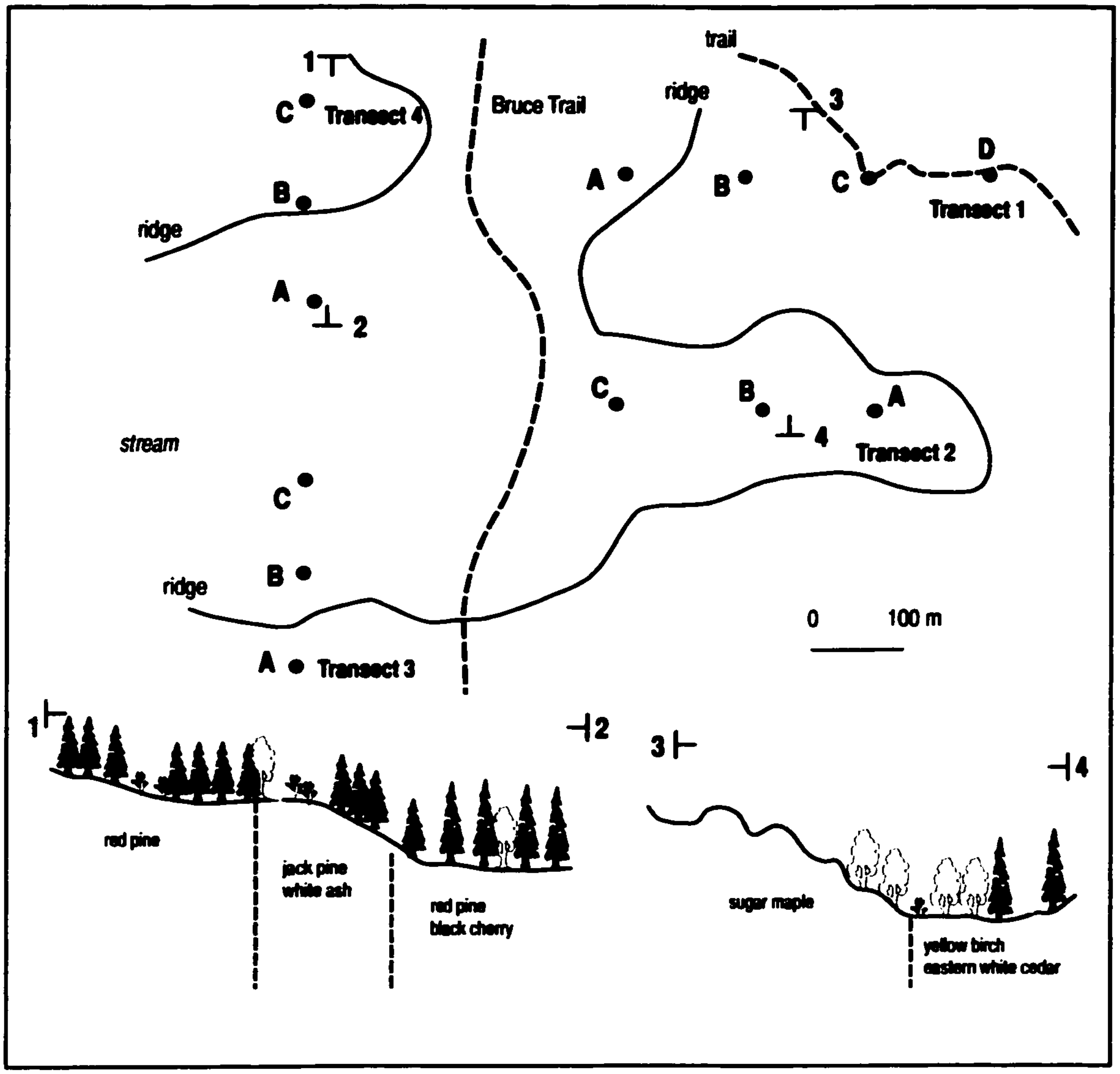


Figure A.17 Geomorphic processes, vegetation profiles and survey transects and stops at Palgrave.

three of the four stops (Appendix M). White ash is important at stops A and B, while American beech is a co-dominant at stop C. The forest appears to be in a stable state, with sugar maple dominating the different strata of the forest. However, there were several sites of disturbance which affect the structure of the forest. At stop A, a number of large maples were knocked down during a high wind storm, and at stop D areas around the trail have been cleared and the forest is regenerating with dense stands of maple saplings.

Vegetation - Structure

The forest along this transect was completely deciduous with scores of 100 for both old and new stem. It had a more equal ratio between old and new stems compared to some of the other upland deciduous forests. The density of all stems was average but the canopy cover was quite high. There were very low scores for multistems and multistem area as well as for snags.

Bird Populations

This transect had a low richness with only 18 species recorded (see Appendix M). These species were dominated by forest interior and resident species. As with other upland transects the transect was dominated by Red-eyed Vireo with a very high relative abundance score (30), more than double the next nearest score. Other interior species with high scores included Eastern Wood-Pewee, Scarlet Tanager, Wood Thrush, Ovenbird and Rose-breasted Grosbeak. Resident species also scored high, especially American Robin which had the third highest score. Also important were Blue Jay, Black-capped Chickadee and White-breasted Nuthatch. Of note is the presence of Black-throated Blue Warbler and the high score for Great Crested Flycatcher.

There were no obvious spatial relationships along the transect, except that the last stop is in a more open area where there has likely been some logging in the past. This might attract species more related to edge habitats such as the resident species. This effect has been more noticeable with data collected during other times of the year. At stop A, there was a small gap created from a windstorm which attracted Winter Wren during the migration season.

A.11.2 Palgrave Transect 2 - Valley

Geomorphology

This transect is situated in the low-lying drainage area between two slopes, and consequently the surface material is mainly organic deposits in a small valley floodplain. A small stream drained the area and it was often inundated with standing water especially during spring and early summer. There was minimal slope angle and no record for the azimuth. The slope shape was plain. There was little evidence of human disturbance on this transect although it was located close to several trails (30m). Natural disturbance was minimal and would be associated with seasonal moisture levels. Windthrow may have been a factor in the cedar stands but there was little evidence of storm events during the study period.

Vegetation - Species

The small area and its location between upland habitat creates a variable environment which is reflected in the diversity of species recorded here. Eleven tree species were identified with no real dominant species. Stop A also had a diverse cover and no dominant species. This site was located at the edge of the wetland and had a mixture of species found in the surrounding deciduous forest. Consequently, there were high numbers of red maple, sugar maple, American elm, eastern hemlock and white ash. It is possible this site had been disturbed at one time, since there were a large number of younger stems. Eastern white cedar was dominant at stop C in an area along the stream. It had a dense cover of cedars with many multi-stem trees. There were a few other species interspersed amongst these stems, including American elm and black ash. There were also single stems of basswood, white birch, and yellow birch. Stop D was in the centre of the wetland area and had the greatest diversity of trees - dominant ones were yellow birch, eastern white cedar, with black ash and American elm.

Vegetation - Structure

The forest on this transect had an old/young stem ratio of 51. It was a mixed forest with a deciduous ratio of 58 for both old and new stems, however this varied considerably between the three stops. At stop A the forest was, as mentioned, predominantly coniferous, while at stop C the old stems were 90% deciduous. In contrast the deciduous ratio for young stems was highest at stop B. This forest had high scores for multistem and multistem cover which may relate to the importance of cedar in this forest. It also had some of the highest densities of old and young stems as well as sapling density. In contrast it had a low score for snags.

Bird Populations

The bird populations for this transect were quite diverse but, as with the trees, there was considerable variation between surveys. Only one species, Black-capped Chickadee, was observed on each visit and in high numbers, and consequently scored the highest IV (26). Black-throated Green Warbler was the only other species observed on more than 50% of the visits but with only two or three individuals on any one visit, it had a lower IV (11). Other common species included American Robin and Blue Jay. Species indicative of this habitat included Ruffed Grouse, Red-breasted Nuthatch and Winter Wren. There were also good representation of deciduous forest interior species, likely from the nearby forest canopy as described in Transect 1. These included Eastern Wood-Pewee, Ovenbird, Scarlet Tanager, Red-eyed Vireo and Great Crested Flycatcher.

A.11.3 Palgrave Transect 3 - Plantation Upland One

Geomorphology

Transect 3 was on an upland area of glacial deposit and undulating hills of sand and till with no exposed bedrock. The transect sloped towards the east-northeast at an average angle of 8° and an azimuth reading between 15° and 46°. The slope then leveled off to a plain at stop C (Figure A.17). The slope shape changed from convex to concave and then plain from stop A to C. Natural disturbance was primarily from windthrow and there was one significant event during the study period at stop A. Otherwise there was little evidence of physical stress or disturbance, although the slopes do experience a certain amount of sheetwash and creep. These processes may be limited because of the thick layer of duff that develops beneath the pine canopy. Human disturbance was from forest removal and replanting with dense stands of pine. There was no evidence of current management but the arrangement of stems was more formal than the plantation described at Alton, indicating that this transect has been managed more rigorously in the past.

Vegetation - Species

This forest was a mature white pine plantation. Each stop was dominated by white pine in the canopy with IVs ranging from 80-200 (Appendix M). At stop A there was a mixture of white pine and jack pine. There were also some deciduous species - white ash and black cherry. At stops B and C, white pine was the only species in the sample. At all three stops, there was evidence the forest has been managed, but currently this forest appears to be in the initial stages of transition to a natural community as the pines die off. There is significant undergrowth that is primarily red-berried elder *(Sambucus pubens)*, especially at stops B and C. The wind event created a gap in the forest that initiated successional processes. As seen in Appendix M, there was already a presence of successional species at this stop, including white ash and black cherry.

Vegetation - structure

This transect had a very distinctive forest cover dominated by the formal strucutre of the pine plantation. It had one of the highest ratios of old to new stems, as evidenced by the high density of old stems and low density of young stems as well as a fairly high percentage of canopy cover (80%). There was little presence of deciduous trees along this transect. It had the lowest ratio of deciduous older stems but it did have a very high ratio within the young stems. This transect also had the lowest number of multistems for the study, which is typical of a managed plantation. There is some regeneration beginning at this site as is evident from the density of saplings (16).

Bird populations

This plantation transect at Palgrave had one of the lowest richness scores for all the transects, as might be expected within a monoculture. Consequently, the IV values are higher for the dominant species than some of the other transects. The highest value was recorded for Black-capped Chickadee, with a very high abundance score of 30 and overall IV of 23 (Appendix M). The other high-scoring resident species was Cedar Waxwing. Although there are records of this species for most transects, this is one of the few transects where the species had a large score. Species indicative of the coniferous cover included Yellow-rumped Warbler, Pine Warbler and Chipping Sparrow. As in the coniferous forests at Alton, Ovenbird had a high score.

There were some variations across the transect that created patterns in the populations. At the first stop, blowdown created a significant gap which attracted species such as Winter Wren and American Robin. At the second stop there was a dense undergrowth of red-berried elder which attracted species such as Rose-breasted Grosbeak.

A.11.4 Palgrave Transect 4 - Plantation Upland Two

Geomorphology

The transect for the second plantation is somewhat a mirror image of Transect 3. This transect also slopes to the wetland area on the opposite side of the stream channel, and has a lowland plain, a convex-concave slope, and an upland hill area (Figure A.17). The overall slope angle, 8°, is similar to Transect 3 but the slope faces to the south-southwest with azimuths ranging from 148° to 253°. The slope shape is straight to convex for the three stops with the steepest slope at stop B. This line is situated on material similar to Transect 3 with sand and till deposits. There is similar disturbance to this site, with some evidence of windthrow, but the main disturbance is from human alteration of the forest cover by replacing the natural forest with a pine plantation. This site does not appear to be actively managed but on the upper section of the slope there was some evidence of logging in the past. This area of the plantation is most typical of managed woodlots with little undergrowth and older trees in well ordered rows.

Vegetation - Species

Transect 4 is also situated in an upland plantation, but unlike transect 3, this plantation is a combination of red pine, white pine with a small pocket of jack pine (Appendix M). White pine is the dominant tree at stop A. This is an older stand with an extensive undergrowth of deciduous saplings, predominantly black cherry, white ash and American elm. In comparison, the upland has been planted with red pine. Stop A is on the ridge of the upland, where the slope has been planted with jack pine. Stop B is on the edge of a blowdown within the jack pine patch and consequently is a combination of red pine, jack pine and successional species such as white ash and black cherry. Between stops B and C is a mature red pine forest that appears to have been managed recently, as there are few trees or shrubs in the undergrowth. Stop C is a young, densely-planted red pine forest with no other species in the canopy or undergrowth.

Vegetation - Structure

This transect had a lower ratio of old stems compared to Transect 3 because of the low concentration of older stems at stop B, which is in an area of windthrow and there is presently natural regeneration occurring. The ratio at this stop is only 36 which skews the overall average. This stop also accounts for the higher deciduous ratio compared to Transect 3. This transect had the highest number of saplings of all the transects, which is surprising since it is a plantation. There were a large number of deciduous saplings in the undergrowth of stop A and to a lesser extent in the open area of stop B. This suggests a change in the structure of the forest as the older pines die off or are removed. This transect also had a low number of multistems, although it was higher than the other two plantations and some of the mature deciduous upland forests.

Bird Populations

The highest value was for Pine Warbler which is associated with the red and white pines of the plantation. Other species associated specifically with this habitat include Red-breasted Nuthatch and Chipping Sparrow. Deciduous forest interior species were also present including high scores for Ovenbird and Eastern Wood-Pewee. Some of the highest scores were recorded by the resident species including Black-capped Chickadee and Blue Jay. American Robin also scored relatively high (see Appendix M).

There was a certain variability along this transect as each stop had differences in species composition and forest structure. The first stop had a strong undergrowth of deciduous shrubs. In this area, forest interior species such as Eastern Wood-Pewee, Wood Thrush and Scarlet Tanager were observed. At the second stop, the forest appeared to be more managed except for a few patches of undergrowth. In one of these areas a pair of Northern Goshawk (*Accipiter gentilis*) had nested during one season. In the open area of pines there was a pair of Blue-headed Vireo. Both these species were very rare during the study period. At the second stop, the gap attracted a variety of species which accounted for the higher diversity at this site. Some of these species included Black-and-white Warbler, Black-throated Green Warbler and Northern Flicker (*Colaptes auratus*). The third stop was very densely planted and there were few records of any species at this stop.

APPENDIX B

BIRD AND VEGETATION SPECIES CODE KEYS

BIRD SPECIES CODE KEY

Code	Bird Species
amcr	American Crow
amgo	American Goldfinch
amre	American Redstart
amro	American Robin
baor	Baltimore Oriole
bbcu	Black-billed Cuckoo
bcch	Black-capped Chickadee
beki	Belted Kingfisher
bhco	Brown-headed Cowbird
bhvi	Blue-headed Vireo
blww	Blue-winged Warbler
blja	Blue Jay
blwa	Blackburnian Warbler
bobo	Bobolink
brcr	Brown Creeper
btbw	Black-throated Blue Warbler
btgw	Black-throated Green Warbler
bwwa	Black-and-white Warbler
cago	Canada Goose
cawa	Canada Warbler
cewa	Cedar Waxwing
chsp	Chipping Sparrow
cogr	Common Grackle
coha	Cooper's Hawk
cora	Common Raven
coye	Common Yellowthroat
cswa	Chestnut-sided Warbler
dowo	Downy Woodpecker
eaki	Eastern Kingbird
eaph	Eastern Phoebe
eato	Eastern Towhee
ewpe	Eastern Wood-Pewee
fisp	Field Sparrow
gbhe	Great Blue Heron
gcfl	Great Crested Flycatcher
gcki	Golden-crowned Kinglet
ghow	Great Horned Owl
grca	Gray Catbird
gwwa	Golden-winged Warbler
hawo	Hairy Woodpecker
heth	Hermit Thrush

Code	Bird Species
hofi	House Finch
howr	House Wren
inbu	Indigo Bunting
lefl	Least Flycatcher
mall	Mallard
mawa	Magnolia Warbler
modo	Mourning Dove
mowa	Mourning Warbler
nawa	Nashville Warbler
noca	Northern Cardinal
nofl	Northern Flicker
noor	Northern Oriole
nowa	Northern Waterthrush
oven	Ovenbird
piwa	Pine Warbler
piwo	Pileated Woodpecker
rbgr	Rose-breasted Grosbeak
rbnu	Red-breasted Nuthatch
revi	Red-eyed Vireo
rsha	Red-shouldered Hawk
rtha	Red-tailed Hawk
rthu	Ruby-throated Hummingbird
rugr	Ruffed Grouse
rwbl	Red-winged Blackbird
rwsw	Northern Rough-winged Swallow
scta	Scarlet Tanager
sosp	Song Sparrow
spsa	Spotted Sandpiper
ssha	Sharp-shinned Hawk
trsw	Tree Swallow
tuvu	Turkey Vulture
veer	Veery
wbnu	White-breasted Nuthatch
wiwr	Winter Wren
wodu	Wood Duck
wtsp	White-throated Sparrow
woth	Wood Thrush
ybsa	Yellow-bellied Sapsucker
yrwa	Yellow-rumped Warbler
ytvi	Yellow-throated Vireo

VEGETATION SPECIES CODE KEY

Code	Vegetation Species
alde	alder
aldo	alternate-leaved dogwood
ambe	American beech
amel	American elm
appl	apple
bafi	balsam fir
bapo	balsam poplar
bass	basswood
bihi	bitternut hickory
blas	black ash
blbe	blue beech
blch	black cherry
buck	buckthorn
butt	butternut
doha	downy hawthorn
eahe	eastern hemlock
ewce	eastern white cedar
gras	green ash
grdo	gray dogwood
iron	ironwood

Code	Vegetation Species
japi	jack pine
ltas	large-toothed aspen
mama	Manitoba maple
moma	mountain maple
ntha	narrow-leaved hawthorn
rema	red maple
reoa	red oak
repi	red pine
sewi	serviceberry
shwi	shining willow
sima	silver maple
suma	sugar maple
tama	tamarack
tras	trembling aspen
whas	white ash
whbi	white birch
whpi	white pine
whsp	white spruce
will	willow sp
yebi	yellow birch

APPENDIX C

SPEYSIDE UPLAND ONE
SPEYSIDE UPLAND TWO

Speyside Upland One (Swamp)

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	19	1	2	1	5	1
B	10	16	1	2	1	1	1
C	10	16	1	2	2	5	1
Total	10	17	1	2	1.33	3.67	0.67

Vegetational Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	18.8	100	92.3	2.2	2.7	12	9	36	20	66.3	20
B	100	100	na	4.8	12.4	5	23	0	22	16.3	90
C	47.2	100	84.2	19.2	37.4	8	17	19	11	1	80
Total	55.33	100.00	58.83	8.73	17.50	8.33	16.33	18.33	17.67	27.87	63.33

Vegetation Species Parameters

Tree Species	Density					Cover					Frequency	Importance Value Density + Cover
	Stops			Total	Relative	Stops			Total	Relative		
	1	2	3			1	2	3				
amel	1		1	2	1.85	7.5		5.5	13	0.75	2	2.60
bass	2	1		3	2.78	13	35		48	2.76	2	5.54
blas	1		2	3	2.78	4		13	17	0.98	2	3.76
blch	2			2	1.85	10			10	0.58	1	2.43
eahe	2		3	5	4.63	17		21	38	2.19	2	6.82
sima			23	23	21.30			483.5	483.5	27.84	1	49.13
suma	7	18		25	23.15	184	486		670	38.57	2	61.72
whas	32	4		36	33.33	253	138		391	22.51	2	55.84
yebi			9	9	8.33			66.5	66.5	3.83	1	12.16
Total				108	100				1737	100.00	15	200.00

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	21/06/96	04/07/96	19/07/99	26/06/97	10/07/97	01/07/98	15/06/98	28/05/99	average abundance	relative abundance	frequency	relative frequency	importance value
amco								1	0.13	0.75	1	1.20	0.98
amgo								1	0.13	0.75	1	1.20	0.98
amro		2		1	1		1		0.63	3.73	4	4.82	4.28
bcch	1	1			4	1			0.88	5.22	4	4.82	5.02
bhco	1						2		0.38	2.24	2	2.41	2.32
blja			1	2	1			2	0.75	4.48	4	4.82	4.65
brcr	1	1		1			1		0.50	2.99	4	4.82	3.90
bwha								1	0.13	0.75	1	1.20	0.98
cewa								1	0.13	0.75	1	1.20	0.98
cogr			1						0.13	0.75	1	1.20	0.98
dowo		1			3			1	0.63	3.73	3	3.61	3.67
ewpe	3	3	1	2	1	1	2	1	1.75	10.45	8	9.64	10.04
gcfl	2		3	2	1			3	1.38	8.21	5	6.02	7.12
grca		1							0.13	0.75	1	1.20	0.98
nofl		2					1		0.38	2.24	2	2.41	2.32
nowa	2			1			3	1	0.88	5.22	4	4.82	5.02
oven	2	2		3	1	3		4	1.88	11.19	6	7.23	9.21
rbgr	1	1		1	1				0.50	2.99	4	4.82	3.90
revi		2	3	2	3		1	4	1.88	11.19	6	7.23	9.21
rwbl						1			0.13	0.75	1	1.20	0.98
scta	1						1		0.25	1.49	2	2.41	1.95
veer	1		3	1	2			3	1.25	7.46	5	6.02	6.74
wbnu	2		1		2			1	0.75	4.48	4	4.82	4.65
wiwr		1		1					0.25	1.49	2	2.41	1.95
wodu	1						1	2	0.50	2.99	3	3.61	3.30
woth			1	1	1				0.38	2.24	3	3.61	2.93
ybsa						1			0.13	0.75	1	1.20	0.98
Total									16.75	100.00	83	100.00	100.00

Speyside Upland Two (Trail)

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	12	1	2	1	2	1
B	10	17	1	2	1	2	1
C	10	15	1	2	2	2	1
D	10	18	1	2	2	2	1
E	10	18	1	2	2	2	1
F	8	17	1	2	1	2	4
Total	9.67	16.17	1	2	1.5	2	0.67

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	46.6	33.3	54.8	3.6	4	6	18	31	17	56.3	90
B	58.8	90	85.7	15.4	30.9	1	9	6	na	na	na
C	42.6	100	96.3	15.4	21.5	4	20	26	31	50	nd
D	68.9	100	100	16.7	28.5	9	31	14	41	4	90
E	35	100	100	2.6	11.2	1	14	26	nd	nd	nd
F	29.5	100	100	10.5	40.8	4	13	31	nd	nd	nd
Total	46.90	87.22	89.47	10.70	22.82	4.17	17.50	22.33	29.67	36.77	90.00

Vegetation Species Parameters

Tree Species	Density								Cover								Frequency	Importance Value Density + Cover
	stop						total	relative	stop						total	relative		
	1	2	3	4	5	6			1	2	3	4	5	6				
amel		2	5	6	1	1	15	5.75		37	44	51	11	7	150	4.59	5	10.33
bass				2		1	3	1.15				36.5		4	40.5	1.24	2	2.39
bihi						1	1	0.38						4.5	4.5	0.14	1	0.52
blbe	1						1	0.38	7						7	0.21	1	0.60
eahe	32						32	12.26	347.5						347.5	10.63	1	22.89
ewce		2	1				3	1.15		34.5	9				43.5	1.33	2	2.48
gras		3					3	1.15		27					27	0.83	1	1.98
iron				2	1	2	5	1.92				33.5	14.5	13.5	61.5	1.88	3	3.80
rema			23				23	8.81			196				196	5.99	1	14.81
sima		4	16				20	7.66		114.5	407.5				522	15.96	2	23.63
suma	4			30	25	48	107	41.00	116			522	199.5	383.5	1221	37.34	4	78.34
whas	20			4	6	1	31	11.88	244			71	62.5	4	381.5	11.67	4	23.54
whbi			1		6		7	2.68			7.5		156		163.5	5.00	2	7.68
yebi	1	6	1	1	1		10	3.83	19	46	6	16	17.5		104.5	3.20	5	7.03
Total							261	100							3270	100	34	200

