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On the Use of Enduring Features Analysis for Protected Areas Planning

by

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A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

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Abstract

The pressures upon natural systems as a result of resource extraction, agriculture and increasing urbanisation has placed pressure on nations on how best to protect remaining wilderness areas. One of the many challenges facing nations is not only how to protect these places, but which areas to protect. There has been a movement to emphasize protection of landscapes and biotic communities based on Enduring Features Gap Analysis instead of on individual populations. This analytical technique is based on unique units of soil and landform. This is a coarse filter conservation strategy, which relies on geographical information systems (GIS) and satellite technologies, and on the idea of representation. In 1990 Manitoba adopted enduring features gap analysis as part of its Protected Areas Initiative (PAI). Enduring features are assumed to be a surrogate for biodiversity, with the idea that by protecting a portion of all enduring features within a region, all biotic community types will be represented. These assumptions can be misleading, biological features do not necessarily coincide with the underlying enduring features. The purpose of this thesis is to determine what differences may exist between vegetation communities as defined by the enduring features. This will help determine the effectiveness of enduring features gap analysis as a surrogate for biological diversity, and its effectiveness as a representative criteria of gap analysis. A botanical survey was conducted within Chitek Lake Park Reserve, a protected area located 350 km northwest of Winnipeg. Within three enduring features, different biological communities were selected for the vegetation survey, and within each survey site a soil pit was dug. A total of 76 sites were surveyed in three different enduring features. A Digital Elevation Model

(DEM) was also used to compare and contrast geophysical landforms, vegetation communities and enduring features. Canonical Correlation Analysis (CCA) and Principal Components Analysis (PCA) were conducted to determine correlation between the three groups. Overall, enduring features appeared to do an adequate job of differentiating different plant communities. Enduring features with a mineral component did not perform as well in differentiating vegetation communities than those enduring features which are defined by an organic soil component. There is also doubt as to whether enduring features analysis at the map scale that Manitoba Conservation currently uses is an effective one. It was also observed that there were some species, most notably black spruce (*Picea mariana*) and tamarack (*Larix larcinia*), whose distribution was not determined by enduring features.

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Meegwetch.

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Introduction

The pressures upon natural systems as a result of resource extraction, agriculture and urban development have increased awareness of the importance of protecting the natural diversity of our planet. While constraints of time and money prevent the necessary research, the list of endangered species and places is growing (Ehrlich 1988, Prendergast et al. 1993). In the last 20 years there has been a movement to emphasize protection of landscapes and biotic communities as opposed to dealing with individual species. From this movement came a variety of conservation techniques and theories based upon landscape analysis to help parks planners and managers identify those areas that need to be protected (Prendergast et al. 1999, Hoctor et al. 2000). One of these techniques involves identifying the different biotic and abiotic components of the landscape and determining if they are adequately represented in a network of protected areas. It is known as enduring features gap analysis (Manitoba Conservation 2000). Enduring features gap analysis is used as an analytical tool that enables parks planners to assess where there are "gaps" in current parks protection networks, and provides a framework to allow them to identify where those gaps can be filled. Since enduring features gap analysis always uses the existing protected areas system as the starting point, it has an advantage of extending or completing a protected reserve system, as compared to other reserve selection techniques (Prendergast et al. 1999, Hoctor et al. 2000).

Enduring features gap analysis is used in almost all provinces and territories of Canada, yet despite the fact that all of these governments use this technique to develop a protected areas network within their regions, there is almost no scientific literature on the subject. To date, there have been no peer-reviewed studies looking at the effectiveness of enduring features gap analysis, and a review of the literature has found no studies on enduring features gap analysis.

The goal of this project is to determine if enduring features gap analysis can be used as a proxy for biological diversity by determining if there is any significant difference between vegetation communities and landform variables as defined by enduring features. It is the hope that this project will shed some light on the effectiveness of enduring features gap analysis as a surrogate for assessing changes in biological diversity across the landscape and as a representative criteria of Gap Analysis for protected areas management.

Conservation/Parks planning dilemma

What to protect, where to protect, how much to protect

To understand the importance of enduring features gap analysis, it is best to start with understanding what conservation biology is, since gap analysis is one of many tools used for the purposes of conservation biology. Conservation biology is defined as a science or discipline that combines applied management principles with theories from the basic sciences, in order to address problems of maintaining biodiversity within a region (Baydack et al. 1999). The first and most important stage in conservation biology is to identify those elements or components of biodiversity that require conservation. The primary criteria used to identify these areas are biodiversity, rarity, population abundance, and environmental representativeness (Prendergast et al. 1993).