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	21/06/96	04/07/96	19/07/99	26/06/97	10/07/97	01/07/98	15/06/98	28/05/99	average abundance	relative abundance	frequency	relative frequency	importance value
amre	1								0.13	0.53	1	0.99	0.76
amro			2	1	2	1		1	0.88	3.72	5	4.95	4.34
baor	1	1							0.25	1.06	2	1.98	1.52
bcch		1	1			8	1	3	1.75	7.45	5	4.95	6.20
bhco		1		1					0.25	1.06	2	1.98	1.52
blja	4	1						1	0.75	3.19	3	2.97	3.08
bwha								1	0.13	0.53	1	0.99	0.76
cago	1								0.13	0.53	1	0.99	0.76
cewa						1			0.13	0.53	1	0.99	0.76
cogr		20	1				1		2.75	11.70	3	2.97	7.34
dowo	2	1	1		1				0.63	2.66	4	3.96	3.31
ewpe	1	1	1					1	0.50	2.13	4	3.96	3.04
gcfl		2	1	2			1	2	1.00	4.26	5	4.95	4.60
hawo							2	1	0.38	1.60	2	1.98	1.79
mawa								1	0.13	0.53	1	0.99	0.76
mowa					1	1			0.25	1.06	2	1.98	1.52
noca						1			0.13	0.53	1	0.99	0.76
nofl					1			1	0.25	1.06	2	1.98	1.52
nowa	5	2		4	2	3	2	2	2.50	10.64	7	6.93	8.78
oven	1		1	3	2	4	2	2	1.88	7.98	7	6.93	7.45
rbgr	3	1		1		2	2	3	1.50	6.38	6	5.94	6.16
revi	1		2	2	2	1	2	6	2.00	8.51	7	6.93	7.72
rthu	1								0.13	0.53	1	0.99	0.76
scta	1				1	1			0.38	1.60	3	2.97	2.28
sosp		1		1	1	1		1	0.63	2.66	5	4.95	3.81
veer	1	4		1	2		1	3	1.50	6.38	6	5.94	6.16
wbnu			1		3	1	1	1	0.88	3.72	5	4.95	4.34
wiwr				3	1				0.50	2.13	2	1.98	2.05
woth					1		2	1	0.50	2.13	3	2.97	2.55
ybsa	2			2			1	1	0.75	3.19	4	3.96	3.58
Total									23.50	100.00	101	100.00	100.00

APPENDIX D

LIMEHOUSE UPPER RIDGE
LIMEHOUSE FIELD
LIMEHOUSE LOWER RIDGE
LIMEHOUSE VALLEY

Limehouse Upper Ridge

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	9	11	2	2	1	2	1
B	9	17	2	2	3	2	1
C	5	18	2	2	3	2	1
D	10	16	2	2	3	2	2
Total	8.25	17	2	2	2.5	2	1.33

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	33.8	100	100	18.2	39.7	6	24	47	30	77.5	50
B	100	100	na	31.3	53.9	6	22	0	7	20.3	100
C	83.3	100	100	0	0	1	10	2	6	60	nd
D	27.7	83.3	95.7	18.9	26.1	1	18	47	44	15	100
Total	61.20	95.83	98.57	17.10	29.93	3.5	18.50	24.00	21.75	43.20	83.33

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe			1		1	0.60			22		22	0.96	1	1.56
amel				1	1	0.60				5	5	0.22	1	0.81
bass	3				3	1.79	19				19	0.83	1	2.62
bihi		2			2	1.19		50			50	2.18	1	3.37
blch	2			5	7	4.17	10.5			53.5	64	2.80	2	6.96
buck	6				6	3.57	34				34	1.49	1	5.06
doha	17			15	32	19.05	122.5			100	222.5	9.72	2	28.77
moma			1		1	0.60			4		4	0.17	1	0.77
reoa				14	14	8.33				143.5	143.5	6.27	1	14.60
suma	4	20	10	19	53	31.55	52.5	518	304	134	1008.5	44.05	4	75.60
whas	27			6	33	19.64	235.5			74.5	310	13.54	2	33.18
whbi	10				10	5.95	320				320	13.98	1	19.93
whpi				5	5	2.98				87	87	3.80	1	6.78
Total					168	100					2289.5	100	19	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	03/06/99	14/06/96	10/07/96	28/05/97	14/07/97	14/06/98	14/07/99	23/06/97	01/07/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr	1	4	3	1						1.00	6.34	4	4.82	5.58
amgo				3	2	2				0.78	4.93	4	4.82	4.87
amro			1		1	1		1		0.44	2.82	4	4.82	3.82
bcch		2	3	4				2		1.22	7.75	4	4.82	6.28
bhco	1									0.11	0.70	1	1.20	0.95
blja		3	1		1		1	4		1.11	7.04	5	6.02	6.53
blww				1						0.11	0.70	1	1.20	0.95
cago		1								0.11	0.70	1	1.20	0.95
cewa				2						0.22	1.41	1	1.20	1.31
coye			1							0.11	0.70	1	1.20	0.95
dowo				1	1					0.22	1.41	2	2.41	1.91
eato				1						0.11	0.70	1	1.20	0.95
ewpe	1	2	1		1	2	1	1		1.00	6.34	7	8.43	7.39
fisp		1		1						0.22	1.41	2	2.41	1.91
gcfl		1		1	1	1		1		0.56	3.52	5	6.02	4.77
hawo						1				0.11	0.70	1	1.20	0.95
inbu	1	5		2		2		2	3	1.67	10.56	6	7.23	8.90
modo						1				0.11	0.70	1	1.20	0.95
noca		2	1			1				0.44	2.82	3	3.61	3.22
nofl						2	1			0.33	2.11	2	2.41	2.26
oven	1			2		1	1	2	1	0.89	5.63	6	7.23	6.43
piwa									1	0.11	0.70	1	1.20	0.95
rbgr							2		1	0.33	2.11	2	2.41	2.26
revi	4	5	1	3	3	3	3	3	3	3.11	19.72	9	10.84	15.28
wbnu		1		1	2	1	1			0.67	4.22	5	6.02	5.12
wodu				2						0.22	1.41	1	1.20	1.31
woth		1		1					2	0.44	2.82	3	3.61	3.22
Total										15.78	99.99	83	100	99.99

Limehouse Field

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	15	1	2	1	4	4
B	10	16	1	2	1	4	4
C	10	15	1	2	1	4	4
D	10	17	1	2	1	4	4
Total	10	15.75	1	2	1	4	4

Vegetational Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	3.5	100	100	25	53.3	0	8	35	30	92.5	8
B	8.1	100	100	20	36.7	2	6	68	45	95	50
C	2.9	100	100	10	17	5	2	67	75	90	70
D	22.9	72.7	100	10	14.9	4	11	37	17	95	15
Total	9.35	93.18	100.00	16.25	30.48	2.75	6.75	51.75	41.75	93.13	35.75

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel		3	8	10	21	8.97		31	72	129.5	232.5	14.28	3	23.25
appl	10	4	14	6	34	14.53	75	19	73	36.5	203.5	12.50	4	27.03
nlha				3	3	1.28				14	14	0.86	1	2.14
suma	1	21	2	3	27	11.54	5	103	10	14	132	8.11	4	19.64
whas	32	46	45	23	146	62.39	257.5	282.5	285.5	143.5	969	59.50	4	121.90
whpi				3	3	1.28				77.5	77.5	4.76	1	6.04
Total					234	100					1628.5	100	17	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	03/06/99	14/06/96	10/07/96	28/05/97	14/07/97	14/06/98	14/07/99	23/06/97	01/07/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr	3	3	1		1				1	9	5.23	5	4.85	5.04
amgo		1					1			2	1.16	2	1.94	1.55
amre					1			2		3	1.74	2	1.94	1.84
amro			1	2		1	3	2		9	5.23	5	4.85	5.04
baor				1						1	0.58	1	0.97	0.78
bcch	1	2	1	3	1		2	1	4	15	8.72	8	7.77	8.24
bhco	1	1		1				1		4	2.33	4	3.88	3.10
blja		1						1	2	4	2.33	3	2.91	2.62
blww	1	2					1	4		8	4.65	4	3.88	4.27
bobo				1				1		2	1.16	2	1.94	1.55
btbw					2					2	1.16	1	0.97	1.07
cewa							2			2	1.16	1	0.97	1.07
coye	1	1		2	1		3	1	1	10	5.81	7	6.80	6.31
cswa								1	1	2	1.16	2	1.94	1.55
dowo							1			1	0.58	1	0.97	0.78
eaki				1		1				2	1.16	2	1.94	1.55
eato				4				2		6	3.49	2	1.94	2.72
fisp		1	2		3	1		3	2	12	6.98	6	5.83	6.40
gcfl		1	2							3	1.74	2	1.94	1.84
grca			1		1	1			1	4	2.33	4	3.88	3.10
gwwa				3	2					5	2.91	2	1.94	2.42
inbu	3	2	2	2	1	1	6	2	3	22	12.79	9	8.74	10.76
mawa				2						2	1.16	1	0.97	1.07
modo								1	1	2	1.16	2	1.94	1.55
mowa	1									1	0.58	1	0.97	0.78
nawa				4						4	2.33	1	0.97	1.65
noca	1	2	1				3		2	9	5.23	5	4.85	5.04
nofl								1		1	0.58	1	0.97	0.78
oven						1			2	3	1.74	2	1.94	1.84
piwa					1	1				2	1.16	2	1.94	1.55
rbgr			1							1	0.58	1	0.97	0.78
revi		1								1	0.58	1	0.97	0.78
rthu									1	1	0.58	1	0.97	0.78
rwbl						2				2	1.16	1	0.97	1.07
sosp	3	3	2	1	1	1	1	1	2	15	8.72	9	8.74	8.73
Total										172	100.00	103	100.00	100.00

Limehouse Lower Ridge

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	15	2	2	1	4	1
B	10	16	2	2	1	4	1
C	10	17	2	2	1	4	1
D	10	16	2	2	1	4	1
Total	10	16	2	2	1	4	1

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	46.6	39	83	18.1	28.9	23	41	47	3	6.3	90
B	55.8	16.3	55.9	5.6	7.8	28	43	34	1	0.5	90
C	44.2	56.5	93.1	25	32.7	0	23	29	6	30.3	80
D	55.6	30	70.8	15.6	16.8	14	30	24	4	22.5	nd
Total	50.55	35.45	75.70	16.08	21.55	16.25	34.25	33.50	3.50	14.90	86.67

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel	4		1		5	1.85	63.5		6.5		70	2.05	2	3.90
appl	40	16	6	1	63	23.25	350	126.5	46	9.5	532	15.58	4	38.83
blch		4			4	1.48		22.5			22.5	0.66	1	2.13
buck	5		2		7	2.58	32		11.5		43.5	1.27	2	3.86
doha	4		21	22	47	17.34	26		184.5	195.5	406	11.89	3	29.23
ewce				1	1	0.37				4	4	0.12	1	0.49
nlha	1			1	2	0.74	5			14	19	0.56	2	1.29
suma		5	1	2	8	2.95		48.5	5	11.5	65	1.90	3	4.86
whas	1	1	9		11	4.06	8	7.5	100.5		116	3.40	3	7.46
whpi	33	51	12	27	123	45.39	515	787	335	499.5	2136.5	62.57	4	107.96
Total					271	100					3414.5	100	25	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	03/06/99	14/06/96	10/07/96	28/05/97	14/07/97	14/06/98	14/07/99	23/06/97	01/07/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr	1	1						3		0.56	4.31	3	4.62	4.46
amgo	2						1			0.33	2.59	2	3.08	2.83
amro			1		1	1	3	2	5	1.44	11.21	6	9.23	10.22
bcch	4		3	3	4	7	4	1	7	3.67	28.45	8	12.31	20.38
bhco	1									0.11	0.86	2	3.08	1.97
blja	1	1	2	1		2	1		1	1.00	7.76	7	10.77	9.26
blww				1				1		0.22	1.72	2	3.08	2.40
btgw		1								0.11	0.86	1	1.54	1.20
cewa							2			0.22	1.72	1	1.54	1.63
coye			1	2						0.33	2.59	2	3.08	2.83
dowo	1									0.11	0.86	1	1.54	1.20
ewpe							1			0.11	0.86	1	1.54	1.20
gcfl			3	1						0.44	3.45	2	3.08	3.26
gwwa				1						0.11	0.86	1	1.54	1.20
hawo							1			0.11	0.86	1	1.54	1.20
inbu		2	2		2		3	2		1.22	9.48	5	7.69	8.59
modo								1		0.11	0.86	1	1.54	1.20
nawa				1						0.11	0.86	1	1.54	1.20
noca	1		1				1	1	1	0.56	4.31	5	7.69	6.00
nofl							1			0.11	0.86	1	1.54	1.20
oven									1	0.11	0.86	1	1.54	1.20
piwa	2		2	1		1	2		2	1.11	8.62	6	9.23	8.93
rbgr				1						0.11	0.86	1	1.54	1.20
revi		1								0.11	0.86	1	1.54	1.20
rthu							1			0.11	0.86	1	1.54	1.20
scta							1			0.11	0.86	1	1.54	1.20
sosp								2		0.22	1.72	1	1.54	1.63
Total										12.89	99.99	65	100	100.00

Limehouse Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	1	15	4	2	3	1	3
B	0	16	4	2	3	2	3
C	10	15	4	2	3	1	4
D	10	16	4	2	3	1	4
Total	5.25	15.5	4	2	3	1.25	3.5

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	55.9	42.1	78.6	0	0	0	19	14	18	20	nd
B	80	100	100	11.1	23.2	5	16	4	7	5.3	nd
C	78.1	16	28.6	17.9	30.3	1	25	7	0	57.5	40
D	66.1	70.3	100	3.9	10.6	9	37	19	5	70	90
Total	70.03	57.10	76.80	8.23	16.03	3.75	24.25	11.00	7.50	38.20	65.00

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel				38	38	26.95				532	532	19.79	1	46.74
appl				3	3	2.13				38	38	1.41	1	3.54
blch	2		2		4	2.84	11		22		33	1.23	2	4.06
doha			2	1	3	2.13			18.5	8	26.5	0.99	2	3.11
eahe				2	2	1.42				32	32	1.19	1	2.61
ewce	1		25	9	35	24.82	11		587	156.5	754.5	28.06	3	52.89
iron				1	1	0.71				25.5	25.5	0.95	1	1.66
suma	9	20	2		31	21.99	270.5	522.5	17.5		810.5	30.15	3	52.13
whas	8			1	9	6.38	60			6	66	2.45	2	8.84
whbi				1	1	0.71				26	26	0.97	1	1.68
whpi	13		1		14	9.93	310.5		34		344.5	12.81	2	22.74
Total					141	100					2688.5	100	19	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	03/06/99	14/06/96	10/07/96	28/05/97	14/07/97	14/06/98	14/07/99	23/06/97	01/07/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr								2		0.22	2.27	1	1.96	2.12
amro						1	2	1	3	0.78	7.95	4	7.84	7.90
bcch	1	1		3		5	7	2	4	2.56	26.13	7	13.73	19.93
blja	2	2	3	1					1	1.00	10.22	5	9.80	10.01
blwa				1						0.11	1.14	1	1.96	1.55
btgw		1								0.11	1.14	1	1.96	1.55
chsp							2			0.22	2.27	1	1.96	2.12
coye							1			0.11	1.14	1	1.96	1.55
ewpe		3					1	1		0.56	5.68	3	5.88	5.78
gcfl			2							0.22	2.27	1	1.96	2.12
hawo	1									0.11	1.14	1	1.96	1.55
inbu						3	2			0.56	5.68	2	3.92	4.80
modo		1								0.11	1.14	1	1.96	1.55
noca	1									0.11	1.14	1	1.96	1.55
oven					1					0.11	1.14	1	1.96	1.55
piwa		1	1	1		1		1	2	0.78	7.95	6	11.76	9.86
rbgr	1	1		1						0.33	3.41	3	5.88	4.65
revi	2	1	2	1			4		1	1.22	12.50	6	11.76	12.13
rthu					1					0.11	1.14	1	1.96	1.55
rwbl					1					0.11	1.14	1	1.96	1.55
scta							1			0.11	1.14	1	1.96	1.55
sosp									1	0.11	1.14	1	1.96	1.55
wbnu		1								0.11	1.14	1	1.96	1.55
Total										9.78	99.97	51	100	99.98

APPENDIX E

SILVER CREEK UPLAND
SILVER CREEK RIM
SILVER CREEK SLOPE
SILVER CREEK VALLEY

Silver Creek Upland

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	17	1	2	1	1	4
B	10	18	1	2	1	1	4
C	10	16	1	2	1	1	4
D	10	17	1	2	1	1	4
Total	10	17	1	2	1	1	4

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	73.5	88	100	17.2	19.5	3	25	9	0	47.5	100
B	62.5	100	100	38.9	45.4	25	33	20	5	28.8	95
C	62.5	100	100	4.3	5.8	4	15	9	42	58.8	85
D	84.2	100	100	11.8	18.7	3	16	3	1	51.3	90
Total	70.68	97.00	100.00	18.05	22.35	8.75	22.25	10.25	12.00	46.60	92.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
bass	3				3	2.34	43				43	1.87	2	4.22
bihi		1	2	2	5	3.91		26.5	75	63.5	165	7.18	3	11.09
blbe			3		3	2.34			15.5		15.5	0.67	1	3.02
blch		2		1	3	2.34		38		28	66	2.87	2	5.22
ewce	3				3	2.34	38				38	1.65	1	4.00
iron	14	5	2		21	16.41	183	35	10.5		228.5	9.95	2	26.35
reoa	1	2	3		6	4.69	25.5	41	100		166.5	7.25	3	11.94
suma	11	38	13	13	75	58.59	273.5	648.5	268	273	1463	63.69	4	122.29
whas		5	1	1	7	5.47		67.5	7.5	4	79	3.44	3	8.91
whbi	2				2	1.56	32.5				32.5	1.41	1	2.98
Total					128	100					2297	100	22	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	02/07/98	11/07/97	12/07/96	06/06/97	26/06/96	27/05/96	15/07/99	19/06/98	08/06/99	average abundance	relative abundance	frequency	relative frequency	importance value
amgo			1				1			0.22	1.80	2	3.08	2.44
amro	3	2					1	2	1	1.00	8.11	5	7.69	7.90
bcch	3		1					6	1	1.22	9.91	4	6.15	8.03
bhco									1	0.11	0.90	1	1.54	1.22
blja				1		1				0.22	1.80	2	3.08	2.44
brcr	1									0.11	0.90	1	1.54	1.22
bwwa									1	0.11	0.90	1	1.54	1.22
coye									1	0.11	0.90	1	1.54	1.22
dowo	1		2		1					0.44	3.60	3	4.62	4.11
ewpe	2	1	1	1	1	2	2	2	2	1.56	12.61	9	13.85	13.23
gcfl		1	1		1			1	1	0.56	4.50	5	7.69	6.10
hawo			1					1		0.22	1.80	2	3.08	2.44
nofl									1	0.11	0.90	1	1.54	1.22
oven	3		1	2	1	1		3		1.22	9.91	6	9.23	9.57
revi	4	3	2	4	3	5	2	2	6	3.44	27.93	9	13.85	20.89
rwbl				1						0.11	0.90	1	1.54	1.22
veer			1	1	1			1		0.44	3.60	4	6.15	4.88
wbnu	3	1	1		1		1			0.78	6.31	5	7.69	7.00
wiwr		1		1						0.22	1.80	2	3.08	2.44
woth			1							0.11	0.90	1	1.54	1.22
Total										12.33	100.00	65	100.00	100.00

Silver Creek Rim

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	19	1	2	5	2	4
B	10	19	1	2	5	2	4
C	10	19	1	2	5	2	1
D	10	19	1	2	5	2	4
E	10	19	1	2	2	2	4
F	10	19	1	2	2	2	4
Total	10	19	1	2	3.67	2	3.5

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	74.4	69	90	11.1	21.7	4	29	10	21	79	45
B	74.2	100	100	3.2	6.9	6	23	8	4	50	80
C	61.5	75	100	13	15.5	5	16	10	38	62.5	75
D	95.5	100	100	4.8	5.9	6	21	1	4	56.3	90
E	74.4	100	100	36.7	65.8	17	32	11	nd	nd	nd
F	75	100	100	10.3	18.1	2	24	8	nd	nd	nd
Total	75.83	90.67	98.33	13.18	22.32	6.67	24.17	8.00	16.75	61.95	72.50

Vegetation Species Parameters

Tree Species	Density								Cover								Frequency	Importance Value Density + Cover
	stop						total	relative	stop						total	relative		
	1	2	3	4	5	6			1	2	3	4	5	6				
aldo						1	1	0.52						4	4	0.11	1	0.63
amel			1				1	0.52			16.5				16.5	0.47	1	0.99
bass	4	1	4	1			10	5.15	49	37	63.5	46.5			196	5.63	4	10.79
bihi		1					1	0.52		4					4	0.11	1	0.63
blch					5		5	2.58					93		93	2.67	1	5.25
ewce	10		4				14	7.22	146.5		96.5				243	6.99	2	14.20
iron	1	10			1	4	16	8.25	21	175			15.5	25.5	237	6.81	4	15.06
ltas	1						1	0.52	23						23	0.66	1	1.18
moma		1	5				6	3.09		4	28				32	0.92	2	4.01
reoa					14		14	7.22					433		433	12.45	1	19.66
suma	7	11	9	20	19	24	90	46.39	84	175	197	428	196.5	423	1503.5	43.22	6	89.61
whas	6	8	3	1	4	3	25	12.89	63.5	141.5	88.5	35	105	71	504.5	14.50	6	27.39
whbi	10						10	5.15	189						189	5.43	1	10.59
total	39						194	100							3478.5	100	31	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	02/07/98	11/07/97	12/07/96	06/06/97	26/06/96	27/05/96	15/07/99	19/06/98	08/06/99	average abundance	relative abundance	frequency	relative frequency	importance value
amcr						2				0.22	1.04	1	1.05	1.05
amgo		2		1	1	3	1			0.89	4.17	5	5.26	4.71
amro	1	1					3	1	3	1.00	4.69	5	5.26	4.98
bcch	1	1	2	1	2	1		1	3	1.33	6.25	8	8.42	7.34
bhco				1	1					0.22	1.04	2	2.11	1.57
blja						3		1	3	0.78	3.65	3	3.16	3.40
brcr			1		2	1	2			0.67	3.13	4	4.21	3.67
bwwa	1							1		0.22	1.04	2	2.11	1.57
cewa							1	1		0.22	1.04	2	2.11	1.57
dowo						1			1	0.22	1.04	2	2.11	1.57
eato						1				0.11	0.52	1	1.05	0.79
ewpe	1		1	2	3			4		1.22	5.73	5	5.26	5.50
gcfl	1		3	1	1	4			1	1.22	5.73	6	6.32	6.02
inbu						1				0.11	0.52	1	1.05	0.79
noca						1				0.11	0.52	1	1.05	0.79
oven			1	2	3	2				0.89	4.17	4	4.21	4.19
rbgr	1		1	3			2	2	3	1.33	6.25	6	6.32	6.28
revi	4	1	4	2	4	5	7	4	6	4.11	19.27	9	9.47	14.37
scta	1		2			1		1		0.56	2.60	4	4.21	3.41
tuvu			1							0.11	0.52	1	1.05	0.79
veer	2	2	3	3	2	2		5	2	2.33	10.94	8	8.42	9.68
wbnu	1		2	2	3	4	1	2		1.67	7.81	7	7.37	7.59
wiwr	1	1		1		1				0.44	2.08	4	4.21	3.15
woth		1	5			3				1.00	4.69	3	3.16	3.92
ybsa		3								0.33	1.56	1	1.05	1.31
Total										21.33	100.00	95	100.00	100.00

Silver Creek Slope

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	2	9	3	2	5	1	2
B	2	11	3	2	3	1	3
C	7	10	3	2	3	1	3
D	4	11	3	2	5	1	2
Total	3.8	10.3	3	2	4	1	2.5

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	32.3	100	100	10.7	14	6	10	21	35	45	40
B	66.7	100	100	3.4	5.7	5	20	10	8	56.3	40
C	51.1	100	100	13.5	19.7	6	23	22	18	57.5	90
D	26.7	100	100	7.1	12.1	4	8	22	13	55	20
Total	44.20	100.00	100.00	8.68	12.88	5.25	15.25	18.75	18.50	53.45	47.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
aldo			1		1	0.74			5		5	0.29	1	1.03
amel	2	1	1	6	10	7.35	12.5	22	36.5	49	120	7.00	4	14.35
bass	6		1	1	8	5.88	34.5		48	21	103.5	6.03	3	11.92
bihi		3		1	4	2.94		45.5		4	49.5	2.89	2	5.83
blas				1	1	0.74				5.5	5.5	0.32	1	1.06
blbe			1	2	3	2.21			5	11.5	16.5	0.96	2	3.17
iron	4	7	3	4	18	13.24	31.5	59	17	34	141.5	8.25	4	21.48
reoa	1				1	0.74	4.5				4.5	0.26	1	1.00
suma	8	29	20	15	72	52.94	99	338	355	188	980	57.13	4	110.07
tras	4				4	2.94	20.5				20.5	1.19	1	4.14
whas	3	5	3	1	12	8.82	62.5	83	83.5	29	258	15.04	4	23.86
will	2				2	1.47	11				11	0.64	1	2.11
Total					136	100					1715.5	100	28	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	02/07/98	11/07/97	12/07/96	06/06/97	26/06/96	27/05/96	15/07/99	19/06/98	08/06/99	average abundance	relative abundance	frequency	relative frequency	importance value
amgo							3	4		0.78	2.32	2	1.46	1.89
amro	2	2	2	1			3		2	1.33	3.97	6	4.38	4.18
baor					2		2			0.44	1.32	2	1.46	1.39
bcch	8	2	7	1	2	1	3	8	4	4.00	11.92	9	6.57	9.25
bhco					3	1				0.44	1.32	2	1.46	1.39
blja		1	1	1	1	1	1			0.67	1.99	6	4.38	3.18
brcr	3		2	1	1					0.89	2.65	5	3.65	3.15
btgw	1									0.11	0.33	1	0.73	0.53
bwwa				1						0.11	0.33	1	0.73	0.53
cawa						1				0.11	0.33	1	0.73	0.53
cewa									2	0.22	0.66	1	0.73	0.70
dowo	1	1	2	1	1		2	3		1.22	3.64	7	5.11	4.38
ewpe	3	1	4	3	3	3	2		4	2.56	7.62	8	5.84	6.73
gcfl	2	1	2	2	2	2				1.22	3.64	6	4.38	4.01
hawo	2			1		1	1		2	0.78	2.32	5	3.65	2.98
howr		3	1							0.44	1.32	2	1.46	1.39
inbu							1			0.11	0.33	1	0.73	0.53
lefl			1							0.11	0.33	1	0.73	0.53
mowa		2		1	2			2	2	1.00	2.98	5	3.65	3.31
nawa				1						0.11	0.33	1	0.73	0.53
nofl	1	1	3				1		1	0.78	2.32	5	3.65	2.98
nowa						1				0.11	0.33	1	0.73	0.53
oven	2		1	1		1			1	0.67	1.99	5	3.65	2.82
rbgr	2	4	2	4	3	1	1	1	2	2.22	6.62	9	6.57	6.60
revi	4	1	2	3	2	7	3	2	4	3.11	9.27	9	6.57	7.92
rthu		1			2		1			0.44	1.32	3	2.19	1.76
rugr		1								0.11	0.33	1	0.73	0.53
scta	3		3				3			1.00	2.98	3	2.19	2.58
tuvu			10		10			1		2.33	6.95	3	2.19	4.57
veer	4	3	3	1	3		2	1	1	2.00	5.96	8	5.84	5.90
wbnu	6	1	2	1	2	1	3	2	1	2.11	6.29	9	6.57	6.43
wiwr	1		1	2		1				0.56	1.66	4	2.92	2.29
woth		1				3				0.44	1.32	2	1.46	1.39
ybsa		4	2		1			3		1.11	3.31	4	2.92	3.12
Total										33.67	100.33	138	100.73	100.53

Silver Creek Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	5	8	4	2	2	1	2
B	5	9	4	2	2	1	2
C	4	11	4	2	2	1	3
D	7	11	4	2	2	1	1
Total	5.25	9.75	4	2	2	1	2

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	56.3	100	100	3.2	2.2	4	18	14	66	38.8	60
B	46.5	100	100	12.5	19.7	3	13	15	29	20	85
C	59.5	80	82.4	7.9	12.3	6	25	17	42	29.5	90
D	77.3	100	100	22.2	37.7	2	17	5	15	48.8	90
Total	59.90	95.00	95.60	11.45	17.98	3.75	18.25	12.75	38.00	34.28	81.25

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel	2				2	1.61	11.5				11.5	0.60	1	2.21
bass	4	8	5		17	13.71	21	94	61.5		176.5	9.21	3	22.92
blas		3	3		6	4.84		89	29		118	6.16	2	10.99
eahe			8		8	6.45			110		110	5.74	1	12.19
iron	2	1	2	1	6	4.84	13.5	9	18	4	44.5	2.32	4	7.16
suma	23	14	14	21	72	58.06	398.5	141	195.5	492.5	1227.5	64.03	4	122.10
whas	1	2	6		9	7.26	34	63.5	78		175.5	9.15	3	16.41
whbi			1		1	0.81			19		19	0.99	1	1.80
yebi			3		3	2.42			34.5		34.5	1.80	1	4.22
Total					124	100					1917	100	20	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	02/07/98	11/07/97	12/07/96	06/06/97	26/06/96	27/05/96	15/07/99	19/06/98	08/06/99	average abundance	relative abundance	frequency	relative frequency	importance value
alfl								1		0.11	0.36	1	0.72	0.54
amgo		2							1	0.33	1.09	2	1.44	1.26
amro	2	2	1	3		4	1	2	1	1.78	5.82	8	5.76	5.79
baor					1					0.11	0.36	1	0.72	0.54
bcch	9	7	4		4	4		2	2	3.56	11.64	7	5.04	8.34
beki		1	1							0.22	0.73	2	1.44	1.08
blja	4		3	1	1	1		1		1.22	4.00	6	4.32	4.16
brcr		1	1	1		2	1		1	0.78	2.55	6	4.32	3.43
btgw	2									0.22	0.73	1	0.72	0.72
bwwa		1								0.11	0.36	1	0.72	0.54
coye		1		1			2	1	2	0.78	2.55	5	3.60	3.07
dowo	2			1	1		1	1		0.67	2.18	5	3.60	2.89
ewpe	2	1	1	1	2	1		2	1	1.22	4.00	8	5.76	4.88
gcfl		1		2	1	2				0.67	2.18	4	2.88	2.53
hawo						1				0.11	0.36	1	0.72	0.54
howr	3	4	4	4	2		4	3	1	2.78	9.09	8	5.76	7.42
inbu							1			0.11	0.36	1	0.72	0.54
mowa		1		2	2	1	1		2	1.00	3.27	6	4.32	3.79
nawa						2				0.22	0.73	1	0.72	0.72
nowa	2		1	1		2				0.67	2.18	4	2.88	2.53
oven				1	1					0.22	0.73	2	1.44	1.08
piwa			1						1	0.22	0.73	2	1.44	1.08
rbgr		3			1	5				1.00	3.27	3	2.16	2.72
revi	2	1		3		2	2	3		1.44	4.73	6	4.32	4.52
rsha					1					0.11	0.36	1	0.72	0.54
rthu		1								0.11	0.36	1	0.72	0.54
rugr								1		0.11	0.36	1	0.72	0.54
rwbl				1	1					0.22	0.73	2	1.44	1.08
scta	1		3		1	1		2		0.89	2.91	5	3.60	3.25
sosp	5	2	6	1	1	1	7	2	3	3.11	10.18	9	6.47	8.33
veer	1	1	4	2	2	1		2		1.44	4.73	7	5.04	4.88
wbnu		1		1	1	2	2			0.78	2.55	5	3.60	3.07
wiwr	2	4		4	2	2	1	1	3	2.11	6.91	8	5.76	6.33
woth	2	1	4	2	3	2		2		1.78	5.82	7	5.04	5.43
yewa				2						0.22	0.73	1	0.72	0.72
ybsa		1								0.11	0.36	1	0.72	0.54
Total										30.56	100.00	139.00	100.00	100.00

APPENDIX F

TERRA COTTA UPLAND

Terra Cotta

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	9	13	1	2	1	2	1
B	8	11	1	2	1	2	1
C	10	13	1	2	1	2	1
D	10	2	1	2	2	2	3
E	10	12	1	2	1	2	4
F	10	13	1	2	1	1	3
G	10	12	1	2	2	1	3
H	10	13	1	2	2	1	3
I	10	12	1	2	2	1	2
J	10	12	1	2	1	2	4
K	5	2	1	2	1	2	4
L	7	12	1	2	1	2	1
Total	9.17	10.58	1	2	1.33	1.67	2.5

Vegetation Structural Parameter

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	100	100	na	0	0	1	27	0	18	18	100
B	91.4	100	100	22.2	40.4	12	53	5	0	57.5	na
C	87.5	100	100	16.7	25.6	6	42	6	1	30	98
D	87	100	100	17.1	31.3	4	40	6	0	32	92
E	100	100	na	2.7	4.5	3	38	0	46	63.8	100
F	100	100	na	6.7	22.8	5	32	0	nd	nd	nd
G	84.2	100	100	16.1	32.3	9	32	6	nd	nd	nd
H	96.9	100	100	50	74.5	6	31	1	nd	nd	nd
I	43.2	100	85.7	29.6	46.7	6	16	18	nd	nd	nd
J	37.8	100	100	9.1	25.5	3	14	23	nd	nd	nd
K	50	100	100	0	0	3	10	10	nd	nd	nd
L	90.2	100	100	23.3	40.8	13	37	4	nd	nd	nd
Total	80.68	100.00	98.41	16.13	28.70	5.91	31.00	6.58	13.00	40.26	97.50

Vegetation Species Parameters

Tree Species	Density							Cover							Frequency	Importance Value Density + Cover
	Stops					Total	Relative	Stops					Total	Relative		
	1	2	3	4	5			1	2	3	4	5				
ambe	3					3	1.55	101					101	2.27	1	3.82
amel				1		1	0.52				40.5		40.5	0.91	1	1.43
bass		2	2	6	1	11	5.67		53	15.5	113.5	20.5	202.5	4.56	4	10.23
blas				1		1	0.52				12.5		12.5	0.28	1	0.80
tras				1		1	0.52				33		33	0.74	1	1.26
whas		2	10	1	1	14	7.22		63.5	228	7.5	27	326	7.34	3	14.55
Total						194	100						4444	100.00	19	200.00

Bird Population Parameters

Bird Species	Observation Dates										Population Characteristics				
	17/06/96	11/07/96	04/06/97	12/07/97	23/06/98	13/07/98	27/07/98	04/06/99	28/07/99	30/07/96	average abundance	relative abundance	frequency	relative frequency	importance value
amcr	4			1							0.50	1.84	2	1.92	1.88
amgo		1			2			3		2	0.80	2.94	4	3.85	3.39
amro	1		2	2	2				1		0.80	2.94	5	4.81	3.87
bcch	2		3	1	6	1	1	3	2	4	2.30	8.46	9	8.65	8.55
bhco			1								0.10	0.37	1	0.96	0.66
blja			2		1			8			1.10	4.04	3	2.88	3.46
brcr	3	2	1	2	2		4	3	2		1.90	6.99	8	7.69	7.34
btgw				2	1						0.30	1.10	2	1.92	1.51
bwwa	1										0.10	0.37	1	0.96	0.66
cewa									1	2	0.30	1.10	2	1.92	1.51
dowo								3	3		0.60	2.21	2	1.92	2.06
ewpe	6	2	4	2	6	3	2	5	2	3	3.50	12.87	10	9.62	11.24
gcfl	2		2	1							0.50	1.84	3	2.88	2.36
hawo	2		1	1				1		1	0.60	2.21	5	4.81	3.51
mowa									1		0.10	0.37	1	0.96	0.66
nowa	2										0.20	0.74	1	0.96	0.85
oven	6	4	5	3	7	2		4			3.10	11.40	7	6.73	9.06
rbgr	1		1					1		1	0.40	1.47	4	3.85	2.66
revi	7	6	8	5	9	5	3	7	4	11	6.50	23.90	10	9.62	16.76
rsha								1			0.10	0.37	1	0.96	0.66
rthu									1		0.10	0.37	1	0.96	0.66
scta	2		2	1	1	1	1	2	1		1.10	4.04	8	7.69	5.87
veer	2	1									0.30	1.10	2	1.92	1.51
wbnu		1	1			1		2	2	4	1.10	4.04	6	5.77	4.91
wiwr				1	1					1	0.30	1.10	3	2.88	1.99
woth			2	1						2	0.50	1.84	3	2.88	2.36
Total											27.20	100.00	104	100.00	100.00

APPENDIX G

FORKS OF THE CREDIT VALLEY
FORKS OF THE CREDIT FACE

Forks of the Credit Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	6	4	3	4	1	3
B	10	6	4	3	4	1	3
C	10	5	4	3	4	1	3
D	10	5	4	3	4	1	3
Total	10	5.5	4	3	4	1	3

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	56.9	100	86.4	5.1	53.9	1	29	22	21	90	75
B	30.8	70	75.6	0	0	2	20	45	22	71.3	60
C	21.1	71.4	42.9	10	16.5	2	28	105	18	60	80
D	63.4	46.2	80	8.1	18.2	5	26	15	3	37.5	na
Total	43.05	71.90	71.23	5.80	22.15	2.50	25.75	46.75	16.00	64.70	71.70

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel	34	40	32		106	36.43	350	298	225.5		873.5	29.31	3	65.73
bapo			3		3	1.03			63.5		63.5	2.13	1	3.16
bass		1		1	2	0.69		13		4.5	17.5	0.59	2	1.27
blas			1		1	0.34			7		7	0.23	1	0.58
ewce	3	17	69	17	106	36.43	21.5	132.5	465	321.5	940.5	31.56	4	67.98
shwi	12				12	4.12	463.5				463.5	15.55	1	19.67
whas	2	2	1	23	28	9.62	25.5	36.5	15	254.5	331.5	11.12	4	20.74
whbi		5	28		33	11.34		52	231.5		283.5	9.51	2	20.85
Total					291	100					2980.5	100	18	200

Bird Population Parameters

Bird Species	Observation Date											Population Characteristics				
	09/06/99	21/07/99	04/08/98	07/06/98	17/06/98	13/07/98	19/06/97	14/07/97	01/07/96	17/07/96	27/05/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr				3				1			2	0.55	4.03	3	3.75	3.89
amro			1	2	1		2	1	1			0.73	5.37	6	7.50	6.43
bcch	1	4	10		2	6	8		3		3	3.36	24.83	8	10.00	17.42
beki								1				0.09	0.67	1	1.25	0.96
blja	1	1	1	3	4		4		1		4	1.73	12.75	8	10.00	11.38
btgw	1				1		1			1	1	0.45	3.36	5	6.25	4.80
bwwa	1			1			1	1	1		2	0.64	4.70	6	7.50	6.10
cewa			2			3		1				0.55	4.03	3	3.75	3.89
cogr	4										1	0.45	3.36	2	2.50	2.93
dowo	1							1				0.18	1.34	2	2.50	1.92
gcfl					2							0.18	1.34	1	1.25	1.30
mall			1									0.09	0.67	1	1.25	0.96
mowa				1								0.09	0.67	1	1.25	0.96
nawa										1		0.09	0.67	1	1.25	0.96
noca	1		2	2							1	0.55	4.03	4	5.00	4.51
nowa	1			3	1		1	1			1	0.73	5.37	6	7.50	6.43
oven						1						0.09	0.67	1	1.25	0.96
revi				1			1			1		0.27	2.01	3	3.75	2.88
rthu			2									0.18	1.34	1	1.25	1.30
rwsw	1											0.09	0.67	1	1.25	0.96
sosp	2	3		2	1	2	3	2			1	1.45	10.74	8	10.00	10.37
spsa		1										0.09	0.67	2	2.50	1.59
trsw									5			0.45	3.36	1	1.25	2.30
wiwr				1	1	1				1		0.36	2.68	4	5.00	3.84
woth			1									0.09	0.67	1	1.25	0.96
Total												13.55	100.00	80	100.00	100.00

Forks of the Credit Slope

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	3	4	3	3	5	1	3
B	1	3	3	3	3	1	2
C	0	5	3	3	4	1	2
D	1	4	3	3	2	1	3
E	3	12	3	3	2	1	3
Total	1.60	5.60	3	3	3.20	1	2.60

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	9.7	33.3	35.7	25	38.6	2	3	28	nd	nd	nd
B	88.2	34.3	22.2	8.5	13.4	13	67	9	1	6.8	90
C	20.5	88.9	74.3	10.8	31.8	3	9	35	19	27.5	80
D	57.1	100	100	23.3	40.7	6	24	18	3	71.3	88
E	71.2	100	100	13.3	51.7	1	28	11	3	77.5	100
Total	49.34	71.30	66.44	16.18	35.24	5	26.20	20.20	6.50	45.78	89.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
bass		4	1		5	3.01		79	4		83	2.99	2	6.00
blch				1	1	0.60				174	174	6.27	1	6.88
eahe	3				3	1.81	52.5				52.5	1.89	1	3.70
ewce	44	9			53	31.93	671	68.5			739.5	26.66	2	58.59
iron		14	5	24	43	25.90		183	35	263.5	481.5	17.36	3	43.26
suma	2	4	23	2	31	18.67	43.5	110.5	461.5	35.5	651	23.47	4	42.15
tras		2			2	1.20		16			16	0.58	1	1.78
whas		3	1	3	7	4.22		17	2	146.5	165.5	5.97	3	10.18
whbi	20	1			21	12.65	399.5	11			410.5	14.80	2	27.45
Total					166	100					2773.5	100	19	200.00

Bird Population Parameters

Bird Species	Observation Date											Population Characteristics				
	09/06/99	21/07/99	04/08/98	07/06/98	17/06/98	13/07/98	19/06/97	14/07/97	01/07/96	17/07/96	27/05/98	abundance	relative abundance	frequency	relative frequency	importance value
amcr					3							0.27	1.63	1	1.14	1.38
amgo								2				0.18	1.09	1	1.14	1.11
amro	4	2	2	3	7	4	6	5	1	1	4	3.55	21.19	11	12.50	16.85
bcch		8	2	2	4	2	6	4	4	3	3	3.45	20.65	10	11.36	16.01
blja	2			1	3					1	4	1.00	5.98	5	5.68	5.83
btgw			2	1	2		1	2				0.73	4.35	5	5.68	5.01
bwwa	1			1	1		1	1	1		1	0.64	3.80	7	7.95	5.88
cewa			2		4		2				1	0.82	4.89	4	4.55	4.72
dowo											1	0.09	0.54	1	1.14	0.84
ewpe	1	3		2	1	1	1	1	1	1	1	1.18	7.06	10	11.36	9.21
gcfl	1						1		2		1	0.45	2.72	4	4.55	3.63
hawo				1								0.09	0.54	1	1.14	0.84
inbu									1			0.09	0.54	1	1.14	0.84
nawa									1			0.09	0.54	1	1.14	0.84
noca				2		1					1	0.36	2.17	3	3.41	2.79
oven	1	1		1	1		3	1	1		3	1.09	6.52	8	9.09	7.81
revi	2	2		3	3	2			3	1	3	1.73	10.32	8	9.09	9.71
rugr	1											0.09	0.54	1	1.14	0.84
scta								2				0.18	1.09	1	1.14	1.11
veer					2						1	0.27	1.63	2	2.27	1.95
woth	1		1				2					0.36	2.17	3	3.41	2.79
Total												16.73	99.98	88	100.00	99.99

APPENDIX H

INGLEWOOD UPLAND

Inglewood

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	18	1	2	1	2	1
B	10	18	1	2	2	2	1
C	10	19	1	2	1	2	1
D	10	15	1	2	1	2	1
Total	10	17.50	1	2	1.25	2	1

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	38.9	100	100	5.6	7.8	24	44	69	30	35	80
B	58	100	100	9.1	36.8	20	29	21	10	31.8	nd
C	56.4	96.2	92.7	14.1	24.6	12	53	41	10	20.5	85
D	50	100	100	15.2	37.6	5	39	39	8	18	95
Total	50.83	99.05	98.18	11.00	26.70	15.25	41.25	42.50	14.50	26.33	86.67

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe				7	7	2.09				47	47	1.19	1	3.28
amel	2	20			22	6.57	14.5	210			224.5	5.69	2	12.25
bass	9	1	1	1	12	3.58	54.5	5	21	5.5	86	2.18	4	5.76
blch	1		1		2	0.60	4.5		23		27.5	0.70	2	1.29
eahe			5		5	1.49			58.5		58.5	1.48	1	2.97
gras	1				1	0.30	6				6	0.15	1	0.45
iron	1		2	2	5	1.49	8		22	18.5	48.5	1.23	2	2.72
rema	4	4	4		12	3.58	49	52.5	36		137.5	3.48	3	7.06
reoa			1		1	0.30			49		49	1.24	1	1.54
serv	2				2	0.60	13.5				13.5	0.34	1	0.94
sima		9			9	2.69		284			284	7.19	1	9.88
suma	27	4	71	48	150	44.78	258	31	765.5	607.5	1662	42.10	4	86.87
whas	66	12	9	10	97	28.96	647.5	153	173	131	1104.5	27.98	4	56.93
whbi				10	10	2.99				199.5	199.5	5.05	1	8.04
Total					335	100					3948	100	28	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics					
	17/06/97	26/06/97	08/07/97	09/06/98	02/07/98	27/07/98	04/06/99	11/06/99	16/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amcr				10			1	1		1.33	4.17	3	2.86	3.51
amgo			2			2		2	2	0.89	2.78	4	3.81	3.29
amro	2	3	3	3	2		10	7	4	3.78	11.81	8	7.62	9.71
bcch	3	5	5	3	1	2	2	2	1	2.67	8.33	9	8.57	8.45
bhco							1			0.11	0.35	1	0.95	0.65
blja			1					1		0.22	0.69	2	1.90	1.30
brcr		1					2	2	1	0.67	2.08	4	3.81	2.95
btgw	1			1						0.22	0.69	2	1.90	1.30
cewa	2	2	2	3				1		1.11	3.47	5	4.76	4.12
chsp								1		0.11	0.35	1	0.95	0.65
dowo	1	1	1	1	1					0.56	1.74	5	4.76	3.25
ewpe	2	1	4	2	1		2	2		1.56	4.86	7	6.67	5.76
gcfl	1	3			1		1			0.67	2.08	4	3.81	2.95
ghow				1						0.11	0.35	1	0.95	0.65
hawo	1	1			1		1	4		0.89	2.78	5	4.76	3.77
nowa		3		2			3	1	1	1.11	3.47	5	4.76	4.12
oven	2	4	8	4	2		4	2		2.89	9.03	7	6.67	7.85
piwo				1					1	0.22	0.69	2	1.90	1.30
rbgr		4		2			1			0.78	2.43	3	2.86	2.64
revi	5	11	12	13	9	9	11	12	7	9.89	30.90	9	8.57	19.74
rugr							1			0.11	0.35	1	0.95	0.65
scta		2	1	1		1			1	0.67	2.08	5	4.76	3.42
veer	1	1			1					0.33	1.04	3	2.86	1.95
wbnu					1		1			0.22	0.69	2	1.90	1.30
wiwr		1	1	1			1			0.44	1.39	4	3.81	2.60
woth			2		1		1			0.44	1.39	3	2.86	2.12
Total										32.00	100.00	105	100.00	100

APPENDIX I

GLEN HAFFY UPPER FACE
GLEN HAFFY LOWER FACE

Glen Haffy Upper Face

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	0	18	3	3	3	1	2
B	1	18	3	3	2	2	2
C	10	18	2	3	1	2	1
D	10	18	2	3	1	1	3
Total	5.25	18	2.5	3	1.75	1.5	2

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	92.9	92.3	100	0	0	0	13	1	11	45	95
B	91.7	36.4	100	0	0	0	11	1	32	10.8	nd
C	15.6	80	96.3	0	0	1	5	27	24	1.5	95
D	56.5	76.9	100	4.5	8.5	2	13	10	58	68.8	35
Total	64.18	71.40	99.08	1.13	2.13	0.75	10.50	9.75	31.25	31.53	75.00