Park planners and land managers often have to incorporate conservation biology into a larger ecosystem management plan. Ecosystem management is different from conservation biology, because ecosystem management involves the development of land use plans that conserve biodiversity while meeting society's demands, values and economic needs (Baydack et al. 1999). Needless to say, it is a difficult balancing act and has resulted in a wide variety of management plans and regulations. Jonathan Haufler (1999) outlines five of the most common kinds of biodiversity conservation strategies. These strategies determine not only what areas should receive priority for protection, but how the area should be managed. Each of these strategies has an underlying assumption that justifies the reasoning behind the strategy. All of the provinces and territories in Canada use a combination of these strategies in order to meet conservation targets within their regions.

Strategy 1: Bioreserve

Bioreserves area defined as areas that are set aside or conserved specifically for the preservation and maintenance of biodiversity. Bioreserves are often developed with the intention of restricting or even prohibiting any access by people. The basic assumption behind the Bioreserve strategy is that human activity is the cause of biodiversity decline. Thus to maintain or even enhance biodiversity all human activities within these areas must be minimised or removed entirely.

Manitoba does develop and maintain a system of bioreserves, known as Ecological Reserves. The purpose of an ecological reserve is to preserve unique and rare natural features (both biological and geological) of the province (Manitoba Conservation, 2002). As such all resource extraction and recreational activities are prohibited, and any other human activity (such as scientific research, hunting, and travel with the reserve) requires prior approval from the government of Manitoba. No damage is allowed to occur within an ecological reserve, and nothing is allowed to be removed. Ecological Reserves are one of the only areas in Manitoba that could restrict traditional use by First Nations people, depending upon the ecological sensitivity of the area.

The largest problem with the Bioreserve strategy is the assumption that removing human activity will halt biodiversity declines (Haufler 1999). The strategy assumes that human activity has no integral part of ecosystem function. Certainly in the modern era there is little reason to assume otherwise; industrial logging, mining and urbanisation are destructive to ecosystems. Historically, however, there are many ecosystems that have persisted because of human activity; primarily through controlled burning (Bowman 1998).

Strategy 2: Emphasis Area

This strategy assumes that biodiversity is dependant upon unique habitats or key areas of the landscape and the dynamic processes that maintain these landscapes (Haufler 1999). The goal of this strategy is to manage both these areas and the processes that maintain them in order to protect their ecological values. Emphasis Area conservation uses flexible boundaries and allows management activities as a way to both recognise the dynamic nature of these systems and to simulate these systems to preserve and maintain the desired ecological conditions (Haufler 1999).

Strategy 3: Coarse filter

Coarse filter strategies aim to conserve biodiversity by protecting ecosystems at the landscape level (Haufler 1999). The assumption is that by protecting a sufficient number or mix of ecosystems and ecological communities biological diversity will be maintained (Haufler 1999). Enduring feature gap analysis is a coarse filter conservation strategy, since the emphasis is placed on identifying landscape level features for protection. The two most common kinds of coarse-filter strategies are described below.

3a: Habitat Diversity: This coarse filter approach assumes that by protecting a portion of all successional stages of an ecosystem sufficient protection will be provided to maintain the biological community and all the ecological functions of that community (Haufler 1999).

3b: Historical Range of Variability: This strategy relies on maintaining or preserving the historical level of ecosystem variation within a landscape region, primarily by controlling or maintaining the natural disturbance regime that maintained these ecosystems to begin with (Haufler 1999). By protecting all the different ecosystems that occur, the habitat requirements of all species will be met and biodiversity maintained. This strategy is often a management tool used to preserve or maintain the ecosystem viability of commercially important species (Haufler 1999).

Within Manitoba, historical range of variability is used to maintain forests by using logging to simulate the natural disturbance regime of fire. Duck Mountain Provincial Park and Whiteshell Provincial Park are examples.

Strategy 4: Fine Filter

Fine-filter conservation strategies focus on the protection of individual species or groups of species. The idea is that the ultimate purpose of conservation is to protect all of the species that make up a biological community. Fine-filter strategies have been one of the most widely used in the past and is still used extensively today (Government of Ontario 2007, United States 1973). One of the largest reasons is that almost all endangered species legislation focuses only on individual species and the habitat requirements of individual species (Government of Ontario 2007, United States 1973). Because of this many conservation programs target these threatened species; the western prairie fringed orchid (*Platanthera praeclara*) and the burrowing owl (*Athene cunicularia*) are both examples within Manitoba of fine filter conservation strategies. This is a common conservation strategy among environmental organisations, who will use species with a federally or provincially recognised threatened status to justify protection of large areas of land (Lambeck 1997).

Strategy 5: Coarse Filter with Species Assessment

This strategy is similar to strategy 3b, only instead of placing the focus solely upon the historical range of variability, a mix of ecological communities at the landscape level are protected with an assessment on the viability of selected species as the check to ensure a sufficient amount of area is being protected (Haufler 1999). This allows for less total area to be maintained for conservation than under strategy 3b. The Owl Lake woodland caribou (*Rangifer tarandus*) management plan is an example of this strategy within Manitoba. The core winter and summer areas of the Caribou are maintained as the minimum amount of area to be protected. As new habitat becomes available with the aging of the surrounding forest the boundaries will be changed as the caribou move to new areas.