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe				1	1	1.23				65	65	4.29	1	5.53
butt	1				1	1.23	37.5				37.5	2.48	1	3.71
eahe	1	7	2	2	12	14.81	53.5	240	40.5	24	358	23.65	4	38.46
iron	2				2	2.47	35.5				35.5	2.34	1	4.81
suma	10	5	30	20	65	80.25	302.5	156.5	293	266	1018	67.24	4	147.49
Total					81	100					1514	100	11	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	28/07/98	09/06/97	07/07/97	14/06/96	19/07/96	09/06/98	29/06/98	07/07/99	07/06/99	abundance	relative abundance	frequency	relative frequency	importance value
amcr		2								0.22	0.95	1	1.03	0.99
amgo								1	1	0.22	0.95	2	2.06	1.51
amro	1	2				3	2			0.89	3.81	4	4.12	3.97
bcch	4	6	1			4	6	1		2.44	10.48	6	6.19	8.33
bhco						1				0.11	0.48	1	1.03	0.75
blja		8	1		1	1	3			1.56	6.67	6	6.19	6.43
brcr	2									0.22	0.95	1	1.03	0.99
btbw		1	2	3		2	1	2	1	1.33	5.71	7	7.22	6.47
btgw							1	2	2	0.56	2.38	3	3.09	2.74
bwha									1	0.11	0.48	1	1.03	0.75
cewa	1									0.11	0.48	1	1.03	0.75
dowo	2					2		1	1	0.67	2.86	4	4.12	3.49
ewpe	1	8	3	2		3	2	2	2	2.56	10.95	8	8.25	9.60
gcfl				2		1		1		0.44	1.90	3	3.09	2.50
hawo		1		2	1					0.44	1.90	3	3.09	2.50
noca								1		0.11	0.48	1	1.03	0.75
nofl			2			1				0.33	1.43	2	2.06	1.75
oven		1	1	1		5	4		1	1.44	6.19	6	6.19	6.19
piwo							4	2		0.67	2.86	2	2.06	2.46
rbgr		1		1		1	1			0.44	1.90	4	4.12	3.01
rbnu							1			0.11	0.48	1	1.03	0.75
revi	4	8	7	5	1	8	6	5	5	5.44	23.33	9	9.28	16.31
rthu								1		0.11	0.48	1	1.03	0.75
rugr						1				0.11	0.48	1	1.03	0.75
scta	1	2	1				1	1		0.67	2.86	5	5.15	4.01
wbnu	2					1	1			0.44	1.90	3	3.09	2.50
wiwr		1		1	1					0.33	1.43	3	3.09	2.26
woth	1	2			1	1	2			0.78	3.33	5	5.15	4.24
ybsa			1				2	1		0.44	1.90	3	3.09	2.50
Total										23.33	100.00	97	100.00	100.00

Glen Haffy Lower Face

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	4	16	4	3	1	3	2
B	7	8	4	3	1	3	2
C	9	12	4	3	2	5	3
D	9	12	4	3	2	5	3
Total	7.25	12	4	3	1.5	4	2.5

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	100	56.3	na	0	0	3	16	0	3	24	100
B	89.3	28	66.7	3.7	4.9	4	25	3	1	0	100
C	46.3	87.1	94.4	10	17.5	17	31	36	12	25	nd
D	55.4	63.9	100	20	48.1	10	36	29	22	15	95
Total	72.75	58.83	87.03	8.43	17.63	8.50	27.00	17.00	9.50	16.00	98.33

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe	5				5	2.86	142				142	4.84	1	7.70
amel			16	6	22	12.57			179	54	233	7.94	2	20.51
appl				1	1	0.57				10.5	10.5	0.36	1	0.93
butt				1	1	0.57				2.4	24	0.82	1	1.39
eabe	7	19			26	14.86	216	559.5			775.5	26.43	2	41.28
ewce				12	12	6.86				259	259	8.83	1	15.68
iron		1			1	0.57		16			16	0.55	1	1.12
nldo				1	1	0.57				4.5	4.5	0.15	1	0.72
tras				1	1	0.57				15	15	0.51	1	1.08
whas			28	10	38	21.71			431.5	105	536.5	18.28	2	40.00
whbi				2	2	1.14				2.2	22	0.75	1	1.89
whpi			3		3	1.71			57		57	1.94	1	3.66
whsp			3	1	4	2.29			22.5	14	36.5	1.24	2	3.53
yebi		4			4	2.29		104.5			104.5	3.56	1	5.85
Total					175	100					2934.5	100	22	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	28/07/98	09/06/97	07/07/97	14/06/96	19/07/96	09/06/98	29/06/98	07/07/99	07/06/99	abundance	relative abundance	frequency	relative frequency	importance value
amcr									1	0.11	0.68	1	1.32	1.00
amgo	2									0.22	1.37	1	1.32	1.34
amro	2					1				0.33	2.05	2	2.63	2.34
bcch	5	7	4	2		2	9	3	3	3.89	23.97	8	10.53	17.25
blja	3	4	3			1		1	2	1.56	9.59	6	7.89	8.74
blwa								2		0.22	1.37	1	1.32	1.34
brcr	1		1						1	0.33	2.05	3	3.95	3.00
btbw							1			0.11	0.68	1	1.32	1.00
btgw						1	1	1	1	0.44	2.74	4	5.26	4.00
bwha									1	0.11	0.68	1	1.32	1.00
bwwa						2				0.22	1.37	1	1.32	1.34
cawa		1								0.11	0.68	1	1.32	1.00
cewa	2									0.22	1.37	1	1.32	1.34
dowo	3						1	1		0.56	3.42	3	3.95	3.69
ewpe	1	1			4	2	1			1.00	6.16	5	6.58	6.37
gcfl						1				0.11	0.68	1	1.32	1.00
gcki								2		0.22	1.37	1	1.32	1.34
hawo		2						1		0.33	2.05	2	2.63	2.34
noca						1				0.11	0.68	1	1.32	1.00
oven		3	1			1	2	1	1	1.00	6.16	6	7.89	7.03
rbgr			1							0.11	0.68	1	1.32	1.00
revi	2	3		4	2	4	2	3	3	2.56	15.75	8	10.53	13.14
rugr		1								0.11	0.68	1	1.32	1.00
scta	1	1	1		2	1			1	0.78	4.79	6	7.89	6.34
wbnu	1	1	1	1			3			0.78	4.79	5	6.58	5.69
wiwr		2	1		1	1				0.56	3.42	4	5.26	4.34
woth			1							0.11	0.68	1	1.32	1.00
Total										16.22	100.00	76	100.00	100.00

APPENDIX J

HOCKLEY VALLEY VALLEY
HOCKLEY VALLEY FACE
HOCKLEY VALLEY UPLAND

Hockley Valley Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	7	14	4	3	4	1	3
B	10	12	4	3	4	1	3
C	10	12	4	3	4	1	3
D	10	12	4	3	4	1	3
Total	9.25	12.5	4	3	4	1	3

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	43.9	100	100	5.1	7.1	0	18	23	14	23.8	60
B	47.3	88.6	94.9	2.8	3.6	10	35	39	18	13.8	nd
C	40.7	81.1	62.3	4.7	11.2	10	37	54	13	12	70
D	63.8	33.3	52.9	9.5	11.7	20	30	17	3	36.3	60
Total	48.93	75.75	77.53	5.53	8.40	10.00	30.00	33.25	12.00	21.48	63.33

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel	2	16	7	3	28	11.07	14	157.5	59	32.5	263	8.69	4	19.76
bass	2	10	10	4	26	10.28	30.5	98.5	103	59	291	9.62	4	19.90
bapo		6	10	1	17	6.72		216.5	191	60	467.5	15.45	3	22.17
blas			3	2	5	1.98			46.5	19.5	66	2.18	2	4.16
ewce		6	28	28	62	24.51		62.5	254	486	802.5	26.53	3	51.03
gras	2				2	0.79	21.5				21.5	0.71	1	1.50
iron	2	1	1		4	1.58	23.5	9	7		39.5	1.31	3	2.89
moma	3			1	4	1.58	14			4.5	18.5	0.61	2	2.19
suma	22	26	8	1	57	22.53	185	182	131	4.5	502.5	16.61	4	39.14
whas	3	4	22	4	33	13.04	42	53.5	198	39.5	333	11.01	4	24.05
whbi	2	5	2	2	11	4.35	50	78.5	13	24	165.5	5.47	4	9.82
yebi	3		1		4	1.58	42.5		12		54.5	1.80	2	3.38
Total					253	100					3025	100	36	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	20/07/96	21/07/96	27/06/97	11/07/97	10/06/98	10/07/98	05/08/98	30/06/99	26/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amgo				2						0.22	1.55	1	1.56	1.56
amro			4		1	2	2		1	1.11	7.75	5	7.81	7.78
bcch	1	3	2	3	2	1	10	2	5	3.22	22.48	9	14.06	18.27
blja			2	1	3	1	2			1.00	6.98	5	7.81	7.39
btgw	1	1		2	3			1		0.89	6.20	5	7.81	7.01
bwwa				1		1		1	3	0.67	4.65	4	6.25	5.45
coye								1		0.11	0.78	1	1.56	1.17
dowo			1			1	1			0.33	2.33	3	4.69	3.51
eaph				1						0.11	0.78	1	1.56	1.17
ewpe				1						0.11	0.78	1	1.56	1.17
gcfl			1							0.11	0.78	1	1.56	1.17
hawo									1	0.11	0.78	1	1.56	1.17
nowa		2	6		2		1	2		1.44	10.08	5	7.81	8.95
oven						3				0.33	2.33	1	1.56	1.94
revi	1	2	1		1		6	2	1	1.56	10.85	7	10.94	10.90
rthu									1	0.11	0.78	1	1.56	1.17
scta				1		1				0.22	1.55	2	3.13	2.34
veer			2		1					0.33	2.33	2	3.13	2.73
wbnu									4	0.44	3.10	1	1.56	2.33
wiwr			4	2	1	3	1	2	3	1.78	12.40	7	10.94	11.67
woth							1			0.11	0.78	1	1.56	1.17
Total										14.33	100.00	64	100	100.00

Hockley Valley Face

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	3	18	3	3	2	1	2
B	5	17	3	3	2	1	3
C	3	17	3	3	2	1	2
D	0	16	3	3	3	1	2
Total	2.75	17	3	3	2.25	1	2.25

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	50	100	71.4	7.7	23	4	7	7	0	67.5	85
B	77.3	100	100	4.8	9.1	5	17	5	2	19.3	85
C	85.7	100	100	5	7.9	3	18	3	4	23	90
D	100	100	na	0	0	2	12	0	17	13.8	70
Total	78.25	100.00	90.47	4.38	10.00	3.50	13.50	3.75	5.75	30.90	82.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe	7	4			11	15.94	145.5	33.5			179	10.09	2	26.03
amel		1			1	1.45		55			55	3.10	1	4.55
bass		1			1	1.45		25			25	1.41	1	2.85
butt		2			2	2.90		84			84	4.74	1	7.63
eahe	2				2	2.90	10.5				10.5	0.59	1	3.49
suma	5	14	21	7	47	68.12	126.5	427	544.5	130.5	1228.5	69.27	4	137.38
whas				4	4	5.80				166.5	166.5	9.39	1	15.18
yebi				1	1	1.45				25	25	1.41	1	2.85
Total					69	100					1773.5	100	12	200

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics					
	20/07/96	21/07/96	27/06/97	11/07/97	10/06/98	10/07/98	05/08/98	30/06/99	26/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amgo			1							0.11	0.59	1	1.37	0.98
amro					5	3	2	2	4	1.78	9.47	5	6.85	8.16
bbcu									1	0.11	0.59	1	1.37	0.98
bcch		1	1	1	3				4	1.11	5.92	5	6.85	6.38
blja				2	1			3		0.67	3.55	3	4.11	3.83
brcr			2		5	2	2			1.22	6.51	4	5.48	5.99
btbw			2	4						0.67	3.55	2	2.74	3.15
btgw	2		1	2					3	0.89	4.73	4	5.48	5.11
bwwa		1								0.11	0.59	1	1.37	0.98
cewa									1	0.11	0.59	1	1.37	0.98
dowo					2	3				0.56	2.96	2	2.74	2.85
ewpe	1	4	3	2	3	2	4	2	2	2.56	13.61	9	12.33	12.97
gcfl		1			2					0.33	1.78	2	2.74	2.26
hawo	1		1		2	1	1	2	1	1.00	5.33	7	9.59	7.46
nofl		1		1						0.22	1.18	2	2.74	1.96
oven		1	4	2	3	2				1.33	7.10	5	6.85	6.97
piwa								1		0.11	0.59	1	1.37	0.98
rbgr								1		0.11	0.59	1	1.37	0.98
revi	4	2	5	5	6	7	1	3	6	4.33	23.08	9	12.33	17.70
rtha								1		0.11	0.59	1	1.37	0.98
rthu				1						0.11	0.59	1	1.37	0.98
scta				3		3				0.67	3.55	2	2.74	3.15
wbnu						1			2	0.33	1.78	2	2.74	2.26
woth					1					0.11	0.59	1	1.37	0.98
ybsa				1						0.11	0.59	1	1.37	0.98
Total										18.77	99.99	73	100	99.99

Hockley Valley Upland

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	7	12	1	3	2	2	3
B	5	15	1	3	2	2	3
C	7	19	1	3	1	2	2
D	6	18	1	3	1	2	3
Total	6.25	16	1	3	1.5	2	2.75

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	93.5	100	100	14.8	18.5	4	29	2	32	47.5	100
B	95.5	100	100	4.5	14.2	1	20	1	10	23.8	60
C	90	100	100	0	0	6	18	2	6	12.5	100
D	83.3	100	100	0	0	3	15	3	13	8.8	90
Total	90.58	100.00	100.00	4.83	8.18	3.5	20.50	2.00	15.25	23.15	87.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe			1		1	1.11			4.5		4.5	0.19	1	1.30
blch	5				5	5.56	155.5				155.5	6.44	1	11.99
suma	21	16	19	17	73	81.11	415	359.5	607	443	1824.5	75.52	4	156.63
whas	5	5		1	11	12.22	199	193		39.5	431.5	17.86	3	30.08
Total					90	100.00					2416	100.00	9	200.00

Bird Population Parameters

Bird Species	Observation Dates									Population Characteristics				
	20/07/96	21/07/96	27/06/97	11/07/97	10/06/98	10/07/98	05/08/98	30/06/99	26/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amcr			2							0.22	0.78	1	1.03	0.90
amgo				2				3	2	0.78	2.72	3	3.09	2.91
amro		2	6		6	7	7	3	2	3.67	12.84	7	7.22	10.03
bbcu								1		0.11	0.39	1	1.03	0.71
bcch			1	1	1		1	1	1	0.67	2.33	6	6.19	4.26
bhco								2		0.22	0.78	1	1.03	0.90
blja	1		2		2	1				0.67	2.33	4	4.12	3.23
brcr		2	1	2	1	3	4		1	1.56	5.45	7	7.22	6.33
btbw			1	1	1	1		1		0.56	1.95	5	5.15	3.55
btgw								1		0.11	0.39	1	1.03	0.71
coha			1							0.11	0.39	1	1.03	0.71
dowo							1			0.11	0.39	1	1.03	0.71
ewpe	1	1	3	1	5		3		2	1.78	6.23	7	7.22	6.72
gcfl			2					1		0.33	1.17	2	2.06	1.61
hawo				1	1	1	1		3	0.78	2.72	5	5.15	3.94
howr								1		0.11	0.39	1	1.03	0.71
nowa		1								0.11	0.39	1	1.03	0.71
oven			6	8	5	1		1		2.33	8.17	5	5.15	6.66
rbgr			1	4	4	2	1	7		2.11	7.39	6	6.19	6.79
revi	5	5	8	9	12	11	6	7	12	8.33	29.18	9	9.28	19.23
rsha								1		0.11	0.39	1	1.03	0.71
scta	2	2		2		2		1	1	1.11	3.89	6	6.19	5.04
ssha							1			0.11	0.39	1	1.03	0.71
veer						1				0.11	0.39	1	1.03	0.71
wbnu	1		1				2	2		0.67	2.33	4	4.12	3.23
woth	3	1	1		2			2	1	1.11	3.89	6	6.19	5.04
ybsa			2		2	1		1		0.67	2.33	4	4.12	3.23
Total										28.56	99.99	97	100.00	100.00

APPENDIX K

MONO CLIFFS UPLAND
MONO CLIFFS VALLEY
MONO CLIFFS SLOPE

Mono Cliffs Upland

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	9	11	1	1	1	1	1
B	8	16	1	1	1	1	2
C	8	14	1	1	1	1	2
D	9	14	1	1	1	1	1
Total	8.5	13.75	1	1	1	1	1.5

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	71.4	100	100	12.2	21.5	6	40	16	3	31.3	100
B	89.3	100	100	0	0	7	25	3	0	4	100
C	100	100	na	4.8	12.3	1	22	0	29	17	95
D	94.1	100	100	0	0	2	16	0	60	13	40
Total	88.70	100.00	100.00	4.25	8.45	4.00	25.75	4.75	23.00	16.33	83.75

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe	4	1	2		7	5.69	172	28.5	21.5		222.00	7.69	3	13.38
bass	1	1	1	3	6	4.88	43	56	29	79.5	207.50	7.18	4	12.06
suma	12	20	22	33	87	70.73	314	620.5	506	392	1832.50	63.45	4	134.18
whas			3	11	14	11.38			115	311.5	426.50	14.77	2	26.15
whbi				9	9	7.32				199.5	199.50	6.91	1	14.22
Total					123	100.00					2888.00	100.00	14	200.00

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	06/24/98	06/18/99	07/27/99	05/29/96	06/28/96	07/16/96	06/13/97	07/16/97	average abundance	relative abundance	frequency	relative frequency	importance value
amcr				1					0.13	0.74	1	1.32	1.03
amgo			2						0.25	1.48	1	1.32	1.40
amro	1	1			1		1	2	0.75	4.44	5	6.58	5.51
bcch					2	4	2		1.00	5.92	3	3.95	4.94
blwa				1					0.13	0.74	1	1.32	1.03
blja								2	0.25	1.48	1	1.32	1.40
brcr	1				1		1		0.38	2.22	3	3.95	3.08
btbw		1	2						0.38	2.22	2	2.63	2.43
btgw		1		1	1	3	1		0.88	5.18	5	6.58	5.88
bwwa				2			2		0.50	2.96	2	2.63	2.80
cewa			1						0.13	0.74	1	1.32	1.03
cora		1							0.13	0.74	1	1.32	1.03
dowo			1	1	1	1			0.50	2.96	4	5.26	4.11
ewpe	2		1		3	1	1	2	1.25	7.41	6	7.89	7.65
gcfl							1		0.13	0.74	1	1.32	1.03
hawo						1	1		0.25	1.48	2	2.63	2.06
inbu							1		0.13	0.74	1	1.32	1.03
nofl						1	1	1	0.38	2.22	3	3.95	3.08
oven	2	5		3	4	5	4	2	3.13	18.51	7	9.21	13.86
piwo			1						0.13	0.74	1	1.32	1.03
rbgr				1	1			2	0.50	2.96	3	3.95	3.45
revi	1	3	3	3	5	2	6	5	3.50	20.73	8	10.53	15.63
scta	1	1	1		1			2	0.75	4.44	5	6.58	5.51
wbnu	1					1		1	0.38	2.22	3	3.95	3.08
woth		1					2		0.38	2.22	2	2.63	2.43
ybsa	1	1		2				1	0.63	3.70	4	5.26	4.48
Total									16.88	99.97	76	100	99.99

Mono Cliffs Valley
Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	4	7	4	1	4	2	3
B	0	7	4	1	3	2	3
C	2	7	4	1	4	2	3
D	0	7	4	1	3	2	4
E	8	7	4	1	4	2	2
F	0	8	4	1	3	2	4
G	4	8	4	1	4	2	3
Total	3.2	7.29	4	1	3.57	2	3.15

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	86.7	100	100	2.3	6.3	15	39	6	0	31.3	100
B	37.5	95.2	100	7.8	11.5	7	21	35	7	20	90
C	43.5	100	100	9.5	18.6	14	20	26	1	25	95
D	60.7	81.1	83.3	1.8	1.2	8	37	24	0	22.5	nd
E	60.5	100	100	11	15.8	12	49	32	nd	nd	nd
F	83.7	36.6	37.5	6.7	8.7	7	41	8	nd	nd	nd
G	42.9	100	100	6.2	10.8	11	30	40	nd	nd	nd
Total	59.36	87.56	88.69	6.47	10.41	10.57	33.86	24.43	2.00	24.70	71.25

Vegetation Species Parameters

Tree Species	Density									Cover									Frequency	Importance Value Density + Cover
	Stops							total	rel dens	Stops										
	1	2	3	4	5	6	7			1	2	3	4	5	6	7				
aldo		2			5			7	1.73		9			36			45	0.80	2	2.53
ambe							2	2	0.50							11.5	11.5	0.20	1	0.70
amel		3	1					4	0.99		38	13					51	0.91	2	1.90
bafi				1				1	0.25				13				13	0.23	1	0.48
bapo				1				1	0.25				22				22	0.39	0	0.64
bass		1						1	0.25		7						7	0.12	1	0.37
blas				1				1	0.25				8				8	0.14	1	0.39
blch		2	1	1				4	0.99		80	37.5	19				136.5	2.43	2	3.42
eahe				6		31		37	9.16				55		666.5		721.5	12.82	1	21.98
ewce		1						1	0.25		12						12	0.21	2	0.46
iron			1		1		2	4	0.99			15.5		7.5		20.5	43.5	0.77	4	1.76
ltas	4				3		7	14	3.47	117.5				99		345.5	562	9.99	3	13.45
moma					7			7	1.73					47			47	0.84	1	2.57
rema		1		1	14			16	3.96		34.5		37	266.5			338	6.01	2	9.97
suma	40	36	37	32	38	5	63	251	62.13	575	344.5	343	277.5	339	98	696.5	2673.5	47.50	7	109.63
tras	1	2	1	5				9	2.23	16.5	49	16	147.5				229	4.07	3	6.30
whas		3	4	1	1			9	2.23		17	117.5	14	13.5			162	2.88	3	5.11
whbi		5	1	6	1	6	7	26	6.44		87	13	89.5	23.5	92.5	105.5	411	7.30	6	13.74
yebi				2		7		9	2.23				22		112.5		134.5	2.39	2	4.62
Total								404	100								5628	100	44	200

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	06/24/98	06/18/99	07/27/99	05/29/96	06/28/96	07/16/96	06/13/97	07/16/97	average abundance	relative abundance	frequency	relative frequency	importance value
amcr					2				2	1.71	1	1.47	1.59
amro	1						1		2	1.71	2	2.94	2.33
bcch		1	2			3	2	1	9	7.69	5	7.35	7.52
bhco						1			1	0.85	1	1.47	1.16
blja		1			2	2	1	3	9	7.69	5	7.35	7.52
btbw					3				3	2.56	1	1.47	2.02
btgw	2	2	1		3	3	3	3	17	14.53	7	10.29	12.41
bwwa	2			1	2		2		7	5.98	4	5.88	5.93
cora					2				2	1.71	1	1.47	1.59
gcfl				1	1				2	1.71	2	2.94	2.33
hawo						1			1	0.85	1	1.47	1.16
nawa							1		1	0.85	1	1.47	1.16
nofl	1								1	0.85	1	1.47	1.16
nowa		1							1	0.85	1	1.47	1.16
oven	1	3		2	3	2	2	4	17	14.53	7	10.29	12.41
rbgr				1	1		1		3	2.56	3	4.41	3.49
revi			2	1	4	1	1	1	10	8.55	6	8.82	8.69
scta	1					1		1	3	2.56	3	4.41	3.49
veer	1	2		1		2	2		8	6.84	5	7.35	7.10
wiwr		3	1	1	2	2	1	2	12	10.26	7	10.29	10.28
woth	1				1	2		2	6	5.13	4	5.88	5.51
Total									117	100	68	100	100

Mono Cliffs Face

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	8	11	3	1	5	1	2
B	3	12	3	1	5	1	2
C	2	12	3	1	5	1	2
D	2	12	3	1	5	1	2
Total	3.75	11.75	3	1	5	1	2

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	37.7	75	90.9	11.4	20.8	9	20	33	10	31.3	95
B	38.1	50	100	28.6	38.7	11	8	13	10	42.5	80
C	65.1	100	100	10.5	19.5	16	28	15	1	39.5	100
D	77.3	76.5	100	4.8	13.3	12	17	5	3	25	90
Total	54.55	75.38	97.73	13.83	23.08	12	18.25	16.50	6.00	34.58	91.25

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
aldo		1			1	0.73		6.5			6.5	0.35	1	1.08
ambe	1		4		5	3.65	5		74.5		79.5	4.26	2	7.91
amel	3				3	2.19	32.5				32.5	1.74	1	3.93
bafi	6				6	4.38	67				67	3.59	1	7.97
bass	5	1	2		8	5.84	51.5	8.5	19.5		79.5	4.26	3	10.10
ewce	2	4		4	10	7.30	26	88.5		101	215.5	11.55	2	18.85
grdo				1	1	0.73				4.5	4.5	0.24	1	0.97
iron	4			1	5	3.65	23.5			8.5	32	1.72	1	5.37
moma	1	8		2	11	8.03	6	40.5		14.5	61	3.27	2	11.30
suma	19	5	31	11	66	48.18	170	71	385.5	219.5	846	45.36	4	93.54
tras	4				4	2.92	72.5			147.5	220	11.80	2	14.72
whas	2				2	1.46	10.5				10.5	0.56	2	2.02
whbi	4	1	5	2	12	8.76	49.5	18	71	39.5	178	9.54	4	18.30
yebi		1	1	1	3	2.19		4	20	8.5	32.5	1.74	3	3.93
Total					137	100					1865	100	29	200

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	06/24/98	06/18/99	07/27/99	05/29/96	06/28/96	07/16/96	06/13/97	07/16/97	average abundance	relative abundance	frequency	relative frequency	importance value
amcr							1		0.13	0.41	1	0.83	0.62
amre								2	0.25	0.82	1	0.83	0.82
amro	1		1	1	5		1	1	1.25	4.08	6	5.00	4.54
baor						1			0.13	0.41	1	0.83	0.62
bcch	1	2	2	5	2	2	2	8	3.00	9.79	8	6.67	8.23
bhco	1			2					0.38	1.22	2	1.67	1.45
bhvi			1						0.13	0.41	1	0.83	0.62
blja	3		6		1	7	1	2	2.50	8.16	6	5.00	6.58
brcr								2	0.25	0.82	1	0.83	0.82
btbw	2	2		5	2	2	3	1	2.13	6.94	7	5.83	6.39
btgw		3	1	3	1	3	2	1	1.75	5.71	7	5.83	5.77
bwwa		2	1	1	3	1	4	1	1.63	5.31	7	5.83	5.57
cewa		2	1			1			0.50	1.63	3	2.50	2.07
cora						2	1		0.38	1.22	2	1.67	1.45
dowo		2	1	1					0.50	1.63	3	2.50	2.07
eaph		2			1				0.38	1.22	2	1.67	1.45
ewpe	2	3	2			1		1	1.13	3.67	5	4.17	3.92
gcfl	2	1		2	1		3		1.13	3.67	5	4.17	3.92
heth	1								0.13	0.41	1	0.83	0.62
nawa							1		0.13	0.41	1	0.83	0.62
nofl	1					1		1	0.38	1.22	3	2.50	1.86
nowa		1							0.13	0.41	1	0.83	0.62
oven	2	3		2	4	4	2	4	2.63	8.57	7	5.83	7.20
piwa			1	1					0.25	0.82	2	1.67	1.24
piwo							1		0.13	0.41	1	0.83	0.62
rbgr	2			1	1			2	0.75	2.45	4	3.33	2.89
rbnu			1					1	0.25	0.82	2	1.67	1.24
revi	3	8	7	4	4	1	3	4	4.25	13.88	8	6.67	10.27
rwsw		2							0.25	0.82	1	0.83	0.82
scta	2	1				1	1	1	0.75	2.45	5	4.17	3.31
tuvu				2					0.25	0.82	1	0.83	0.82
veer	1	2					3	1	0.88	2.86	4	3.33	3.10
wbnu			2						0.25	0.82	1	0.83	0.82
wiwr	2	2	2	1	1	2	1		1.38	4.49	7	5.83	5.16
woth	1								0.13	0.41	1	0.83	0.62
ytvi	1								0.13	0.41	1	0.83	0.62
Total									30.63	99.98	120	100	99.99

APPENDIX L

ALTON VALLEY
ALTON SWAMP
ALTON PLANTATION

Alton Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	3	5	4	2	1	4
B	10	3	5	4	2	1	4
C	10	3	5	4	2	1	4
D	10	3	5	4	2	1	4
Total	10	3	5	4	2	1	4

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	69.2	100	100	12.5	33.4	2	9	4	0	100	5
B	56.3	33.3	57.1	33.3	59.1	2	9	7	0	77.5	5
C	75.9	68.2	71.4	38.9	54.6	0	22	7	5	87.5	25
D	80	100	100	0	0	1	4	1	1	100	20
Total	70.35	75.38	82.13	21.18	36.78	1.25	11.00	4.75	1.50	91.25	13.75

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
amel			1		1	1.59			18.5		18.5	1.91	1	3.50
bafi		5			5	7.94		57.5			57.5	5.95	1	13.88
blas	5		7	3	15	23.81	96		135	67	298	30.82	3	54.63
blch		2			2	3.17		24			24	2.48	1	5.66
ewce		4	9		13	20.63		109.5	156.5		266	27.51	2	48.14
mama	8	5	12	2	27	42.86	95.5	43.5	144	20	303	31.33	4	74.19
Total					63	100					967	100	12	200.00

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	01/07/96	30/07/97	27/06/97	06/06/98	09/07/98	13/08/98	23/06/99	13/07/99	average abundance	relative abundance	frequency	relative frequency	importance value
amcr	1			4					0.63	1.45	2	1.59	1.52
amgo	1			2		2	7	1	1.63	3.77	5	3.97	3.87
amro	1	1		3	2	1	2	2	1.50	3.48	7	5.56	4.52
baor								1	0.13	0.29	1	0.79	0.54
bbcu			1						0.13	0.29	1	0.79	0.54
bcch	2	3	3	6	10	16	3	10	6.63	15.36	8	6.35	10.86
beki		1		1		1			0.38	0.87	3	2.38	1.63
bhco							1		0.13	0.29	1	0.79	0.54
blja	2	1	1		2	4	2	3	1.88	4.35	7	5.56	4.95
brcr			1		1				0.25	0.58	2	1.59	1.08
btgw			2	1	1			3	0.88	2.03	4	3.17	2.60
bwwa					1	1	1		0.38	0.87	3	2.38	1.63
cago	1								0.13	0.29	1	0.79	0.54
cewa					12	6	3	2	2.88	6.67	4	3.17	4.92
cogr			1						0.13	0.29	1	0.79	0.54
coye	1			2	4	3	2	2	1.75	4.06	6	4.76	4.41
dowo					2	1			0.38	0.87	2	1.59	1.23
eaph		1				1			0.25	0.58	2	1.59	1.08
gbhe	1								0.13	0.29	1	0.79	0.54
gcfl				3			1		0.50	1.16	2	1.59	1.37
hawo		1						1	0.25	0.58	2	1.59	1.08
howr	1	1	1	1	4	1	1		1.25	2.90	7	5.56	4.23
inbu	4	6	1	3	2	1	3	1	2.63	6.09	8	6.35	6.22
lefl						1			0.13	0.29	1	0.79	0.54
mall							1		0.13	0.29	1	0.79	0.54
modo				2					0.25	0.58	1	0.79	0.69
mowa			1	1	4		1		0.88	2.03	4	3.17	2.60
nawa			2	1					0.38	0.87	2	1.59	1.23
noca			1						0.13	0.29	1	0.79	0.54
nofl	2	1							0.38	0.87	2	1.59	1.23
nowa		2		5	1	1		2	1.38	3.19	5	3.97	3.58
rbgr					2				0.25	0.58	1	0.79	0.69
rbnu						2		1	0.38	0.87	2	1.59	1.23
sosp	2	11	6	4	15	10	6	4	7.25	16.81	8	6.35	11.58
spsa								1	0.13	0.29	1	0.79	0.54
wiwr		1	2	1	2	2	2	4	1.75	4.06	7	5.56	4.81
wodu								6	0.75	1.74	1	0.79	1.27
wtsp	2	4	3	8	8	1	2	5	4.13	9.57	8	6.35	7.96
yrwa					1				0.13	0.29	1	0.79	0.54
Total									43.13	100.00	126	100.00	100.00

Alton Swamp

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	3	5	4	2	1	4
B	10	3	5	4	2	1	4
C	10	3	5	4	2	1	4
D	10	3	5	4	2	1	4
Total	10	3	5	4	2	1	4

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	39.1	77.8	78.6	10.8	13.5	8	18	28	52	96.3	30
B	68.8	25	17.2	8.3	14.5	35	64	29	9	81.3	70
C	86.7	7.7	16.7	7.3	13.8	19	39	6	12	95	75
D	55.3	5.8	7.1	2.2	4.1	15	52	42	19	86.3	55
Total	62.48	29.08	29.90	7.15	11.48	19.25	43.25	26.25	23.00	89.73	57.50

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
alde	15	1			16	5.80	75.5	4			79.5	2.12	2	7.92
amel	3				3	1.09	38				38	1.01	1	2.10
bafi	9	24	14	39	86	31.16	105.5	307	211.5	354	978	26.09	4	57.25
bapo	6				6	2.17	57.5				57.5	1.53	1	3.71
blas	2	3		3	8	2.90	33	52.5		14.5	100	2.67	3	5.57
tama		2		7	9	3.26		41.5		148	189.5	5.05	2	8.32
tras	6	1	2		9	3.26	141	32	61		234	6.24	3	9.50
whas	1				1	0.36	6.5				6.5	0.17	1	0.54
whbi	3	14	2	3	22	7.97	31	201.5	23	70	325.5	8.68	4	16.65
whsp	1	1		2	4	1.45	28	30		67.5	125.5	3.35	2	4.80
Total					276	100					3749	100.00	26	200.00

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	01/07/96	30/07/97	27/06/97	06/06/98	09/07/98	13/08/98	23/06/99	13/07/99	average abundance	relative abundance	frequency	relative frequency	importance value
amro		1				1			0.25	3.92	2	8.70	6.31
bcch				2	2	10	1		1.88	29.41	4	17.39	23.40
brcr		2						2	0.50	7.84	2	8.70	8.27
btgw							1		0.13	1.96	1	4.35	3.15
dowo				1					0.13	1.96	1	4.35	3.15
nawa				1	2				0.38	5.88	2	8.70	7.29
nowa						1			0.13	1.96	1	4.35	3.15
oven					2		1		0.38	5.88	2	8.70	7.29
rbnu		3			4	4		1	1.50	23.53	4	17.39	20.46
rugr								6	0.75	11.76	1	4.35	8.06
wiwr							1		0.13	1.96	1	4.35	3.15
wtsp	1								0.13	1.96	1	4.35	3.15
yrwa			1						0.13	1.96	1	4.35	3.15
Total									6.38	100.00	23	100.00	100.00

Alton Plantation

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	6	0	3	4	1	4	3
B	7	4	3	4	1	4	3
C	6	5	3	4	1	4	3
D	4	3	3	4	1	4	3
Total	5.75	3	3	4	1	4	3

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	25.8	18.8	43.5	1.6	3.2	12	16	46	32	44	40
B	54.4	0	36.4	0	0	1	31	26	13	9.5	60
C	45.6	0	0	0	0	0	26	31	19	10	60
D	73.4	21.3	29.4	4.9	6.2	7	47	17	0	6.5	65
Total	49.8	10.03	27.33	1.63	2.35	5.00	30.00	30.00	16.00	17.50	56.25

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
bafi	27	20	34	10	91	38.56	197	129	232	54	612	19.50	4	58.06
blch	19	2		1	22	9.32	125.5	12.5		8	146	4.65	3	13.97
gras		2		10	12	5.08		11.5		187	198.5	6.32	2	11.41
mama	3				3	1.27	19.5				19.5	0.62	1	1.89
repi	8	28	22	28	86	36.44	178	685	513	560	1936	61.68	4	98.12
whas	1	5		2	8	3.39	10.5	27		15.5	53	1.69	3	5.08
whpi				10	10	4.24				149.5	149.5	4.76	1	9.00
whsp	3		1		4	1.69	18		6.5		24.5	0.78	2	2.48
Total					236	100					3139	100	20	200

Bird Population Parameters

Bird Species	Observation Dates								Population Characteristics				
	01/07/96	30/07/97	27/06/97	06/06/98	09/07/98	13/08/98	23/06/99	13/07/99	average abundance	relative abundance	frequency	relative frequency	importance value
amcr	3		2				3		1.00	4.37	3	4.17	4.27
amro	1	1		2		5			1.13	4.92	4	5.56	5.24
bcch	2	5	7	5	14	8	4	11	7.00	30.59	8	11.11	20.85
blja	2		1	2	3				1.00	4.37	4	5.56	4.96
brcr	1	2			1			2	0.75	3.28	4	5.56	4.42
btgw				1	1			2	0.50	2.19	3	4.17	3.18
cewa						5			0.63	2.73	1	1.39	2.06
chsp				1	2		2	1	0.75	3.28	4	5.56	4.42
dowo					1	1			0.25	1.09	2	2.78	1.94
ewpe						3			0.38	1.64	1	1.39	1.51
hofi	1								0.13	0.55	1	1.39	0.97
inbu				2					0.25	1.09	1	1.39	1.24
nawa	1			2					0.38	1.64	2	2.78	2.21
noca		1	1						0.25	1.09	2	2.78	1.94
nofl	1	1							0.25	1.09	2	2.78	1.94
oven	2		2	4	2		1	1	1.50	6.56	6	8.33	7.44
piwa	2		1	2	7		3	2	2.13	9.29	6	8.33	8.81
piwo	2						1		0.38	1.64	2	2.78	2.21
rbnu	2	4	1		7	3		6	2.88	12.57	6	8.33	10.45
rtha								2	0.25	1.09	1	1.39	1.24
rwbl	1								0.13	0.55	1	1.39	0.97
wbnu	1								0.13	0.55	1	1.39	0.97
wiwr		1	1	1				1	0.50	2.19	4	5.56	3.87
yrwa		1					1	1	0.38	1.64	3	4.17	2.90
Total									22.88	99.98	72	100.00	99.99

APPENDIX M

PALGRAVE UPLAND
PALGRAVE VALLEY
PALGRAVE PLANTATION UPLAND ONE
PALGRAVE PLANTATION UPLAND TWO

Palgrave Upland

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	6	16	1	4	2	1	3
B	6	11	1	4	1	1	3
C	2	12	1	4	2	2	3
D	8	16	1	4	1	2	3
Total	5.5	13.75	1	4	1.5	1.5	3

Vegetation Structural

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	70.6	100	100	3	3.5	3	24	10	3	5.8	95
B	68.9	100	100	6.1	11.5	0	31	14	4	32.5	85
C	21.4	100	100	2.5	8.8	4	9	33	6	3.8	90
D	80	100	100	0	0	0	4	1	62	83.8	50
Total	60.23	100.00	100.00	2.90	5.95	1.75	17.00	14.50	18.75	31.48	80.00

Vegetation Species Parameters

Tree Species	Density						Cover						Frequency	Importance Value Density + Cover
	Stops				Total	Relative	Stops				Total	Relative		
	1	2	3	4			1	2	3	4				
ambe			6		6	4.76			186.5		186.5	9.09	1	13.85
bass	2	1			3	2.38	71.5	15.5			87	4.24	2	6.62
suma	25	25	36	5	91	72.22	341	267.5	348	171	1127.5	54.97	4	127.19
whas	7	19			26	20.63	166	484			650	31.69	2	52.32
Total					126	100.00					2051	100.00	9	199.98

Bird Population Parameters

Bird Species	Observation Date							Population Characteristics				
	20/06/96	19/07/96	03/07/97	06/08/97	18/06/98	02/08/98	02/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amro	2		2		7	7	2	5	8.47	2.86	12.50	10.49
bcch	2			2		1		3	5.08	0.71	3.13	4.10
blja			2		3	2	1	4	6.78	1.14	5.00	5.89
brcr					2			1	1.69	0.29	1.25	1.47
btbw					1			1	1.69	0.14	0.63	1.16
cewa			2			1		2	3.39	0.43	1.88	2.63
dowo						1		1	1.69	0.14	0.63	1.16
ewpe	1	2	1	4	6	6	2	7	11.86	3.14	13.75	12.81
gcfl			1		1	2	1	4	6.78	0.71	3.13	4.95
hawo			1					1	1.69	0.14	0.63	1.16
nofl				2	2			2	3.39	0.57	2.50	2.94
oven	2		2		5		1	4	6.78	1.43	6.25	6.51
rbgr		1	2		2			3	5.08	0.71	3.13	4.10
revi	4	4	5	3	15	7	10	7	11.86	6.86	30.00	20.93
scta	1	2	1	1	1			5	8.47	0.86	3.75	6.11
wbnu		1	1	2		2		4	6.78	0.86	3.75	5.26
wiwr						1		1	1.69	0.14	0.63	1.16
woth			1	5	3		3	4	6.78	1.71	7.50	7.14
Total								59	100.00	22.86	100.00	100.00

Palgrave Valley

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	10	9	5	4	2	1	4
B	10	9	5	4	2	1	4
C	10	9	5	4	2	1	4
Total	10	9	5	4	2	1	4

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	49.3	90	61.8	1.5	1.8	4	33	34	75	18.8	60
B	58.5	68.8	91.2	23.7	41.1	5	48	34	9	66.3	70
C	44.4	14.6	20	34.4	67.1	0	48	60	17	60	40
Total	50.73	57.80	57.67	19.87	36.67	3.00	43.00	42.67	33.67	48.37	56.67

Vegetation Species Parameters

Tree Species	Density					Cover					Frequency	Importance Value Density + Cover
	Stops			Total	Relative	Stops			Total	Relative		
	1	2	3			1	2	3				
amel	5	9	14	28	10.89	42.5	73	129	244.5	8.68	3	19.57
bass	1	4		5	1.95	11.5	36.5		48	1.70	2	3.65
blas	11	8		19	7.39	94.5	128.5		223	7.92	2	15.31
eahe		1	10	11	4.28		28	93	121	4.30	2	8.58
ewce	89	17	6	112	43.58	902	351.5	66	1319.5	46.84	3	90.42
rema		4	21	25	9.73		33.5	120.5	154	5.47	2	15.19
suma		1	5	6	2.33		7	154	161	5.72	2	8.05
tras			1	1	0.39			8	8	0.28	1	0.67
whas			9	9	3.50			60	60	2.13	1	5.63
whbi	1	1	1	3	1.17	14	22	21	57	2.02	3	3.19
yebi	1	37		38	14.79	5	416		421	14.94	2	29.73
Total				257	100				2817	100	23	200

Bird Population Parameters

Bird Species	Observation Date							Population Characteristics				
	20/06/96	19/07/96	03/07/97	06/08/97	18/06/98	02/08/98	02/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amgo							1	1	2.04	0.19	1.06	1.55
amro			3	2				2	4.08	0.95	5.32	4.70
bcch	3	2	4	6	4	12	4	7	14.29	6.67	37.23	25.76
blja	1				1			2	4.08	0.38	2.13	3.10
brcr						1		1	2.04	0.19	1.06	1.55
btgw			2	1	3	2	3	5	10.20	2.09	11.70	10.95
bwha						1		1	2.04	0.19	1.06	1.55
bwwa			1					1	2.04	0.19	1.06	1.55
cewa						2		1	2.04	0.38	2.13	2.08
dowo							1	1	2.04	0.19	1.06	1.55
ewpe	1			1	1			3	6.12	0.57	3.19	4.66
gcfl			1	1	2			3	6.12	0.76	4.26	5.19
hawo					2			1	2.04	0.38	2.13	2.08
noca							1	1	2.04	0.19	1.06	1.55
nofl			1					1	2.04	0.19	1.06	1.55
oven				2	1		1	3	6.12	0.76	4.26	5.19
piwa							1	1	2.04	0.19	1.06	1.55
rbgr	1							1	2.04	0.19	1.06	1.55
rbnu						3	1	2	4.08	0.76	4.26	4.17
revi	1			1		2		3	6.12	0.76	4.26	5.19
rugr						2	1	2	4.08	0.57	3.19	3.64
scta				1	1			2	4.08	0.38	2.13	3.10
wiwr			1	1		1		3	6.12	0.57	3.19	4.66
woth							1	1	2.04	0.19	1.06	1.55
Total								49	100.00	17.90	100.00	100.00

Palgrave Plantation One

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	9	18	1	4	3	5	1
B	7	19	1	4	1	5	2
C	10	17	1	4	1	5	4
Total	8.70	18	1	4	1.67	5	2.33

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	64.4	7.9	81	1.8	3	11	38	21	7	9.5	nd
B	96.3	0	100	0	0	15	52	2	16	41.3	85
C	100	0	na	0	0	24	50	0	12	53.8	75
Total	86.90	2.63	90.50	0.60	1.00	16.66	46.67	7.67	11.67	34.87	80.00

Vegetation Species Parameters

Tree Species	Density					Cover					Frequency	Importance Value Density + Cover
	Stops			Total	Relative	Stops			Total	Relative		
	1	2	3			1	2	3				
amel	4			4	3.39	62			62	3.25	1	6.64
blch	5	16		21	17.80	20.5	121.5		142	7.45	2	25.24
ewce	1			1	0.85	11			11	0.58	1	1.42
japi		2		2	1.69		27.5		27.5	1.44	1	3.14
repi	2	6	47	55	46.61	51.5	185	763	999.5	52.41	3	99.02
whas	1	9		10	8.47	5	52.5		57.5	3.02	2	11.49
whpi	19	6		25	21.19	461	146.5		607.5	31.86	2	53.04
Total				118	100				1907	100.00	12	200.00

Bird Population Parameters

Bird Species	Observation Date							Population Characteristics				
	20/06/96	19/07/96	03/07/97	06/08/97	18/06/98	02/08/98	02/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amro				2		1		0.57	2.91	2	4.65	3.78
bcch	4	2	1	10	1	9	4	5.90	30.10	7	16.28	23.19
bhco	1							0.19	0.97	1	2.33	1.65
blja							1	0.19	0.97	1	2.33	1.65
brcr					1			0.19	0.97	1	2.33	1.65
cewa	3			5		2	2	2.29	11.65	4	9.30	10.48
chsp	4		2		1			1.33	6.80	3	6.98	6.89
inbu	1						1	0.38	1.94	2	4.65	3.30
oven	3	1	3		4		1	2.29	11.65	5	11.63	11.64
piwa	2	1			1	3	2	1.71	8.74	5	11.63	10.18
rbgr				4				0.76	3.88	1	2.33	3.10
rbnu				2		1		0.57	2.91	2	4.65	3.78
revi				1				0.19	0.97	1	2.33	1.65
wiwr						1		0.19	0.97	1	2.33	1.65
yrwa	2	1	3	1	5	2	1	2.86	14.57	7	16.28	15.42
Total								19.61	100.02	43	100	100.01

Palgrave Plantation Two

Landform Parameters

Stops	slope angle	slope aspect	landscape position	land unit	natural disturbance	human disturbance	site position
A	9	2	1	4	1	5	4
B	6	6	1	4	3	5	1
C	8	6	1	4	1	5	2
Total	7.70	4.70	1	4	1.67	5	2.33

Vegetation Structural Parameters

Stops	oldratio	olddec	newdec	multinum	multibas	snags	oldstem	newstem	sapling	grcover	cancover
A	78.1	16	85.7	0	0	5	25	7	129	41.3	40
B	35.7	6.7	100	7.7	8.5	14	15	27	15	58.8	15
C	97.9	0	0	2.1	3.2	3	47	1	0	4	85
Total	70.57	7.57	61.90	3.27	3.90	7.34	29.00	11.67	48.00	34.70	46.67

Vegetation Species Parameters

Tree Species	Density					Cover					Frequency	Importance Value Density + Cover
	Stops			Total	Relative	Stops			Total	Relative		
	1	2	3			1	2	3				
amel	4			4	3.39	62			62	3.25	1	6.64
blch	5	16		21	17.80	20.5	121.5		142	7.45	2	25.24
ewce	1			1	0.85	11			11	0.58	1	1.42
japi		2		2	1.69		27.5		27.5	1.44	1	3.14
repi	2	6	47	55	46.61	51.5	185	763	999.5	52.41	3	99.02
whas	1	9		10	8.47	5	52.5		57.5	3.02	2	11.49
whpi	19	6		25	21.19	461	146.5		607.5	31.86	2	53.04
Total				118	100				1907	100.00	12	200.00

Bird Population Parameters

Bird Species	Observation Date							Population Characteristics				
	20/06/96	19/07/96	03/07/97	06/08/97	18/06/98	02/08/98	02/07/99	abundance	relative abundance	frequency	relative frequency	importance value
amro	2		1		3	1		1.33	4.86	4	7.02	5.94
bcch	3	4		7	2	6	4	4.95	18.06	6	10.53	14.29
bhvi					1		2	0.57	2.08	2	3.51	2.80
blja	2	5	1	2	2	4	2	3.43	12.50	7	12.28	12.39
brcr				1	1			0.38	1.39	2	3.51	2.45
btgw					1			0.19	0.69	1	1.75	1.22
bwwa					1			0.19	0.69	1	1.75	1.22
cewa			1			2		0.57	2.08	2	3.51	2.80
chsp	2	1	1	5	3			2.29	8.33	5	8.77	8.55
nogo							2	0.38	1.39	1	1.75	1.57
ewpe			1	1	1	1	1	0.95	3.47	5	8.77	6.12
gcfl				1				0.19	0.69	1	1.75	1.22
hawo					1			0.19	0.69	1	1.75	1.22
nofl		4						0.76	2.78	1	1.75	2.27
oven	3		4		4		5	3.05	11.11	4	7.02	9.06
piwa	2	2	5	6	3	4	4	4.95	18.06	7	12.28	15.17
rbnu				4	1	4	3	2.29	8.33	4	7.02	7.68
wiwr						1		0.19	0.69	1	1.75	1.22
woth			2					0.38	1.39	1	1.75	1.57
yrwa	1							0.19	0.69	1	1.75	1.22
total								27.42	100.00	57	100	100.00

References

Able, K.P. and Noon, B.R. 1976. Avian community structure along elevational gradients in the northeastern United States. *Oecologia* 26:275-294.