Literature Review

History

WWF – Endangered Spaces Campaign

In 1989 the World Wildlife Fund of Canada (WWF) launched the Endangered Spaces Campaign. This program had as its primary goal the conservation of Canada's biological diversity (McNamee 1993, Iacobelli Kavanaugh and Rowe 1995, Hummel 1995, Noss 1995) by getting the federal, provincial and territorial governments to commit to a network of protected areas representing each 360 natural regions by the year 2000 (McNamee 1993, Iacobelli Kavanaugh and Rowe 1995, Hummel 1995).

The campaign was launched for a variety of reasons, one of them being the recent release of the World Commission on the Environment and Development (World Commission on Environment and Development 1987). The commission called on all nations to protect the biodiversity of species and ecosystems by completing a network of strictly protected areas that would represent all of the Earth's major ecosystems (World Commission on Environment and Development 1987).

The Federal Task Force on Park Establishment stated that Canada's commitment to complete a national system of protected areas by the year 2000 is highly unlikely given current political and economical circumstances (Canadian Council on Ecological Areas 1992).

It was the recommendation of the Brundtland Report that at least 12% of the Earths landmass be conserved in order to preserve a representative sample of the Earths ecosystems (World Commission on Environment and Development 1987). The WWF decided to use the 12% guideline since the Brundtland report was in general agreement with most nations and industries, and also because it gave the WWF a quantifiable goal to reach for (Hummel 1995). It should be mentioned that 12% is the minimum landmass to be protected, and only applies to core wildland areas (Hummel 1995). It is the intention of WWF to also ensure that lands surrounding protected areas be managed in a sustainable way, to ensure that the complete conservation goal - ecological sustainability - is reached (Hummel 1995).

To achieve the goal of the Endangered Spaces campaign it would be necessary to protect examples of Canada's full array of physical habitats and environmental gradients, something known as ecological representation. The concept of ecological representation is based upon the idea that biodiversity is mainly a function of abiotic factors. Thus the use of a landform-based analysis would provide the most appropriate tool in which to identify a large portion of the biodiversity within Canada (Iacobelli Kavanaugh and Rowe 1995). To that end, the WWF adopted a methodology based upon the results of a draft synthesis report by the Canadian Council on Ecological Areas (CCEA), which was written by specialists in ecological land classification (Iacobelli Kavanaugh and Rowe 1995). The WWF worked with the CCEA to develop the Endangered Spaces campaign using a methodology known as Gap Analysis.

Using this methodology allows the WWF to easily identify terrestrial ecological features that are not yet adequately represented in existing protected areas systems across Canada (Iacobelli Kavanaugh and Rowe 1995). Undertaking a Gap Analysis provides conservationists and policy makers with an important analytical tool with which to assess where additional protection of the landscape is required in order to complete a protected areas system set within the framework of Canada's natural regions (Iacobelli Kavanaugh and Rowe 1995).

The endangered spaces approach starts with a framework of natural regions which recognizes broad-scale changes in climate and landforms across the country. Each of these natural regions is made up of a patchwork of smaller habitat types, local variations in landform and climate that produce a mosaic of what are termed *Enduring Features*. They are called enduring features based upon the assumption that if the vegetation and wildlife are damaged by human activities or natural events such as fire, the landform itself will remain. If left undisturbed over time, this characteristic natural communities will regenerate on the landform. This provides the framework for protected areas planning. To fully represent a natural region, samples of all its enduring features should be included in at least one protected area (World Wildlife Fund 1989).

Thus the first step in meeting the goal of the endangered spaces program is to represent enduring features and the associated biological elements in all protected areas (Noss 1995).

Manitoba Conservation

In 1990 Manitoba became the first province in Canada to commit to the WWF Endangered Spaces Campaign. Manitoba Conservation elected to use enduring features for determining protection criteria because they are easier to define and identify than complex biological communities (Manitoba Conservation 2000). By representing the enduring features in a system of protected lands within each natural region, it is thought to serve as a useful way of protecting biological diversity within each natural region (Manitoba Conservation 2000). This process of identifying the different enduring features and determining if they are adequately represented in Manitoba's network of protected areas is called enduring features (gap) analysis (Manitoba Conservation 2000).

Gap Analysis

Origins of Gap Analysis

The concept of Gap analysis originated from work done in the mid-1980's by Dr. J. Michael Scott, who was a researcher at the University of Idaho and was working on the biodiversity of Hawaiian bird species at the island scale. He looked at the distribution and ranges of endangered Hawaiian forest birds and compared those distributions to the locations of protected areas within the island (Kepler and Scott 1985, Scott et al. 1987). The comparison was done by mapping out both the species ranges and the protected areas and then combining them to determine the level of overlap. This procedure allowed him to determine not only where the protected areas and species areas overlapped, but where the areas of greatest diversity were located. He was able to determine that less than 10% of the ranges of these bird species were actually located within the protected areas. It was studies like this, and similar studies that followed (Burley 1988, Scott et al. 1993, Strittholt and Frost 1997, Allen et al. 1998, Fertig et al. 1998) which allowed for the development of Gap analysis theory and methodology, with the primary assumption behind Gap Analysis that if appropriate habitat is protected, then the species that use those habitats are also protected (Noss 1983, Manitoba Conservation 2000, World Wildlife Fund 1989, Gap Analysis Program 2003).

What is Gap Analysis?

Gap Analysis has many definitions but can be broadly defined as a methodology or procedure used to identify the degree in which animals, plants or natural communities are represented in present day protected areas (Scott et al. 1987, Csuti and Kiester 1996, Scott Tear and Davis 1996). It can also be defined as a method for assessing the representation of terrestrial biodiversity in systems of protected areas (Scott and Jennings 1998, Powell et al. 2000), or a method for identifying the gaps in networks of conservation land and water areas (Jennings et al. 2000). Species and natural communities which are not adequately represented within the current system of protected areas are considered conservation "gaps". By identifying these gaps, spatial information on the distribution of species can be developed by land managers and scientists in order to develop a network of protected areas and procedures which would allow these Gaps to be included (Hummel 1995, Iacobelli Kavanaugh and Rowe 1995, Scott and Jennings 1998, Manitoba Conservation 2000, Wright et al. 2001). Gap analysis is primarily a way to maintain healthy or at least stable populations of common plants and animals by protecting and maintaining the habitats that they require (World Wildlife Fund 1989, McNamee 1993, Gap Analysis Program 2003). Species that are extremely rare, threatened or faced with immediate habitat loss are considered to be a separate class as far as conservation planning is concerned, and are dealt with *in addition to* or *on top of* conservation planning using Gap Analysis (World Wildlife Fund 1989, Iacobelli

Kavanaugh and Rowe 1995, Reid 1996). In and of itself, Gap analysis is not considered to be the primary way of protecting these rare species, but is instead considered a way of keeping "common species common" by maintaining sufficient habitat to allow these species to maintain themselves (Reid 1996, Gap Analysis Program 2003). Because of this methodology and the philosophy behind this methodology, Gap analysis is really a conservation prevention measure, since it is known that cost-wise, it is less expensive to protect already-healthy habitats and populations than to pull threatened habitats and species from the brink of extinction (Scott et al. 1987, Scott et al. 1993, Tear et al. 1993, Kirckpatrick and Brown 1994, Jennings et al. 2000).

Gap analysis is described as a coarse filter conservation strategy, it selects for reserve networks that protect a large number of species that would normally be very difficult or costly to inventory. Gap analysis relies on geographical information system (GIS) and satellite technologies, and on the idea of representation as the underlying principle (Peterson and Peterson 1991, Peterson Peterson and Pollard 1995), with representation being defined as "something characteristic of or serving to exemplify" (Peterson and Peterson 1991). The most common subjects used for representation are vegetation, landforms, species distribution and climate, but almost any criteria can be used. This is different from "fine filter" conservation strategies which are focused on protecting individual species or rare natural communities one at a time. Examples of fine filter conservation strategies are the United States Endangered Species Act of 1973 and the Convention on the International Trade of Endangered Species (CITES). The drawback of fine filter strategies is that they are very expensive and are reactive in nature, as a result they tend to be overwhelmed by increasing lists of endangered species and insufficient resources to protect them (World Wildlife Fund 1989, Zonneveld 1989, Iacobelli Kavanaugh and Rowe 1995, Csuti and Kiester 1996, Wright 1997). Coarse filter strategies such as Gap Analysis help to prevent the further loss of species that are not currently endangered by protecting their habitat from becoming degraded or destroyed due to human activities (Margules et al. 1988, Margules 1989, Wright et al. 2001). This is done because a coarse filter strategy assumes that most common species, including those of groups difficult to inventory, such as most invertebrates, will be represented in a reserve network that contains viable examples of all natural communities (Margules et al. 1988, Margules 1989). Ideally, the best overall conservation strategy would use a combination of both coarse and fine filters: an ecosystem based approach that protects a network of natural regions for biodiversity, adding on species-rich areas for a variety of taxa, and then adding in on an individual basis any species that were missed (Karl et al. 2000, Scott et al. 1987, Wright et al. 2001). All of these areas would be designed to maximize their complementarily (Margules 1989, Loo et al. 1999, Wright et al. 2001). Once those areas are identified, other principles of conservation biology, such as population viability analysis, ecosystem patch dynamics, and habitat quality can be used to select specific sites and determine appropriate management area boundaries.