Agnew, C. and Spencer, T. 1999. Editorial: Where have all the physical geographers gone? *Transactions of the Institute of British Geographers* 24:5-9.

Allen, T.F.H. and Starr, T.B. 1982. *Hierarchy: Perspectives for Ecological Complexity*. University of Chicago Press, Chicago.

Anderson, B.W. and Ohmart, R.D. 1981. Comparisons of avian census results using variable distance transect and variable circular plot techniques. *Studies in Avian Biology* No. 6:186-192.

Andrewartha, H.G. and Birch, L.C. 1954. *The Distribution and Abundance of Animals*. University of Chicago Press, Chicago.

Askins, R.A. 2000. *Restoring North America's Birds: Lessons from Landscape Ecology*. Yale University Press, New Haven.

Askins, A.R., Lynch, J.F., and Greenberg, R. 1990. Population declines in migratory birds in eastern North America. In D.M. Powers (ed.), *Current Ornithology*, vol. 7. Plenum Press, New York.

Bailey, R.G. 1996. *Ecosystem Geography*. Springer-Verlag, New York.

Bailey, R.G., Pfister, R.D. and Henderson, J.A. 1978. Nature of land and resource classification: A review. *Journal of Forestry* 76:650-655.

Baker, W.L. 1992. The landscape ecology of large disturbances in the design and management of nature reserves. *Landscape Ecology* 7:181-194.

Bazzaz, F.A. 1983. Characteristics of populations in relation to disturbance in natural and man-modified ecosystems. In H.A. Mooney and M. Godron, eds. *Disturbance and Ecosystems: Components of Response*. Springer-Verlag, Berlin. pp. 259-275.

Bazzaz, F.A. 1996. *Plants in changing environments: Linking physiological, population and community ecology*. Cambridge University Press, Cambridge.

Beedy, E.C. 1981. Bird communities and forest structure in the Sierra Nevada of California. *Condor* 83:97-105.

Belcher, J.W., Keddy, P.A., and Catling, P.M. 1992. Alvar vegetation in Canada: a multivariate description at two scales. *Canadian Journal of Botany* 70:1279-1291.

Bernstein, C., Krebs, J.R. and Kacelnik, A. 1991. Distribution of birds amongst habitats: theory and relevance to conservation. In *Bird Population Studies: Relevance to Conservation and Management*, C.M. Perrins, J.-D. Lebreton and G.J.M. Hirons (eds.). Oxford University Press, Oxford. pp. 317-345.

Blake, J.G. and Hoppes, W.G. 1986. Influence of resource abundance on use of tree-fall gaps by birds in an isolated woodlot. *Auk* 103:328-340.

Block, W.M. and Brennan, 1993. The habitat concept in ornithology: Theory and applications. *Current Ornithology* 11:35-91.

Bocking, S. 2001. The politics of endangered species: a historical perspective. In *Politics of the Wild: Canada and Endangered Species*. K. Beazley and R. Boardman (eds.), Oxford University Press, Toronto. pp 117-126.

Böhning-Gaese, K. 1997. Determinants of avian species richness at different spatial scales. *Journal of Biogeography* 24:49-60.

Bond, R.R. 1957. Ecological distribution of breeding birds in the upland forests of southern Wisconsin. *Ecological Monographs* 27:351-384.

Boorman, S.A. and Levitt, P.R. 1973. Group selection on the boundary of a stable population. *Theorectical Population Biology* 4:85-128.

Bormann, F.H. and Likens, G.E. 1979. Catastrophic disturbance and the steady state in the northern hardwood forest. *American Scientist* 67:660-669.

Bosakowski, T., Smith, D.G. and Speiser, R. 1992. Status, nesting density, and macrohabitat selection of Red-shouldered Hawks in northern New Jersey. *Wilson Bulletin* 104:434-446.

Botkin, D.B. 1989. Science and the global environment. In *Changing the Global Environment*, D.B. Botkin, M.F. Caswell, J.E. Estes, and A.A. Orio (eds.). Academic Press, Boston. pp. 3-14.

Bourgeron, P.S. and Jensen, M.E. 1994. An overview of ecological principles for ecosystem management. In *Ecosystem Management: Principles and Applications*. USDA. U.S. Forest Service. Pacific Northwest Research Station PNW-GTR-36. pp. 45-57.

Brawn, J.D. and Robinson, S.K. 1996. Source-sink dynamics may complicate the analysis of long-term census data. *Ecology* 77:3-12.

Brittingham, M.C. and Temple, S.A. 1983. Have cowbirds caused forest songbirds to decline? *BioScience* 33:31-35.

Brokaw, N.V.L. 1982. The definition of treefall gap and its effect on measures of forest dynamics. *Biotropica* 14: 158-160.

Brokaw, N. 1985. Gap-phase regeneration in tropical forest. *Ecology* 66:682-687.

Brown, J.H., Reichman, O.J. and Davidson, D.W. 1979. Granivory in desert ecosystems. *Annual Review of Ecology and Systematics* 10:201-227.

Bull, E.L. 1981. Indirect estimates of abundance of birds. *Studies in Avian Biology* No. 6:76-80.

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

Burrows, C.J. 1990. *Processes of Vegetation Change*. Unwin Hyman, London.

Burrows, C.J. and Burrows, V.L. 1976. *Procedures for the study of snow avalanche chronology using growth layers of woody plants*. INSTAAR University of Colorado, Boulder, Occasional Paper No. 23.

Butler, D.R. 1995. *Zoogeomorphology*. Cambridge University Press, New York.

Cadman, M.D., Eagles, P.F.J. and Helleiner, F.M. 1987. *Atlas of the breeding birds of Ontario*. University of Waterloo Press, Waterloo, Ontario.

Cain, M.D. and Shelton, M.G. 1995. Thirty-eight years of autogenic, woody understory dynamics in a mature, temperate pine-oak forest. *Canadian Journal of Forest Research* 25:1997-2009.

Canterbury, G.E. and Blockstein, D.E. 1997. Local changes in a breeding bird community following forest disturbance. *Journal of Field Ornithology* 68:537-546.

Canterbury, G.E., Martin, T.E., Petit, D.R., Petit, L.J., and Bradford, D.F. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. *Conservation Biology* 14:544-557.

Cantlon, J.E. 1953. Vegetation and microclimates on north and south slopes of Cushetunk Mountain, New Jersey. *Ecological Monographs* 23:241-270.

Carey, M. and Nolan, V. 1975. Polygyny in indigo buntings: a hypothesis tested. *Science* 190:1296-1297.

Carlton, G.C. and Bazzaz, F.A. 1998. Resource congruence and forest regeneration following an experimental hurricane blowdown. *Ecology* 79:1305-1319.

Chazdon, R.I. and Fetcher, N. 1984. Photosynthetic light environments in a lowland tropical rain forest in Costa Rica. *Journal of Ecology* 72:553-564.

Chorley, R.J. and Kennedy, B.A. 1971. *Physical Geography: A Systems Approach*. Prentice Hall, London.

Clark, D.B., Clark, D.A., and Rich, P.M. 1993. Comparative analysis of microhabitat utilization by saplings of nine tree species in neotropical rain forest. *Biotropica* 254:397-407.

Clark, J. and Pelton, M. 1999. Management of a large carnivore: black bear. In *Ecosystem Management for Sustainability: Principles and Practices Illustrated by a Regional Biosphere Reserve Cooperative*. J.D. Peine (ed.). Lewis Publishers, New York. pp. 209-224.

Cody, M.L. 1974. *Competition and the Structure of Bird Communities*. Princeton University Press, Princeton, New Jersey.

Cody, M.L. 1975. Towards a theory of continental species diversities: bird species distributions over Mediterranean habitat gradients. In *Ecology and Evolution of Communities*, M.L. Cody and J.M. Diamond (eds.). Belknap Press, Cambridge, Massachusetts. pp. 214-257.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199:1302-1310.

COSEWIC. 2000. *Canadian Species at Risk*. Committee on the Status of Wildlife in Canada, Ottawa.

Couturier, A., McCracken, J. and Bradstreet, M. 1998. *Conservation Priorities for the Birds of the Niagara Escarpment Plan Area* (draft report). Bird Studies Canada/Long Point Bird Observatory.

Cowell, C.M. 1993. Environmental gradients in secondary forests of the Georgia Piedmont, U.S.A. *Journal of Biogeography* 20:199-207.

Cowell, C.M. and Gallien, G.S. 1997. Human and environmental influences on forest composition of a Tennessee loess bluff. *Physical Geography* 18:232-245.

Cowell, D. 1995. Geomorphological research on the northern Bruce Peninsula and Tobermory Islands. In *Leading Edge '94 Conference Proceedings*. S. Carty, G. Whitelaw, J. Connolly, and M. Alles-De Vos (eds.). Ministry of Energy and Environment, Toronto. pp. 336-349.

Cox, G.W. 1985. The evolution of avian migration systems between temperate and tropical regions of the New World. *American Naturalist* 126:451-474.

Credit Valley Conservation (CVC), 1998. *Credit Watershed Bird Species of Conservation Concern*. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation (CVC), 1999. *Habitat Utilization Table for the Birds of the Credit Watershed*. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation, 2000. Land Owner Contact. Map 1:20000, Credit Valley Conservation, Meadowvale, Ontario.

Cremeans, D.W. and Kalisz, P.J. 1988. Distribution and characteristics of windthrow microtopography on the Cumberland Plateau of Kentucky. *Soil Science Society of America Journal* 52: 816-821.

Currie, D.J. 1991. Energy and large-scale patterns of animal- and palnt-species richness. *American Naturalist* 137:27-49.

Dalling, J.W., Hubbell, S.P. and Silvera, K. 1998. Seed dispersal, seedling establishment and gap partitioning among tropical pioneer trees. *Journal of Ecology* 86:674-689.

Dawson, D.K. 1981. Sampling in rugged terrain. *Studies in Avian Biology* No. 6:311-315.

Day, F.P. and Monk, C.D. 1974. Vegetation patterns on a southern Appalachian watershed. *Ecology* 55: 1064-1074.

DeGraaf, R.M. and Miller, R.I. 1996. The importance of disturbance and land-use history of New England: implications for forested landscapes and wildlife conservation. In *Conservation of Faunal Diversity in Forested Landscapes*. R.M. DeGraaf and R.I. Miller (eds.), Chapman and Hall, New York. pp. 3-36.

DeJong, T.M. 1975. A comparison of three diversity indices based on their components of richness and evenness. *Oikos* 26:222-227.

del Moral, R. and Fleming, R.S. 1979. Structure of coniferous forest communities in western Washington: diversity and ecotope properties. *Vegetatio* 41:143-154.

den Boer, P.J. 1981. On the survival of populations in a heterogeneous and variable environment. *Oecologia* 50:39-53.

Denny, C.S. and Goodlett, J.C. 1956. Microrelief resulting from fallen trees. In Surficial Geology and Geomorphology of Potter County, Pennsylvania. *U.S. Geological Survey Professional Paper* 288: 59-66.

Denslow, J.S. 1980. Gap partitioning among tropical rainforest trees. *Biotropica* 12(Suppl.):47-55.

Denslow, J.S. 1995. Disturbance and diversity in tropical rain forests: the density effect. *Ecological Applications* 5:962-968.

Denslow, J.S., Ellison, A.M., and Sandord, R.E. 1998. Treefall gap size effects on above- and below-ground processes in a tropical wet forest. *Journal of Ecology* 86:597-609.

Diaz, M., Carbonell, R., Santos, T. and Telleria, J.L. 1998. Breeding bird communities in pine plantations of the Spanish plateau: biogeography, landscape and vegetation effects. *Journal of Applied Ecology*. 35: 562-574.

Drury, W.H. and Nisbet, I.C.T. 1971. Inter-relations between developmental models in geomorphology, plant ecology and animal ecology. *General Systems* 16:57-68.

Dunn, E.H., Hussell, D.J.T., and Welsh, D.A. 1999. Priority-setting tool applied to Canada's landbirds based on concern and responsibility for species. *Conservation Biology* 13:1404-1415.

Dunning, J.B. 1986. Shrub-steppe birds revisited: implications for community theory. *American Naturalist*. 128:82-98.

Dunning, J.B. and Brown, J.H. 1982. Summer rainfall and winter sparrow densities: a test of food limitation hypothesis. *Auk* 99:123-129.

ECOMAP. 1993. *National hierarchical framework of ecological units*. Unpublished administrative paper. Washington, DC, U.S. Department of Agriculture, Forest Service.

Edwards, D.K., Dorsey, G.L. and Crawford, J.A. 1981. A comparison of three avian census methods. *Studies in Avian Biology* No. 6:170-176.

Evans, D.J.A. and Rea, B.R. 1999. Geomorphology and sedimentology of surging glaciers:a land-systems approach. *Annals of Glaciology* 28:75-82.

Evans, F.C. 1956. Ecosystem as the basic unit in ecology. *Science* 123:1227-1228.

Fahey, B.F.D. and Dagesse, D.F. 1984. An experimental study of the effect of humidity and temperature variation on the granular disintegration of argillaceous carbonate rocks in cold climates. *Arctic and Alpine Research* 16:291-298.

Fahey, B.F.D. and Lefebvre, T.H. 1988. The freeze-thaw weathering regime at a section of the Niagara Escarpment on the Bruce Peninsula, Southern Ontario, Canada. *Earth Surface Processes and Landforms* 13:293-304.

Fahrig, L. and Merriam, G. 1994. Conservation of fragmented populations. *Conservation Biology* 8:50-59.

Faith, D.P. and Walker, P.A. 1996. How do indicator groups provide information about the relative biodiversity of different sets of areas?: on hotspots, complementarity and pattern-based approaches. *Biodiversity Letters* 3:18-25.

Feinsinger, P., Busby, W.H., Murray, K.G., Beach, J.H., Pounds, W.Z. and Linhart, Y.B. 1988. Mixed support for spatial heterogeneity in species interactions: Hummingbirds in a tropical disturbance mosaic. *American Naturalist* 131:33-57.

Flaccus, E. 1959. Revegetation of landslides in the White Mountains of New Hampshire. *Ecology* 40:692-703.

Flather, C.H., Knowles, M.S. and Kendall, I.A. 1998. Threatened and Endangered Species Geography: characteristics of hot spots in the conterminous United States. *BioScience* 48:365-376.

Flather, C.H. and Sauer, J.R. 1996. Using landscape ecology to test hypotheses about large-scale abundance patterns in migratory birds. *Ecology* 77:28-35.

Forcier, L.K. 1975. Reproductive strategies and the co-occurrence of climax tree species. *Science* 189:808-809.

Ford, W.M., Odom, R.H., Hale, P.E., and Chapman, B.R. 2000. Stand age, stand characteristics and landform effects on understory herbaceous communities in Southern Appalachian cove-hardwoods. *Biological Conservation* 93:1237-1246.

Forman, R.T.T. 1995. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge.

Forman, R.T.T., Galli, A.E. and Leck, C.F. 1976. Forest size and avian diversity in New Jersey woodlots with some land use implications *Oecologia* 26:1-8.

Forman, R.T.T. and Godron, M. 1986. *Landscape Ecology*. John Wiley and Sons, New York.

Foster, D.R. and Boose, E.R. 1992. Patterns of forest damage resulting from catastrophic wind in central New England, USA. *Journal of Ecology* 80:79-98.

Fox, J.F. 1979. Intermediate-disturbance hypothesis. *Science* 204:1344-1345.

Fralish, J.S. 1994. The effect of site environment on forest productivity in the Illinois Shawnee Hills. *Ecological Applications* 4:134-143.

Fralish, J.S., Crooks, F.B., Chambers, J.L., and Harty, F.M. 1991. Comparison of presettlement, second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. *American Midland Naturalist* 125:294-309.

Frank, E.C. and Lee, R. 1966. Potential solar beam irradiation on slopes for 30 to 50 degrees latitude. *U.S. Forest Service Research Paper. No. RM-18.*

Franzreb, K.E. and Ohmart, R.D. 1978. The effects of timber harvesting on breeding birds in a mixed-coniferous forest. *Condor* 80: 431-441.

Freemark, K.E. and Collins, B. 1992. Landscape ecology of birds breeding in temperate forest fragments. In *Ecology and conservation of neotropical migrant landbirds*, J.M. Hagan and D.W. Johnston, eds. Smithsonian Institute Press, Washington, D.C.

Freemark, K.E., Dunning, J.B., Hejl, S.J. and Probst, J.R. 1995. A landscape ecology perspective for research, conservation, and management. In *Ecology and Management of Neotropical Migratory Birds*, T. Martin and D. Finch (eds.). Oxford University Press, New York.

Freemark, K.E. and Merriam, H.G. 1986. Importance of area and habitat heterogeneity on bird assemblages in temperate forest fragments. *Biological Conservation* 36:115-141.

Fretwell, S.D. 1972. *Populations in a Seasonal Environment*. Princeton University Press, Princeton, New Jersey.

Fretwell, S.D. and Lucas, H.L., Jr. 1970. On territorial behaviour and other factors influencing habitat distribution in birds. I. Theoretical development. *Acta Biotheoretica*. 19:16-36.

Friesen, L.E., Eagles, P.F.J., and Mackay, R.J. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. *Conservation Biology* 9:1408-1414.

Frissell, S.S. 1973. The importance of fire as a natural ecological factor in Itasca State park, Minnesota. *Quaternary Research* 3:397-407.

Furness, R.W., Greenwood, J.J.D. and Jarvis, P.J. 1993. Can birds be used to monitor the environment? In *Birds as Monitors of Environmental Change*, R.W. Furness and J.J.D. Greenwood (eds.). Chapman and Hall, New York. pp. 1-41.

Gates, J.E. and Gysel, L.W. 1978. Avian nest dispersion and fledgling success in field-forest ecotones. *Ecology* 59:871-883.

Gauch, H.G. and Whittaker, R.H. 1981. Hierarchical classification of community data. *Journal of Ecology* 69:135-152.

Gauch, H.G., Jr. 1982. *Multivariate Analysis and Community Structure*. Cambridge University Press, Cambridge.

Gauthier, D. and Wiken, E. 2001. Avoiding the endangerment of species: the importance of habitats and ecosystems. In *Politics of the Wild: Canada and Endangered Species*. K. Beazley and R. Boardman (eds.), Oxford University Press, Toronto. pp. 49-74.

Geiger, R. 1965. *The Climate Near the Ground*. Harvard University Press, Cambridge, Massachusetts.

Gibbs, J.P. and Faaborg, J. 1990. Estimating the viability of Ovenbird and Kentucky Warbler populations in forest fragments. *Conservation Biology* 4:193-196.

Goguen, C.B. and Mathews, N.E. 1998. Songbird community composition and nesting success in grazed and ungrazed pinyon-juniper woodlands. *Journal of Wildlife Management* 62:474-484.

Gregory, S.V., Swanson, F.J., McKee, W.A. and Cummins, K.W. 1991. An ecosystem perspective of riparian zones. *BioScience* 41:540-551.

Grieg-Smith, P. 1964. *Quantitative Plant Ecology*. Butterworths, London.

Grime, J.P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *American Naturalist* 11:1169-1194.

Grime, J.P. 1979. *Plant Strategies and Vegetation Processes*. Wiley, New York.

Grimm, F.W. 1996. Molluscs of the Alvar Arc and the Niagara Cuesta uplands and barren zones. In *Leading Edge '95 Conference Proceedings*. S. Carty, G. Whitelaw, and S. Powell (eds.). pp. 112-124.

Grubb, P.J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Review* 52:107-145.

Grumbine, R.E. 1994. What is ecosystem management? *Conservation Biology* 9:1408-1414.

Hack, J.T. and Goodlett, J.C. 1960. Geomorphology and forest ecology of a mountain region in the central Applachians. *US Geological Survey Professional Paper* 347, Reston, Virginia.

Hallë, F., Oldeman, R.A. and Tomlinson, P.B. 1978. *Tropical trees and forests: an architectural analysis*. Springer-Verlag, New York.

Hannon, S.J. and Cotterill, S.E. 1998. Nest predation in aspen woodlots in an agricultural area in Alberta: the enemy from within. *Auk* 115:16-25.

Harpley, P.J and Milne, R.J. 1996. The use of avian faunas in delineating wetlands in the Baldwin wetland complex, Southern Ontario. In *Wetlands: Environmental Gradients, Boundaries and Buffers*, (eds.) G. Mulamoottil, B.G. Warner and E.A. McBean, CRC/Lewis Publishers, New York.

Harris L.D. 1984. *The fragmented forest*. University of Chicago Press, Chicago.

Haskell, D.G. 1995. A reevaluation of the effects of forest fragmentation on rates of bird-nest predation. *Conservation Biology* 9:1316-1318.

Helle, E. and Helle, P. 1982. Edge effect on forest bird densities on offshore islands in the northern Gulf of Bothnia. *Annales Zoologici Fennici* 19:165-169.

Hill, M.O. 1979. *TWINSPAN-A FORTRAN Program for Arranging Multivariate Data in an Ordered Two-way Table by Classification of the Individuals and Attributes*. Cornell University, Ithaca, New York.

Hills, A. 1952. *The classification and evaluation of site for forestry*. Research Report 24. Ontario Department of Lands and Forest.

Holling, C.S. 1978. *Adaptive Environmental Assessment and Management*. John Wiley & Sons, New York.

Holmes, R.T., Bonney, R.E., Jr. and Pacala, S.W. 1979. Guild structure of the Hubbard Brook bird community: a multivariate approach. *Ecology* 60:512-520.

Holmes, R.T., Marra, P.P. and Sherry, T.W. 1996. Habitat-specific demography of breeding black-throated blue warblers (Dendroica caerulescens): implications for populations dynamics. *Journal of Animal Ecology* 65:183-195.

Holmes, R.T., Sherry, T.W. and Sturges, F.W. 1986. Bird community dynamics in a temperate deciduous forest: long-term trends at Hubbard Brook. *Ecological Monographs* 56:201-220.

Horn, H.S. 1971. *The Adaptive Geometry of Trees*. Princeton University Press, Princeton, New Jersey.

Host, G.E., Pregitzer, K.S., Ramm, C.W., Hart, J.B. and Cleland, D.T. 1987. Landform-mediated differences in successional pathways among upland forest ecosystems in northwestern lower Michigan. *Forest Science* 33:445-457.

Howard, J.A. and Mitchell, C.W. 1985. *Phytogeomorphology*. John Wiley and Sons, New York.

Howell, D.L. and Chapman, B.R. 1997. Home range and habitat use of Red-shouldered Hawks in Georgia. *Wilson Bulletin* 109:131-144.

Hubbell, S.P., Foster, R.B., O'Brien, S.T., Harms, K.E., Condit, R., Wechsler, B., Wright, S.J., and Loo de Lao, S. 1999. Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science* 283:554-557.

Huggett, R.J. 1991. *Climate, Earth Processes, and Earth History*. Springer, Berlin.