Uses of Gap Analysis

Gap analysis was initially designed for the conservation of wildlife species (Scott et al. 1987, Gap Analysis Program 2003). As such, Gap analysis focuses on acquiring information on the ranges, distributions, hotspots and population densities of wildlife populations and comparing this information with the areas and locations of protected areas. However, it became apparent that Gap Analysis could be used with other features than wildlife distributions.

One of the important reasons for the development and need of this methodology is that many parks and protected areas are established for reasons other than the conservation values of those lands (McNamee 1993, Hummel 1995). As a result, although there has been an increase in the establishment of protected areas, many of them have not been established in areas that are critical to the maintenance and continuance of plant and animal species (Hummel 1995). Many of the established protected areas are not always managed with the habitat needs of local species in mind (Jennings et al. 2000). This has led to a decrease in the abundance and diversity of wild species, both common and rare.

Drawbacks

One of the drawbacks of Gap analysis is that it requires information that is often incomplete, particularly when considering population information for plants. The vast majority of plant cover is inferred from satellite imagery and thus only conveys a small amount of information on what actually exists on the ground. Since satellite imagery is only capable of showing the dominant canopy cover of a biological community (dominant trees, dominant grass, etc), it cannot adequately convey plant community structure and composition. That must be determined by inference and previous knowledge of on-the-ground-truthing of similar community types. Furthermore, it cannot convey any information on wildlife distribution and movement at all.

Gap analysis also appears to have been designed to be used on a very moderate scale, 1:250,000 seems to be the largest scale that Gap analysis is effective at with a minimum scale of 1:20,000 (Karl et al. 2000, Bossenbroek et al. 2004). While Gap analysis studies can be (and are) conducted at much larger scales, scientific literature shows that there are considerable shortcomings to using scales that are too large or too small in the landscape planning that many park planners engage in. Generally speaking, meso-scale landscapes are the most strongly advised ones to use, which tend on the scale of 1:250,000.

Another drawback is that some species, especially those with restricted distributions, will be missed by the coarse filter approach that Gap Analysis is based on.

Strengths of Gap

One of the strengths is that Gap analysis allows planners to view the larger picture of protected areas networks, it allows them to take different types of data and to compile them together to get a more complete, perhaps even holistic, view of the way conservation, human land use habits, and wildlife/plants species distributions interact and influence one another. This information can give planners and managers greater strength to their proposals of new and protected areas.

Enduring Features/Analysis

History of Enduring Features Analysis

The idea of using Enduring Features was first proposed by the World Wildlife Fund (WWF) in 1988 as part of their Endangered Spaces campaign. Enduring Features were chosen to be the primary elements of ecological diversity to be used when applying a landscape approach to conservation (World Wildlife Fund 1989, Hummel 1995). The initial reasons were based on the realisation that science has only a very limited knowledge of the total biodiversity on the Earth - of an estimated 32 million species on Earth, only 1.4 million have been described (Iacobelli et al. 1995, Hummel 1995). Since all species are dependent upon the habitats that they come from, and because it is much easier to define and identify the different landscapes than it is the different species, it was felt that using a system that defined terrestrial qualities would be a better method for conservation purposes (World Wildlife Fund 1989, Watkins et al. 1994, Hummel 1995, Reid 1996, Karl et al. 2000).

Enduring Features are defined by topography, parent material, soils, and other physical factors such as slope and elevation (Noss and Cooperider 1994, Noss 1995). The WWF defines enduring features as "a part of the landscape that has relatively uniform types of mineral soil deposits or bedrock outcrops, that these materials have a similar origin within the enduring feature, and can also be characterised by consistent changes in elevation (Hummel 1995)." WWF identifies and maps enduring features at scales of approximately 1: 500,000 to 1: 1,000,000 (Hummel 1995) and then uses the mapping and identification of Enduring Features as their primary basis by which they assess progress in the Endangered Spaces campaign goal (World Wildlife Fund 1989, McNamee 1993, Hummel 1995). They do this by conducting a Gap Analysis by using the natural regions framework and then overlapping on top of the framework the Enduring Features and the protected areas network of the various provincial, federal and territorial governments. They then look at these layers to determine where there are gaps in the current protected areas network. From there they can make recommendations.

What are assumptions behind enduring features analysis?

There are three main assumptions behind the use of Enduring Features Gap Analysis (EFGA). The first is that enduring features are more stable in their distribution and composition in the long term than are biotic communities (Peterson and Peterson 1991, Peterson Peterson and Pollard 1995, Noss 1995, Manitoba Conservation 2000); that they largely influence the distribution of species and biotic communities within natural regions, as defined by climate and physiography (World Wildlife Fund 1989, Iacobelli Kavanaugh and Rowe 1995, Peterson Peterson and Pollard 1995, Noss 1995), and that this influence is assumed to be strong enough to allow for the regeneration of the original biotic communities after significant disturbance, either natural or anthropogenic (World Wildlife Fund 1989, Peterson and Peterson 1991, Iacobelli Kavanaugh and Rowe 1995, Peterson Peterson and Pollard 1995). Thus by protecting and representing the enduring features of each natural region, the dynamics between geophysical processes and the biological community of each area will be maintained (Noss and Cooperider 1994, Noss 1995). These assumptions can be misleading - biological features do not necessarily coincide with the underlying enduring features (Noss 1995). This is a problem recognized by WWF Canada and other proponents of enduring features analysis, which is why they recognize that enduring features are a guide to identify initial candidate areas for protection, and then add biological criteria to guide the designing and selection process of reserve networks (Noss and Cooperider 1994, Noss 1995).

One of the underlying principles that tie together Gap Analysis with Enduring Features is the concept of "representativeness". Peterson et al. (1991) suggest that there are two ways to view the concept of representation; one is to use representation as "one of several criteria by which nominated protected areas are evaluated and selected or rejected. The other is to view representation as the underlying principle, or goal, which the selection process aims to satisfy" (Peterson Peterson and Pollard 1995). Peterson et al recommend the second approach as the best way (Hummel 1995, Peterson Peterson and Pollard 1995). By using Enduring Features as the unit of representation, it allows planners and managers to use a non-partisan way to determine which landscape units should be selected for protection, as opposed to methods that are in high public profile at any given time or to ecosystem features that are very changeable (Peterson Peterson and Pollard 1995). There is also the benefit that enduring features are viewed as relatively stable landforms, and as such they provide a foundation by which to judge representation (Peterson Peterson and Pollard 1995, Manitoba Conservation 2000). It has even been suggested that assessment at the level of plant associations or biotic communities should not even be considered unless representativeness has already been assessed at the level of landscape units (Peterson and Peterson 1991). This returns to the underlying assumption that habitats and associations important for wildlife, plants, and biotic communities should automatically be well represented if landscape units (such as enduring features) are well represented; even if many of the surfaces of those landscape units have been substantially modified by human disturbances (Peterson and Peterson 1991, Peterson Peterson and Pollard 1995). However, it is too simple to assume that simply because an area is represented it will remain unaffected; "representation alone does not assure persistence (Noss 1995)." Persistence of ecological systems require that the conditions which created and maintain the system persist into the future. Given the impact that human activities have, it is optimistic to assume that a biotic community will remain well represented simply because the enduring features are present.

Current Projects using Enduring Features Analysis

Currently, all the provinces and territories of Canada, including the Federal Government of Canada, employ some form of Enduring Features analysis into their protected areas planning. This is due to the commitment by all of these jurisdictions to the Endangered Spaces campaign (World Wildlife Fund 1989). WWF also uses Enduring Features as a way of assessing the progress of each of these jurisdictions in the Endangered Spaces Campaign (World Wildlife Fund 1989, McNamee 1993, Hummel 1995).

Manitoba Conservation and Enduring Features

Manitoba's natural region map was first developed in 1977, with 12 natural regions. At the time, the focus was on recreational planning. The classification of each region was based upon observable differences that the average person could determine.

As a result, the criteria that were used to characterize each region was based on the most obvious visual features that differentiated one region from another, primarily vegetation or dominant landform (Watkins et al. 1994).

The latest attempt had the regions classified based on a thematic and hierarchical system similar to the one developed in Alberta (Watkins et al. 1994). The major themes used to classify each region were: Physiographic and Ecoclimatic Regions, Surficial Geology, Soil Landscapes, Vegetation Classification and Land Use, and Aquatic Ecosystems (Achuff and Wallis 1992, Watkins et al. 1994).

Currently, Manitoba is divided into a set of 18 natural regions and sub-regions. Manitoba's action plan (Manitoba Conservation 2000) recognizes representation as the underlying principle in designing networks of protected areas. Manitoba used two criteria to assess representativeness of crown lands in relation to natural regions as a whole: a thorough understanding of what is to be represented and a set of criteria by which to judge candidate lands for inclusion in the network (Watkins et al. 1994).

In 1990 Manitoba adopted enduring features gap analysis as part of their new Protected Areas Initiative. Manitoba Conservation elected to use Enduring Features as their criteria for representation in determining protection because they are easier to define and identify than complex biological communities (Manitoba Conservation 2000). Each natural region was divided into smaller enduring features units, based on soil and landform. These units range in size from a few hectares to over a million hectares in size (Watkins et al. 1994). In total, there are over 800 enduring features in Manitoba.