Huggett, R.J. 1995. *Geoecology: An Evolutionary Approach*. Routledge, New York.

Hughes, F.M.R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21:501-529.

Huhta, E., Jokimaki, J., and Rahko, P. 1998. Distribution and reproductive success of the Pied Flycatcher *Ficedula hypoleuca* in relation to forest patch size and vegetation characteristics; the effect of scale. *Ibis* 140:214-222.

Humphries, C.J. 2000. Form, space and time: which comes first? *Journal of Biogeography* 27:11-15.

Hunt, P.D. 1996. Habitat selection by American Redstarts along a successional gradient in northern hardwoods forest: evaluation of habitat quality. *The Auk* 113:875-888.

Hunter, W.C., Buehler, D.A., Canterbury, R.A., Confer, J.L. and Hamel, P.B. 2001. Conservation of disturbance-dependent birds in eastern North America. *Wildlife Society Bulletin* 29:440-455.

Hupp, C.R. and Osterkamp, W.R. 1996. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology* 66:670-681.

Hutto, R.L., Pletschet, S.M. and Hendricks, P. 1986. A fixed-radius point count method for nonbreeding and breeding use. *Auk* 103:593-602.

Imeson, A.C. 1976. Some effects of burrowing animals on slope processes in the Luxembourg Ardennes, pt. 1: Excavation of animal burrows in experimental plots. *Geografiska Annaler* 58A: 115-125.

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

Izhaki, I. 1999. Passerine bird communities in Mediterranean pine forests. In *Ecology, Biogeography and Management of* Pinus halepensis *and* P. brutia *Forest Ecosystems in the Mediterranean Basin*, G. Ne'eman and L. Traband (eds.). Backhuys Publishers, Leiden, the Netherlands. pp. 1-14.

James, F.C. and Boecklen, W.J. 1984. Interspecific morphological relationships and the densities of birds. In *Ecological Communities: Conceptual Issues and the Evidence*, D.R. Strong, D. Simberloff, L.G. Abele, and A.B. Thistle (eds.). Princeton University Press, Princeton, New Jersey. pp. 458-477.

James, F.C. and Shugart, H.H.,Jr. 1970. A quantitative method of habitat description. *Audubon Field Notes* 24:727-736.

Johnson, E.A. 1985. Disturbance: The process and the response. An epilogue. *Canadian Journal of Forest Research* 15:292-293.

Johnston, D.W. and Odum, E.P. 1956. Breeding bird populations in relation to plant succession on the Piedmont of Georgia. *Ecology* 37:50-62.

Jokimäki, J. and Huhta, E. 1996. Effects of landscape matrix and habitat structure on a bird community in northern Finland: A multi-scale approach. *Ornis Fenniscandia* 73:97-113.

Jones, J., DeBruyn, R.D., Barg, J.J., and Robertson, R.J. 2001. Assessing the effects of natural disturbance on a neotropical migrant songbird. *Ecology* 82:2628-2635.

Karr, J.R. 1968. Habitat and avian diversity on strip-mined land in east-central Illinois. *Condor* 70:348-357.

Karr, J.R. 1971. Structure of avian communities in selected Panama and Illinois habitats. *Ecological Monographs* 41:207-233.

Karr, J.R. and Freemark, K.E. 1985. Disturbance and vertebrates: an integrative perspective. In *The ecology of natural disturbance and patch dynamics*, S.T.A. Pickett and P.S. White, eds. Academic Press, New York. pp. 153-168.

Karr, J.R. and Roth, R.R. 1971. Vegetation structure and avian diversity in several New World areas. *American Naturalist* 105:423-435.

Kauffman, J.B. and Krueger, W.C. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. *Journal of Range Management* 36:685-691.

Kay, J.J. and Schneider, E. 1994. Embracing complexity: the challenge of the ecosystem approach. *Alternatives* 20:32-39.

Keddy, P.A. and Drummond, C.G. 1995. Ecological properties for the evaluation of temperate deciduous forests. In *Ecosystem Monitoring and Protected Areas: Proceedings of the Second International Conference on Science and the Management of Protected Areas*, T.B. Herman, S. Bondrup-Nielsen, J.H.M. Willison, and N.W.P. Munro, eds. SAMPAA, Wolfville. pp. 87-99.

Kelly, P. 1996. Compatibility or conflict: can the ancient cedars of the Niagara Escarpment and the rock climbing community coexist? In *Leading Edge '95: a conference exploring the connections and interrelationships between environment, use and culture in the Niagara Escarpment Biosphere Reserve*, Ministry of Energy and Environment, Collingwood, Ontario. pp.168. (Abstract).

Kelly, P.E., Cook, E.R. and Larson, D.W. 1994. A 1397-year tree-ring chronology of Thuja occidentalis from cliff faces of the Niagara Escarpment, southern Ontario, Canada. Canadian *Journal of Forest Research* 24:1049-1057.

Kelly, P.E. and Larson, D.W. 1997. Dendroecological analysis of the population dynamics of an old-growth forest on cliff-faces of the Niagara Escarpment, Canada. *Journal of Ecology* 85:467-478.

Kilgo, J.C., Sargent, R.A., Miller, K.V. and Chapman, B.R. 1997. Landscape influences on breeding bird communities in hardwood fragments in South Carolina. *Wildlife Society Bulletin* 25:878-885.

Kimmerer, R.W. and Young, C.C. 1996. Effect of gap size and regeneration niche on species coexistence in bryophyte communities. *Bulletin of the Torrey Botanical Club* 123:16-24.

King, D.L, Griffin, C.R. and Degraaf, R.M. 1997a. Effect of clearcut borders on distribution and abundance of forest birds in northern New Hampshire. *Wilson Bulletin* 109:239-245.

King, D.I., Griffin, C.R. and Degraaf, R.M. 1997b. Effect of clearcutting on the habitat use and reproductive success of the Ovenbird (Seiurus aurocapillus) in an extensively forested landscape. *Conservation Biology*

Kirk, D.A., Diamond, A.W., Smith, A.R., Holland, G.E. and Chytyk, P. 1997. Population changes in boreal forest birds in Saskatchewan and Manitoba. *Wilson Bulletin* 109:1-27.

Kneeshaw, D.D. and Bergeron, Y. 1998. Canopy gap characteristics and tree replacement in the southeastern boreal forest. *Ecology* 79:783-794.

Knick, S.T. and Rotenberry, J.T. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. *Conservation Biology* 9:1059-1071.

Kobe, R.K. 1999. Light gradient partitioning among tropical tree species through differential seedling mortality and growth. *Ecology* 80:187-201.

Kotlier, N.B. and Wiens, J.A., 1990. Multiple scaling of patchiness and patch structure: A hierarchical framework for the study of heterogeneity. *Oikos* 59:253-260.

Kroodsma, R.C. 1982. Bird community ecology in power-line corridors in east Tennessee. *Biological Conservation* 23:79-94.

Kroodsma, R.C. 1984. Effect of edge on breeding forest bird species. *Wilson Bulletin* 96:426-436.

Lack, D. 1944. Ecological aspects of species formation in passerine birds. *Ibis* 86:260-286.

Lanyon, S.M. and Thompson, C.F. 1986. Site fidelity and habitat quality as determinants of settlement pattern in male painted bunting. *Condor* 88:206-210.

Larson, D.W., Spring, S.H., Matthes-Sears, U. and Bartlett, R.M. 1989. Organization of the Niagara Escarpment cliff community. *Canadian Journal of Botany* 67:2731-2742.

Larson, D.W. and Kelly, P.E. 1991. The extent of old-growth Thuja occidentalis on the cliffs of the Niagara Escarpment. *Canadian Journal of Botany* 69:1628-1636.

Lay, D. 1938. How valuable are woodland clearings to bird-life? *Wilson Bulletin* 50:254-256.

Lee, H., Bakowsky, W., Riley, J., Bowles, J., Puddister, M., Uhlig, P., and McMurray, S. 1998. *Ecological land classification for 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.

Lent, R.A. and Capen, D.E. 1995. Effects of small-scale habitat disturbance on the ecology of breeding birds in a Vermont (USA) hardwood forest. *Ecography* 18:97-108.

Leopold, A. 1933. *Game Management*. Charles Scribner and Sons, New York.

Lertzman, K.P. 1992. Patterns of gap-phase replacement in a subalpine, old-growth forest. *Ecology* 73:657-669.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73:1943-1967.

Levins, R. 1970. Extinction. In *Lectures on mathematics in the life sciences. Vol. 2.*, M. Gerstenhaber, ed. American Mathematical Society, Providence. pp. 77-107.

Lloyd, A.H., Armbruster, W.S. and Edwards, M.E. 1994. Ecology of a steppe-tundra gradient in interior Alaska. *Journal of Vegetation Science* 5:897-912.

Lloyd, P. and Palmer, A.R. 1998. Abiotic factors as predictors of distribution in southern African Bulbuls. *Auk* 115:404-411.

Lomnicki, A. 1980. Regulation of population density due to individual differences and patchy environment. *Oikos* 35:185-193.

Lord, J.M. and Norton, D.A. 1990. Scale and the spatial concept of fragmentation. *Conservation Biology* 4:197-202.

Lopez de Casenave, J.L., Pelotto, J.P., Caziani, S.M., Mermoz, M., and Protomastro, J. 1998. Responses of avian assemblages to a natural edge in a Chaco semiarid forest in Argentina. *Auk* 115(2):425-435.

Lopez, G. and Moro, M.J. 1997. Birds of Aleppo pine plantations in south-east Spain in relation to vegetation composition and structure. *Journal of Applied Ecology* 34:1257-1272.

Loucks, O.L. 1970. Evolution of diversity, efficiency, and community stability. *American Zoologist* 10:17-25.

Lovejoy, T.E., Bierregaard, R.O.Jr., Rylands, A.B., Malcom, J.R., Quintela, C.E., Harper, L.H., Brown, K. S.Jr., Powell, A.H., Powell, G.V.N., Shubart, H.O.R. and Hayes, M.B. 1986. Edge and other effects of isolation on Amazon forest fragments. In *Conservation Biology: the Science of Scarcity and Diversity*. Ed. M.E. Soule. Sinauer Associates, Sunderland Massachusetts. pp. 79-96.

Lynch, J.F. and Whigham, D.F. 1984. Effects of forest fragmentation on breeding birds communities in Maryland, U.S.A. *Biological Conservation* 28:287-324.

MacArthur, R.H. 1958. Population ecology of some warblers of northeastern coniferous forests. *Ecology* 39:599-619.

MacArthur, R.H. 1964. Environmental factors affecting bird species diversity. *American Naturalist* 98:387-397.

MacArthur, R.H. 1972. *Geographical Ecology*. Harper and Row, New York, New York.

MacArthur, R.H. and MacArthur, J.W. 1961. On bird species diversity. *Ecology* 42:594-598.

MacArthur, R.H., MacArthur, J.W. and Preer, J. 1962. On bird species diversity. II. Prediction of bird census from habitat measurements. *American Naturalist* 96:167-174.

MacArthur, R.H., Recher, H. and Cody, M. 1966. On the relation between habitat selection and species diversity. *American Naturalist* 100:319-322.

MacArthur, R.H. and Wilson, E.O. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton.

MacDonald, C. 1992. Ontario's cavity-nesting birds. *Ontario Birds* 10:93-100.

Major, J. 1951. A functional, factorial approach to plant ecology. *Ecology* 32:392-412.

Martin, T.E. and Karr, J.R. 1986. Patch utilization by migrating birds: resource oriented? *Ornis Scandinavica?*

Maser, C., Geist, J.M., Concannon, D.M., Anderson, R. and Lovell, B. 1979. *Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon*. U.S. Forest Service General Technical Report PWN-99.

Matheson, J.D. and Larson, D.W. 1998. Influence of cliffs on bird community diversity. *Canadian Journal of Zoology* 76:278-287.

May, P.G. 1982. Secondary succession and breeding bird community structure: Patterns of resource utilization. *Oecologia* 55:208-216.

McCormick, F.J. 1999. Principles of ecosystem management and sustainable development. In J.D. Peine (ed.), *Ecosystem Management for Sustainability: Principles and Practices Illustrated by a Regional Biosphere Reserve Cooperative*. Lewis Publishers, New York. pp. 3-22.

McGarigal,K. and McComb, W.C. 1992. Streamside versus upslope breeding bird communities in the central Oregon Coast Range. *Journal of Wildlife Management* 56:10-23.

McGarigal, K., Cushman, S., and Stafford, S. 2000. *Multivariate Statistics for Wildlife and Ecology Research*. Springer, New York.

McIlveen, B. 2001. Pers. Comm.

McIntosh, R.P. 1985. *The Background of Ecology: Concept and Theory*. Cambridge University Press, Cambridge.

McIntyre, N.E. 1995. Effects of forest patch size on avian diversity. *Landscape Ecology* 10(2):85-99.

McLeod, S. and Running, S.W. 1988. Comparing site quality indices and productivity of ponderosa pine stands in western Montana. *Canadian Journal of Forest Research* 18:346-352.

McNab, W.H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. *Canadian Journal of Forest Research* 23:110-1107.

Meents, J.K., Anderson, B.W., and Ohmert, R.D. 1983. Nonlinear relationships between birds and vegetation. *Ecology* 64:1022-1027.

Mehlhop, P. and Lynch, J.F. 1986. Bird/habitat relationships along a successional gradient in the Maryland Coastal Plain. *American Midland Naturalist* 116:225-239.

Merriam, G. and Wegner, J. 1992. Local extinctions, habitat fragmentation and ecotones. In *Landscape boundaries*, A.J. Hansen and F. Di Castri, eds. Springer Verlag, New York. pp. 150-169.

Mills, G.S., Dunning, J.B., Jr., and Bates, J.M. 1991. The relationship between birding bird density and vegetation volume. *Wilson Bulletin* 103:468-479.

Mills, H.H. 1984. Effect of hillslope angle and substrate on tree tilt and denudation of hillslopes by treefall. *Physical Geography* 5:253-261.

Milne, R.J. 1982. *Forest dynamics and geomorphic processes on the Niagara Escarpment, Collingwood, Ontario*. Unpublished M.Sc. Thesis, University of Guelph, Guelph, Ontario.

Milne, R.J. and Bennett, L. 2001. *Breeding Bird Survey: West Credit Subwatershed 15*. Report for Credit Valley Conservation, Mississauga, Ontario.

Milne, R.J., Bennett, L., and Puddister, M. 2000a. 'Species of Conservation Concern' and their role in landscape assessment on the Central Niagara Escarpment. In *Proceedings of Leading Edge '99.* Ministry of Natural Resources, Ontario.

Milne, R.J., Bennett, L., and Puddister, M. 2000b. *Avian monitoring in the Credit Valley Watershed, southern Ontario: Protocol and assessment.* Unpublished presentation at Annual Meeting of the American Association of Geographers, Pittsburg, Pennsylvania.

Milne, R.J. and Moss, M.R. 1988. Forest dynamics and geomorphic processes on the Niagara Escarpment, Collingwood, Ontraio. In: M.R. Moss (Ed.) *Landscape Ecology and Management.* Polyscience, Montreal. Pp. 129-140.

Milne, R.J. and Moss, M.R. 1996. Natural area boundaries and the dynamics of biophysical processes on the Niagara Escarpment. In *Leading Edge '95: a conference exploring the connections and interrelationships between environment, use and culture in the Niagara Escarpment Biosphere Reserve*, Ministry of Energy and Environment, Collingwood, Ontario.

Milne, R.J., Ramsey, D. and Braid, A.M. 1999. *Building on the ONE Monitoring Program: Integrating monitoring programs in protected areas on the central Niagara Escarpment.* Parks Research Forum of Ontario, Ministry of Natural Resources.

Mitchell, C. 1991. *Terrain Evaluation.* John Wiley and Sons, New York.

Mitchell, J.M. 1999. Habitat relationships of five northern bird species breeding in hemlock ravines in Ohio, USA. *Natural Areas Journal* 19:3-11.

Monk, C.D. 1967. Tree species diversity in the eastern deciduous forest with particular reference to north central Florida. *American Naturalist* 101:173-187.

Morrison, M.L., Marcot, B.G. and Mannan, R.W. 1992. *Wildlife-Habitat Relationships: Concepts and Applications.* University of Wisconsin Press, Madison.

Moss, M.R. 1983. Landscape synthesis, landscape processes and land classification: some theoretical and methodological issues. *GeoJournal* 7:145-153.

Moss, M.R. and Milne, R.J. 1995. *Biophysical processes on the Niagara Escarpment: their nature and relevance to natural resources planning.* Report for the Ontario Heritage Foundation and Niagara Escarpment Commission, Ontario.

Moss, M.R. and Milne, R.J. 1998. Biophysical processes and bioregional planning: The Niagara Escarpment of Southern Ontario, Canada. *Landscape and Urban Planning* 40:251-268.

Moss, M.R. and Milne, R.J. 1999. Preface. In *Landscape Synthesis: Concepts and Applications*, M.R.Moss and R.J. Milne (eds.). Faculty of Environmental Science, University of Guelph, Guelph. pp. iii-vi.

Moss, M.R. and Nickling, W.G., 1980. Geomorphological and vegetation interaction and its relationship to slope stability on the Niagara Escarpment, Bruce Peninsula, Ontario. *Geographie physique et Quaternaire*, 24:95-106.

Moss, M.R. and Rosenfeld, C.L. 1978. Morphology, mass wasting and forest ecology of a post glacial re-entrant valley in the Niagara Escarpment. *Geografiska Annaler*, 60A:161-174.

Mowbray, T.B. and Oosting, H.J. 1968. Vegetation gradients in relation to environment and phenology in a southern Blue Ridge gorge. *Ecological Monographs* 38:309-244.

Mueller-Dombois, D. and Ellenberg, H. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley and Sons, Toronto.

Mueller-Dombois, D., Spatz, G., Conant, S., Romich, P.Q., Radovsky, F.J., Tenorio, J.M., Gagné, W., Brennan, B.M., Mitchell, W.C., Springer, D., Samuelson, G.A., Gressit, J.L., Steffan, W.A., Paik, Y.K., Sung, K.C., Hardy, D.E., Delfinado, M.D., Fujii, D., Doty, M.S., Watson, L.J., Stoner, M.F., and Baker, G.E. 1981. Altitudinal distribution of organisms along an island mountain transect. In D, Mueller-Dombois, K.W. Bridges and H.L. Carson (eds), Island Ecosystems: Biological Organization in Selected Hawaiian Communities (US/IBP Synthesis Series, vol. 15), pp. 77-180. Stoudsberg, Pennsylvania and Woods Hole, Massachusetts, Hutchinson Ross.

Myklestad, Å. and Birks, H.J.B. 1993. A numerical analysis of the distribution patterns of Salix L. species in Europe. *Journal of Biogeography* 20:1-32.

Nanson, G.C. and Beach, H.F. 1977. Forest succession and sedimentation on a meandering river floodplain, northeast British Columbia. *Canadian Journal of Biogeography* 4:229-252.

Newton, I. 1986. *The Sparrowhawk*. T. & A.D. Poyser, London.

Newton, I. 1995. The contribution of some recent research on birds to ecological understanding. *Journal of Animal Ecology* 64:675-696.

Niagara Escarpment Commission (NEC). 1979. *The Proposed Plan for the Niagara Escarpment*. NEC, Georgetown, ON.

Niagara Escarpment Commission (NEC). 1991. *Five Year Review: Niagara Escarpment Plan. Map 10. Niagara Escarpment Parks System*. Niagara Escarpment Commission, Georgetown, ON.

Nigh, T.A., Pallardy, S.G. and Garrett, H.E. 1985. Sugar maple-environment relationships in the River Hills and Central Ozark Mountains of Missouri. *American Midland Naturalist* 114:235-251.

Norman, S.A., Schaetzl, R.J. and Small, T.W. 1995. Effects of slope angle on mass movement by tree uprooting. *Geomorphology* 14:19-27.

Noss, R.F. 1991. Effects of edge and internal patchiness on avian habitat use in an old-growth Florida hammock. *Natural Area Journal* 11:34-47.

O'Neill, R.V. 1989. Perspectives in hierarchy and scale. In J. Roughgarden, R.M. May and S.A. Levin (eds.), *Perspectives in Ecological Theory*. Princeton University Press, Princeton. pp. 140-156.

O'Neill, R.V., DeAngelis, D.L., Waide, J.B. and Allen, T.F.H. 1986. *A Hierarchical Concept of Ecosystems*. Princeton University Press.

Odom, R.H.Jr. and McNab, W.H. 2000. *Using digital terrain modeling to predict ecological types in the Balsam Mountains of Western North Carolina*. USDA Forest Service, Southern Research Station. Research Note SRS-8.

Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164:262-270.

Odum, E.P., Finn, J.T., and Franz, E. 1979. Perturbation theory and the subsidy-stress gradient. *BioScience* 29:349-352.

Ontario Ministry of Environment and Energy (OMEE). 1994. *The Niagara Escarpment Plan*. OMEE, Toronto.

Ontario Ministry of Natural Resources (OMNR). 1976. *Significant Natural Areas Along the Niagara Escarpment*. A Report on Nature Reserve Candidates and Other Significant Natural Areas in the Niagara Escarpment Planning Area. Park Planning Branch, OMNR, Toronto.

Oosting, H.J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. *American Midland Naturalist*. 28:1-126.

Orians, G.H. and Wittenberger, J.F. 1991. Spatial and temporal scales in habitat selection. *American Naturalist* 137:S29-S49.

Osterkamp, W.R., Hupp, C.R. and Schening, M.R. 1995. Little River revisited - thirty-five years after Hack and Goodlett. *Geomorphology* 13:1-20.

Paine, R.T. and Levin, S.A. 1981. Intertidal landscapes: disturbance and the dynamics of pattern. *Ecological Monographs* 51:145-178.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. *Ecology* 74:2215-2230.

Parker, A.J. 1982. The topographic relative moisture index: an approach to soil-moisture assessment in mountain terrain. *Physical Geography* 3:160-168.

Parker, K.C. and Bendix, J. 1996. Landscape-scale geomorphic influences on vegetation patterns in four environments. *Physical Geography* 17(2):113-141.

Paton, P.W.C. 1994. The effect of edge on avian nest success: How strong is the evidence? *Conservation Biology* 8:17-26.

Payne, R.B. and Payne, L.L. 1993. Breeding dispersal in indigo buntings: circumstances and consequences for breeding success and population structure. *Condor* 95:1-24.

Pedroli, G.B.M. 1999. The nature of landscape. In *Landscape Synthesis: Concepts and Applications*, M.R. Moss and R.J. Milne eds. University of Guelph, Ontario and University of Warsaw, Poland.

Perera, A.H. and Euler, D.L. 2000. Landscape ecology in forest management: an introduction. In A.H. Perera, D.L. Euler, and I.D. Thompson, eds. *Ecology of a Managed Terrestrial Landscape: Patterns and Processes of Forest Landscapes in Ontario*. UBC Press, Vancouver. pp. 3-11.

Phillips, J.D. 1995. Biogeomorphology and landscape evolution: the problem of scale. *Geomorphology* 13: 337-347.

Pickett, S.T.A. 1980. Non-equilibrium coexistence of plants. *Bulletin of the Torrey Botanical Club* 107:238-248.

Pickett, S.T.A., Kolasa, J., Armesto, J.J. and Collins, S.L. 1989. The ecological concept of disturbance and its expression at various hierarchical levels. *Oikos* 54:129-136.

Pickett, S.T.A. and White, P.S. 1985. *The Ecology of Natural Disturbance and Patch Dynamics.* Academic Press, New York, New York.

Pimm, S.L. and Rosenzweig, M.L. 1981. Competitors and habitat use. *Oikos* 37:1-6.

Pollock, M.M., Naiman, R.J. and Hanley, T.A. 1998. Plant species richness in riparian wetlands - a test of biodiversity theory. *Ecology* 79:94-105.

Porneluzi, P., Bednarz, J.C., Goodrich, L., Zawada, N. and Hoover, J. 1993. Reproductive performance of territorial Ovenbirds occupying forest fragments and a contiguous forest in Pennsylvania. *Conservation Biology* 7:618-622.

Powell, R.A. and Mitchell, M.S. 1998. Topographical constraints and home range quality. *Ecography* 21:337-341.

Power, D.M. 1975. Similarity among avifaunas of the Galapagos Islands. *Ecology* 56:616-626.

Price, T.D. 1991. Morphology and ecology of breeding warblers along an attitudinal gradient in Kashmir, India. *Journal of Animal Ecology* 60:643-664.