By representing the Enduring Features in a system of protected lands within each natural region, it is thought to serve as a useful way of protecting biological diversity within each natural region (Belbin 1993, Manitoba Conservation 2000). Enduring features are assumed to be surrogates for biodiversity, with the idea that by protecting a portion of all enduring features within a region, all biotic community types will be automatically represented (Iacobelli Kavanaugh and Rowe 1995, Peterson Peterson and Pollard 1995). The process of identifying the different combination of soils and landforms, and of determining if they are adequately represented in Manitoba's network of protected areas is called enduring features analysis. (Manitoba Conservation 2000)

By adopting the Endangered Spaces campaign and Enduring Features as their representation criteria, Manitoba aims to achieve the following goals: 1. Protect biodiversity by protecting representative areas and the landscape level processes that maintain them, instead of individual species on a case by case basis and 2. Relate protection standards to the criterion of ecological integrity (Watkins et al. 1994).

In Manitoba, topography was not considered to be a significant enough feature of the landscape, and has been excluded from the Enduring Features definitions (Watkins et al. 1994), with the exception of the escarpments and some beach ridges in the Interlake Region and Hudson Bay region.

Unlike plants and animals, soils and landforms are more stable over time. When an ecological process [i.e., fire] passes through an area, its biodiversity is temporarily changed, but there is potential for it to return to its previous state because the soils and landforms remain. As a result, it is easier to define, measure, and quantify these somewhat more permanent enduring features than it is to define, measure, and quantify the complex biological diversity that occupies a given site over time (World Wildlife Fund 1989).

Problems related particularly to Manitoba in using Enduring Features

The Enduring Features map that was developed by Manitoba Conservation has several significant limitations to its design. One of these limitations has to do with the way the boundary lines were generated; by a union overlay of themes in a GIS program using 1: 1000000 soil maps. This large scale resulted in a margin of error as large as 1 km on each of the boundaries, which means that Enduring Features with a size smaller than 1 km^2 could be considered artefacts of the Union overlay theme (Watkins et al. 1994). The second limitation was that each Enduring Feature was classified based upon the dominant soil type in the region, with a dominant soil type being defined as any one soil class that comprises 51% or greater of the polygon. This meant that up to 49% of an enduring feature polygon could be composed of at least one, if not more, entirely different soil classes. These limitations were always known when the Enduring Features map was created; to deal with these problems each Enduring Feature polygon was to be treated as a hypothetical unit until confirmed on the ground. The purpose of Enduring Features was to use them as a focus for the study of new parks in areas that contained features not adequately represented in the existing park system, and were not intended for setting park reserve boundaries (Watkins et al. 1994, Noss 1995).

Previous Research on Enduring Features Analysis

To date there has been only one other study looking at the effectiveness of Enduring Features analysis within Manitoba. This was produced by the Mixedwood Forest Society, a non-profit society that works to conserve and protect mixedwood forests within Manitoba. Their research focused on comparing the Enduring Features found in the three escarpments of the western uplands region of Manitoba: Riding Mountain, Duck Mountains, and the Porcupine Hills, in order to determine if the areas are similar based on Enduring Features alone. This was done because the Province maintained that Riding Mountain National Park adequately represents the land base of the western escarpment, and that further protection of the western escarpment was not needed. This statement was based upon Enduring Features Gap Analysis.

The Western Uplands project focused on answering two questions: whether the three areas are comparable based solely on Enduring Features, and whether the region's unusual landscapes are adequately represented within Riding Mountain National Park (Gurr Ashcroft and Hinam 2005). The results of their analysis indicated that slope, aspect and climate play a more important role in determining the composition of biotic communities, and that the current map scale used by Manitoba Conservation is too coarse and thus allows for gaps in the representation of unique landscapes within the western uplands region. They also found that vegetation composition in what are identified as similar landscape units (Enduring Features) differed considerably, and that the variation was found to be most evident between the northerly and southerly extents of the study area. Reasons for this difference were attributed to climate and physiography, which were noticeably different between the three upland regions (Gurr Ashcroft and Hinam 2005).

Landscapes, landscape analysis

Use in parks/conservation management

Landscape analysis is an area of study that combines the systems approach developed in the study of ecosystem relationships with geographical methods for describing tracts of land (Turner 1988, Zonneveld 1989). It is the study of the complex array of interactions involving disciplines from biology, soil science, geomorphology, botany, zoology climatology, hydrology and many other disciplines (Turner 1988, Zonneveld 1989). According to Zonnefeld (1989) landscape analysis serves three purposes: it serves as a central concept in landscape ecology hypotheses, it is used as a mapping tool and it works as a means of transferring landscape knowledge, via evaluation, to application (Zonneveld 1989). By using landscape analysis, planners for the evaluation and management of landscapes can reduce the costs of landscape surveys without sacrificing too much accuracy of information (Zonneveld 1989, Scott Tear and Davis 1996, Prendergast et al. 1999). The drawback this is that landscape analysis is largely a hypothetical construct (Zonneveld 1989, Wood 1996), which is not only physically defined by geomorphological processes but also culturally defined by the preconceptions of the user (Wood 1996).