Probst, J.R. and Hayes, J.P. 1987. Pairing success of Kirtland's Warbler in marginal vs. suitable habitat. *Auk* 104:234-241.

Pulliam, H.R. 1975. Coexistence of sparrows: a test of community theory. *Science* 184:474-476.

Pulliam, H.R. 1988. Sources, sinks and population regulation. *American Naturalist* 132:652-661.

Pulliam, H.R. and Danielson, 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. *American Naturalist* 137:S50-S66.

Pulliam, H.R. and Dunning, J.B. Jr. 1987. The influence of food supply on local density and diversity of sparrows. *Ecology* 68:1009-1014.

Pulliam, H.R. and Parker, T.A., III. 1979. Population regulation of sparrows. *Forschritte der Zoologie* 25:137-147.

Rabenold, K.N. and Bromer W.R. 1989. Plant communities as animal habitats: effects of primary resources on the distribution and abundance of animals. In *Plant-Animal Interactions*, Anderson, W.G. ed. McGraw-Hill Book Company, Toronto. pp. 291-353.

Ralph, C.J. and Scott, J.M. 1981. Estimating Numbers of Terrestrial Birds. *Studies in Avian Biology* No. 6

Ranney, J.W., Bruner, M.C. and Levenson, J.B. 1981. The importance of edge in the structure and dynamics of forest islands. In Forest Island Dynamics in Man-dominated Landscapes, Burgess, R.L. and Sharpe, D.M. eds. Springer-Verlag, New York. pp. 67-95.

Rappole, J.H. 1996. The importance of forest for the world's migratory bird species. In *Conservation of Faunal Diversity in Forested Landscapes*, R.M. DeGraaf and R.I. Miller, eds. Chapman and Hall, New York. pp. 389-406.

Raup, H.M. 1975. Species versatility in shore habitats. *Journal of the Arnold Arboretum* 56: 126-163.

Reddy, V. S. and Singh, J. S. 1993. Changes in vegetation and soil during succession following landslide disturbances in the central Himalaya. *Journal of Environmental Management* 39:235-250.

Reice, S.R., 1994. Non-equilibrium determinants of biological community structure. *American Scientist*, 82:424-435.

Reid, M.L. and Weatherhead, P.J. 1988. Topographic constraints on competition for territories. *Oikos* 51:115-117 plus erratum *Oikos* 53:143.

Repasky, R.R. and Schluter, D. 1994. Habitat distributions of wintering sparrows along an elevational gradient: tests of the food, predation and microhabitat structure hypotheses. *Journal of Animal Ecology* 63:569-582.

Repasky, R.R. and Schluter, D. 1996. Habitat distributions of wintering sparrows: foraging success in a transplant experiment. *Ecology* 77:452-460.

Restrepo, C. and Gómez, N. 1998. Responses of understory birds to anthropogenic edges in a neotropical montane forest. *Ecological Applications* 8:170-183.

Rice, J., Anderson, B.W., and Ohmart, R.D. 1984. Comparison of the importance of different habitat attributes to avian community organization. *Journal of Wildlife Management* 48:895-911.

Rice, J.C., Ohmart, D. and Anderson, B.W. 1983. Habitat selection attributes of an avian community: a discriminant analysis investigation. *Ecological Monographs* 53:263-290.

Richling, A. 1999. On the universal natural areal unit. In *Landscape Synthesis: Concepts and Applications*, M.R. Moss and R.J. Milne eds. University of Guelph, Ontario and University of Warsaw, Poland. pp. 67-82.

Ricklefs, R.E. 1977. Environmental heterogeneity and plant species diversity: a hypothesis. *American Naturalist* 111:376-381.

Ricklefs, R.E. 1987. Community diversity: relative roles of local and regional processes. *Science* 235:167-171.

Risser, P.G., Karr, J.R. and Forman, R.T. 1984. Landscape ecology - directions and approaches. *Illinois Natural History Survey* Special Publication No. 2, Illinois Natural History Survey. Champaign, Illinois.

Rivera-Milán, F.F. 1997. *Journal of Field Ornithology* 69:299-305.

Robbins, C.S. 1981a. Bird activity levels related to weather. *Studies in Avian Biology* No. 6:301-310.

Robbins, C.S. 1981b. Effect of time of day on bird activity. *Studies in Avian Biology* No. 6:275-286.

Robinson, S.K. 1998. Another threat posed by forest fragmentation: reduced food supply. *Auk* 115:1-3.

Robinson, S.K. and Holmes, R.T. 1984. Effects of plant species and foliage structure on the foraging behavior of forest birds. *Auk* 101:672-684.

Robinson, S.K., Thompson, F.R.III, Donovan, T.M., Whitehead, D.R. and Faaborg, J. 1995. Regional forest fragmentation and the nesting success of migratory birds. *Science* 267:1987-1990.

Rochow, J.J. 1972. A vegetational description of a mid-Missouri forest using gradient analysis techniques. *American Midland Naturalist*. 87:377-396.

Rosenzweig, M.L. 1991. Habitat selection and population interactions: the search for mechanism. *American Naturalist* 137:S5-S28.

Rosenzweig, M.L. and Abramsky, Z. 1986. Centrifugal community structure. *Oikos* 46:339- 348.

Rotenberry, J.T. 1985. The role of habitat in avian community composition: physiognomy or floristics? *Oecologia* 67:213-217.

Rotenberry, J.T. and Wiens, J.A. 1980a. Habitat structure, patchiness and avian communities in North American steppe vegetation: a multivariate analysis. *Ecology* 61:1228-1250.

Rotenberry, J.T. and Wiens, J.A. 1980b. Temporal variation in habitat structure and shrubsteppe bird dynamics. *Oecologia* 47:1-9.

Roth, R.R. 1976. Spatial heterogeneity and bird species diversity. *Ecology* 57:773-782.

Royama, T. 1984. Population dynamics of the spruce budworm, *Choristoneura fumiferana*. *Ecological Monographs* 37:317-348.

Runkle, J.R. 1981. Gap regeneration in some old-growth forests of the eastern United States. *Ecology* 62:1041-1051.

Runkle, J.R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. *Ecology* 63:1533-1546.

Runkle, J.R. 1998. Changes in southern Appalachian canopy tree gaps sampled thrice. *Ecology* 79:1768-1780.

Sabine, D.L., Boer, A.H. and Ballard, W.B. 1996. Impacts of habitat fragmentation on pairing success of male Ovenbirds, Seiurus aurocapillus, in southern New Brunswick. *Canadian Field-Naturalist* 110:688-693.

Sanders, T.A. and Edge, W.D. 1998. Breeding bird community composition in relation to riparian vegetation structure in the western United States. *Journal of Wildlife Management* 62:461-473.

Saunders, D.A. 1990. Problems of survival in an extensively cultivated landscape: the case of Carnsby's cockatoo *Calyptorhynchus funereus latirostris*. *Biological Conservation* 54:277-290.

Schaefer, C. 1995. Plant communities and environmental factors of alvars of the Bruce Peninsula and a comparison of alvars of the Niagara Escarpment cliff faces. In *Leading Edge '94 Conference Proceedings*. S. Carty, G. Whitelaw, J. Connolly, and M. Alles-De Vos (eds.). Ministry of Energy and Environment, Toronto. pp. 386-392.

Schaetzl, R.J., Johnson, D.L., Burns, S.F. and Small, T.W. 1989. Tree uprooting: Review of terminology, process, and environmental implications. *Canadian Journal of Forest Research* 19: 1-11.

Schaetzl, R.J., Burns, S.F., Small, T.W. and Johnson, D.L. 1990. Tree uprooting: Review of types and patterns of soil disturbance. *Physical Geography* 11: 277-291.

Scott, J.M. and Ramsey, F.L. 1981. Length of count period as a possible source of bias in estimating bird densities. *Studies in Avian Biology* No. 6:409-413.

Scheidegger, A.E. 1986. The catena principle in geomorphology. *Zeitschrift für Geomorphologie* 30:257-273.

Schemske, D.W., and Brokaw, N. 1981. Treefalls and the distribution of understory birds in a tropical forest. *Ecology* 62:938-945.

Schieck, J., Lertzman, K., Nyberg, B., and Page, R. 1995. Effects of patch size on birds in old-growth montane forests. *Conservation Biology* 9:1072-1084.

Schluter, D. 1982. Distributions of Galapagos ground finches along an altitudianl gradient: the importance of food supply. *Ecology* 63:1504-1517.

Schnitzer, S.A. and Carson, W.P. 2001. Treefall gaps and the maintenance of species diversity in a tropical forest. *Ecology* 82:913-919.

Schumm, S.A. and Lichty, R.W. 1965. Time, space and causality in geomorphology. *American Journal of Science* 263:110-119.

Sedgwick, J.A. and Knopf. F.L. 1992. Describing Willow Flycatcher habitats: Scale perspectives and gender differences. *Condor* 94:720-733.

Senft, R.L., Coughenour, M.B., Bailey, D.W., Rittenhouse, L.R., Sala, O.E., and Swift, D.M. 1987. Large herbivore foraging and ecological hierarchies. *BioScience* 37:789-799.

Seymour, N.R. 1992. Significance of estuarine habitat in the annual cycle of waterfowl in Nova Scotia. In *Landscape Approaches to Wildlife and Ecosystem Management*, G.B. Ingram and M.R. Moss (eds.). Polyscience, Montreal. pp75-84.

Sherry, T.W. and Holmes, R.T. 1995. Summer vs. winter limitation of populations: conceptual issues and evidence. In *Ecology and Management of Neotropical Migratory Birds: A Synthesis and Review of the Critical Issues*, T.E. Martin and D.M. Finch (eds.). Oxford University Press, Oxford. pp. 85-120.

Shochat, E., Abramsky, Z. and Pinshow, B. 2001. Breeding bird species diversity in the Negev: effects of scrub fragmentation by planted forests. *Journal of Applied Ecology* 38:1135-1147.

Shroder, J.F., Jr. and Bishop, M.P. 1995. Geobotanical assessment in the Great Plains, Rocky Mountains and Himalaya. *Geomorphology* 13:101-119.

Shugart, H.H. 1984. *A Theory of Forest Dynamics*. Springer, New York.

Sieving, K.E. and Willson, M.F. 1998. Nest predation and avian species diversity in northwestern forest understory. *Ecology* 2391-2402.

Sisk, T.D., Haddad, N.M. and Ehrlich, P.R. 1997. Bird assemblages in patchy woodlands: modeling the effects of edge and matrix habitats. *Ecological Applications* 7:1170-1180.

Slocombe, D.S. 1993. Implementing ecosystem based management. *Bioscience* 43:612-622.

Slocombe, D.S., 1998. Defining goals and criteria for ecosystem-based management. *Environmental Management* 22:483-493.

Smiley, J. 1978. Plant chemistry and the evolution of host specificity: new evidence from *Heliconia* and *Passiflora*. *Science* 201:745-747.

Smith, R. And Dallman, M. 1996. Forest gap use by breeding Black-throated Green Warblers. *The Wilson Bulletin* 108(3):588-591.

Sousa, W.P. 1984. The role of disturbance in natural communities. *Annual Review of Ecological Systems* 15:353-391.

Southwood, T.R.E. 1977. Habitat, the templet for ecological strategies? *Journal of Animal Ecology* 46:337-366.

Spencer, T. and Whatmore, S. 2001. Editorial: Bio-geographies: putting life back into the discipline. *Transactions of the Institute of British Geographers* 26:139-141.

Sprugel, D.G. 1976. Dynamic structure of wave-generated Abies balsamea forest in the northeastern United States. *Journal of Ecology* 64:889-912.

SPSS. 1999. *SPSS Base 10.0.* SPSS Inc., Chicago.

Steele, B.B. 1992. Habitat selection by breeding Black-throated Blue Warblers at two spatial scales. *Ornis Scandinavia* 23:33-42.

Straw, A. 1966. Periglacial mass movements on the Niagara Escarpment near Meaford Grey County, Ontario. *Geographical Bulletin* 8:369-376.

Straw, A. 1968. Late Pleistocene glacial erosion along the Niagara Escarpment of southern Ontario. *Bulletin of the Geological Society of America* 79:889-891.

Strong, T.R. and Bock, C.E. 1990. Bird species distribution patterns in riparian habitats in southeastern Arizona. *Condor* 92:866-885.

Suffling, R., Lihou, C. and Morand Y. 1988. Control of landscape diversity by catastrophic disturbance: a theory and a case study of fire in a Canadian boreal forest. *Environmental Management* 12:73-78.

Sutherland, W.J. and Parker, G.A. 1985. Distribution of unequal competitors. In *Behavioural Ecology: Ecological Consequences of Adaptive Behaviour*, R.M. Sibly and R.H. Smith (eds.). Blackwell Scientific Publications, Oxford. pp. 255-273.

Swanson, F.J., Frederiksen, R.L. and McCorison, F.M. 1982. Material transfer in a western Oregon forested watershed. In *Analysis of Coniferous Forest Ecosystems in the Western United States*, R.L. Edmonds (ed.). Hutchinson Ross, Stroudsburg, Pennsylvania. US/IBP Synthesis Serial 14, pp. 233-266.

Swanson, F.J., Wondzell, S.M. and Grant, G.E. 1992. Landforms, disturbance, and ecotones. In A.J. Hansen and F. di Castri, eds. *Landscape Boundaries: Consequences for Biotic Diversity and Ecological Flows*. Springer-Verlag, New York. pp. 304-323.

Swanson, F.J., Kratz, T.K., Caine, N. and Woodmansee, R.G. 1988. Landform effects on ecosytem patterns and processes. *BioScience* 38:92-98.

Tansley, A.G. 1935. The use and abuse of vegetational concepts and terms. *Ecology* 16:284-307.

Terborgh, J.W. 1989. *Where have all the birds gone*? Princeton University Press, Princeton, New Jersey.

Terborgh, J. and Weske, J.S. 1975. The role of competition in the distribution of Andean birds. *Ecology* 56:562-576.

ter Braak, C.J.F. 1987. *CANOCO - a FORTRAN program for community ordination by (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis*. Version 2.1 ITI-TNO, Wageningen, The Netherlands.

ter Braak, C.J.F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio* 69:69-77.

ter Braak, C.J.F. 1998. CANOCO for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca, New York.

Thornes, J.B. 1990. The interactions of erosional and vegetational dynamics in land degradation: spatial outcomes. In *Vegetation and Erosion*, J.B. Thornes (ed.). Wiley, Chichester. pp. 41-53.

Thornthwaite, C.W. 1954. Topoclimatology. In *Proceedings of the Toronto Meteorological Conference, September 9-15, 1953*. Royal Meteorological Society, London. pp. 227-232.

Tilman, D. 1982. *Resource Competition and Community Structure*. Princeton University Press, Princeton, New Jersey.

Tilman, D. 1986. Evolution and differentiation in terrestrial plant communities: the importnace of the soil resource: light gradients. In J. Diamond and T.J. Case, eds. *Community Ecology*. Harper & Row, New York. pp. 359-380.

Tilman, D. 1999. Diversity by default. *Science* 283:495-496.

Tomialojc, L., Wesolowski, T. And Walankiewicz, W. 1984. Breeding bird community of a primaeval temperate forest (Bialowieza National Park, Poland). *Acta Ornithologica* 20:251-311.

Tomoff, C.W. 1974. Avian species diversity in desert scrub. *Ecology* 55:396-403.

Tovell, W.M. 1992. *Guide to the Geology of the Niagara Escarpment*. Niagara Escarpment Commission, Georgetown, Ontario.

Turner, M.G. and Gardiner, R.H. 1991. *Quantitative Methods in Landscape Ecology: the Analysis and Interpretation of Landscape Heterogeneity*. Ecological Studies 82. Springer, New York.

Tye, A. 1992. Assessment of territory quality and its effects on breeding success in a migrant passerine, the wheatear *Oenanthe oenanthe*. *Ibis* 134:273-285.

Urban, D.L., O'Neill, R.V. and Shugart, H.H. 1987. Landscape ecology. *Bioscience* 37:119-127.

Van Horn, M.A. 1990. The relationship between edge and the pairing success of the Ovenbird (*Seiurus aurocapillus*). M.S. thesis, University of Missouri, Columbia.

Van Hulst, R. 1978. On the dynamics of vegetation: patterns of environmental and vegetational change. *Vegetatio* 38:65-75.

Van Voris, P., O'Neill, R.V., Emanuel, W.R. and Shugart, H.H. Jr. 1980. Functional complexity and ecosystem stability. *Ecology* 61:1352-1360.

Vaughn, T.A. 1978. *Mammalogy*. W.B. Sanuders, Philadelphia.

Veblen, T.T. 1992. Regeneration dynamics. In *Plant Succession: Theory and Prediction* D.C. Glenn-Lewin, R.K. Peet and T.T. Veblen (eds.). Chapman and Hall, London. pp. 152-187.

Veblen, T.T. and Ashton, D.H. 1978. Catastrophic influences on the vegetation of the Valdivian Andes, Chile. *Vegetatio* 36:149-167.

Veblen, T.T., Schlegel, F.M. and Escobar, R.B. 1980. Structure and dynamics of old growth Nothofagus forests in the Valdivian Andes, Chile. *Journal of Ecology* 68:1-31.

Veblen, T.T., Kitzberger, T., and Lara, A. 1992. Disturbance and forest dynamics along a transect from Andean rain forest to Patagonian shrubland. *Journal of Vegetation Science* 3: 507-520.

Verner, J. 1985. Assessment of counting techniques. *Current Ornithology* 2:247-302.

Verner, J. and Larson, T.A. 1989. Richness of breeding bird species in mixed-conifer forests of the Sierra Nevada, California. *Auk* 106:447-463.

Viles, H.A. (ed.). 1988. *Biogeomorphology*. Blackwell, Oxford.

Viles, H.A. 1988. Organisms and karst geomorphology. In *Biogeomorphology*, H.A. Viles (ed.), Blackwell, Oxford. pp. 319-350.

Villard, M-A., Freemark, K.E. and Merriam, G. 1992. Metapopulation dynamics as a conceptual model for neotropical migrant birds: An empirical investigation. In *Ecology and conservation of neotropical migrant landbirds*, J.M. Hagan and D.W. Johnston, eds. Smithsonian Institution Press, Washington, D.C. pp. 474-482.

Vogl, R. 1980. The ecological factors that produce perturbation-dependent ecosystems. In *The Recovery Process in Damaged Ecosystems*, J. Cairns (ed.). Ann Arbor Scientific Publications, Ann Arbor.

Von Haartman, L. 1971. Population dynamics. In *Avian Biology*, Vol. 1, D.S. Farner and J.R. King (ed.). Academic Press, New York. pp. 391-459.

Ward, J.P. and Anderson, S.H. 1988. Influences of cliffs on wildlife communities in southcentral Wyoming. *Journal of Wildlife Management* 52:673-678.

Ware, S., Redfearn, P.L. Jr., Pyrah, G.L., and Weber, W.R. 1992. Soil pH, topography and forest vegetation in the Central Ozarks. *American Midland Naturalist* 128:40-52.

Waring, R.H. and Running, S.W. 1998. *Forest Ecosystems: Analysis at Multiple Scales*. Academic Press, New York.

Watt, A.S. 1947. Pattern and process in the plant community. *Journal of Ecology* 35:1-22.

Whitcomb, R.F., Robbins, C.S., Lynch, J.F., Whitcomb, B.L., Klimkiewicz, M.K., and Bystrak, D. 1981. Effects of forest fragmentation on avifauna on the eastern deciduous forest. In *Forest island dynamics in man-dominated landscapes*, R.L. Burgess and D.M. Sharpe, eds. Springer-Verlag, New York.

White, D.H., Kepler, C.B., Hatfield, J.S., Sykes, P.W. Jr., and Seginak, J.T. 1996. Habitat associations of birds in the Georgia Piedmont during winter. *Journal of Field Ornithology*, 67(1):159-166.

White, P.S. 1979. Pattern, process and natural disturbance in vegetation. *Botanical Review* 45:229-299.

Whitehead, P.J., Bowman, D.M.J.S., and Tidemann, S.C. 1992. Biogeographic patterns, environmental correlates and conservation of avifauna in the Northern Territory, Australia. *Journal of Biogeography* 19:151-161.

Whitmore, T.C. 1978. Gaps in forest canopy. In *Tropical Trees as Living Systems*, P.B. Tomlinson and M.H. Zimmerman (eds.). Cambridge University Press, Cambridge. pp. 639-655.

Whitmore, T.C. 1989. Canopy gaps and the two major groups of forest trees. *Ecology* 70:536-538.

Whitmore, T.C. and Brown, N.D. 1996. Dipterocarp seedling growth in rain forest canopy gaps during six and a half years. *Philosophical Transactions of the Royal Society of London* 351:1195-1203.

Whittaker, R.H. 1975. *Communities and Ecosystems*. Macmillan, New York.

Whittaker, R.H. and Levin, S.A. 1977. The role of mosaic phenomena in natural communities. *Theoretical Population Biology* 12:117-139.

Wiebe, K.L. and Martin, K. 1998. Seasonal use by birds of stream-side riparian habitat in coniferous forest of northcentral British Columbia. *Ecography* 21:124-134.

Wiens, J.A. 1974. Habitat heterogeneity and avian community structure in North American grasslands. *American Midland Naturalist* 43:237-270?

Wiens, J.A. 1976. Population responses to patchy environments. *Annual Review of Ecological Systems* 7:81-120.

Wiens, J.A. 1977. On competition and variable environments. *American Scientist* 65:590-597.

Wiens, J.A. 1985b. Habitat selection in variable environments: shrubsteppe birds. In *Habitat Selection in Birds*, M.L. Cody (ed.). Academic Press Inc., Orlando, Florida. pp. 227-251.

Wiens, J.A. 1986. Spatial scale and temporal variation in studies of shrubsteppe birds. In *Community Ecology*, eds. J. Diamond and T.J. Case, Harper and Row, New York, pp. 154-172.

Wiens, J.A., Crawford, C.S. and Gosz, J.R. 1986. Boundary dynamics: a conceptual framework for studying landscape ecosystems. *Oikos* 45: 421-427.

Wiens, J.A. and Rotenberry, J.T. 1981. Habitat associations and community structure of birds in shrubsteppe environments. *Ecological Monographs* 51:21-41.

Wiens, J.A., Rotenberry, J.T. and Van Horne, B. 1987. Habitat occupancy patterns of North American shrubsteppe birds: The effects of spatial scale. *Oikos* 48:132-147.

Wilcove D.S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66:1211-1314.

Wilcove, D.S., McLellan, C.H. and Dobson, A.P. 1986. Habitat fragmentation in the temperate zone. In M.E. Soulé, ed. *Conservation Biology*. Sinauer Associates, Sunderalnd, Massachusetts. pp. 879-887.

Williamson, G.B. 1975. Pattern and serial composition in an old-growth beech-maple forest. *Ecology* 56:727-731.

Willson, M.F. 1974. Avian community organization and habitat structure. *Ecology* 55:1017-1029.

Willson, M.F., Porter, E.A. and Condit, R.S., 1982. Avian frugivore activity in relation to forest light gaps. *Caribbean Journal of Science* 18:1-6.

Wilson, D.S. 1980. *The natural selection of populations and communities.* Benjamin/Cummings, Menlo Park.

Winternitz, B.L. 1976. Temporal change and habitat preference of some montane breeding birds. *Condor* 78:383-393.

Wright, D.H. 1983. Species-energy theory: an extension of species-area theory. *Oikos* 41:496-506.

Wunderle, J.M.Jr. 1995. Responses of bird populations in a Puerto Rican forest to Hurricane Hugo: The first 18 months. *The Condor* 97:879-896.

Wyatt, V., Cadman, M., Friesen, L. and Ramsey, D. 1998. Nesting productivity of woodland birds in relation to forest size on the central Niagara Escarpment. In *Leading Edge '97: The Edge and The Point, Niagara Escarpment & Long Point World Biosphere Reserves*. Ministry of Environment and Energy, Ontario. pp. 154-160.

Yahner, R.H. 1988. Changes in wildlife communities near edges. *Conservation Biology* 2: 333-339.

Yahner, R.H. and Scott, D.P. 1988. Effects of forest fragmentation on depredation of artificial nests. *Journal of Wildlife Management* 52:158-161.

Zimmermann, R.C. and Thom, B.G. 1982. Physiographic plant geography. *Progress in Physical Geography* 6:45-59.