Landscape ecology has become more attractive for scientists and land planners in recent years due to the availability of high quality satellite images which allow them to view landscapes (Oliver 1992, Peterson Peterson and Pollard 1995). In the past, landscape studies were conducted on an attribute-by-attribute basis, where only one or two areas (soil and vegetation, or soil and climate) would be studied and mapped very intensively (Zonneveld 1989). This resulted in very detailed information being collected, but had as a drawback the ability only to see a very small part of the entire process in the formation and development of landscapes. It was also expensive in terms of time, money and staff (Zonneveld 1989).

In using the concept of land units combined with GIS for the study of landscapes, much of this time and expense are removed. The technique involves using physiographic soil surveys, landscape-guided vegetation surveys, aerial photography and other remote sensing means to interpret directly onto landscape models an analysis of landscape processes, and by doing so developing land units as tangible bodies and thus to determine an accurate idea of what is actually going on within the landscape being analysed (Scott and Jennings 1998, Zonneveld 1989).

GIS programs are a useful tool for doing this work, since they are able to add, subtract and recombine different sources of biophysical data, and can integrate both social and economic spatial data with the biophysical data (Hielkema 1986, Meijerink Valenzuela and Stewart 1988, Zee and Huizing 1988, Zonneveld 1989) to create a comprehensive land management plan (Zonneveld 1989, Oliver 1992, Scott and Jennings 1998). In this way a more inclusive expression of the information can be developed to allow planners and researchers a way to visually understand all of the factors that are occurring on the landscape, and to make the best decisions they can on managing that landscape. However GIS programs should never be viewed as the only tool, or even the best tool for landscape analysis (Zonneveld 1989). Like any method, they should never be used to the exclusion of all other approaches, especially reconnaissance surveys (Zonneveld 1989). It is also important to remember that the area being studied is a complex system, and to resist the impulse to over-simplify or categorise the area based on one or two attributes (Zonneveld 1989).

In order to ensure that GIS based landscape analysis is as accurate as possible, it is important to collect the correct data in order to reduce any potential errors in the analysis. For example, in studies that look at correlations between two factors (such as soil and vegetation) it would be important to ensure that the data be collected in the exact same point and at the same time, in order to remove the potential for error that could be caused by the high variability in soil and vegetation that exists in all landscapes (Zonneveld 1989). On-the-ground surveys should also attempt to identify and classify all of the important attributes of a landscape (soil, vegetation, wildlife) as well as the processes (hydrology, climate, etc.) (Zonneveld 1989).

When using landscape analysis for the purposes of protected areas management there is the underlying assumption of homogeneity. That is, a landscape is defined by its similarity for a particular described or identified trait (Zonneveld 1989); this described trait could be vegetation, soil, or anything else. Thus if a planner is looking at landscapes described by a certain vegetation type, the soil properties in the landscape underneath do not need to be homogeneous, provided they have no influence on the vegetation above (Zonneveld 1989). The same can be applied to the underlying landforms, if there are no distinguishing gradients between one trait or the next, such as organic to mineral, wet to dry, then the area can be considered homogenous and treated as a single landscape for the purposes of that study or management plan (Zonneveld 1989). In order for the concept of homogeneity to work the criteria used should reflect the ecological processes at the scale that the analysis is being done (Zonneveld 1989).

Ultimately, successful land management based on landscape analysis aims towards preserving the natural equilibrium of ecological and landscape processes, and preventing the deterioration of these processes as a result of human activity (Zonneveld 1989, Scott and Jennings 1998).

Landscape and processes

Landscapes are open systems; energy is constantly moving between the landscape and the surrounding environment in a state of self-regulation or equilibrium (Zonneveld 1989). This equilibrium is the product of a complex interplay of geological, climatic, biological and temporal processes (Turner 1988, Zonneveld 1989, Wondzell et al. 1996, Scott Tear and Davis 1996) which can remain the same over a certain period of time or exhibit change that is gradual and free from large, sudden changes (Zonneveld 1989).

Climate is one of the more important features in the formation of landscapes. Climate is defined by the amount and type of precipitation in the region, the temperature, and the wind direction and orientation. Climate affects the amount, kind, and type of vegetation that can grow as well as influencing the rate of decomposition and erosion. This then affects the type of soils which develop and the rate at which they develop. Most of these processes are dependent upon a stable climate to allow for the landscape, soil, and plant communities to maintain themselves in their current state. These stable patterns and ecological processes explain why climate, soil and geomorphic boundaries often match one another so well (Zonneveld 1989). Once the climate changes, then the processes acting on the landscape change in response (Wondzell et al. 1996). When this happens, vegetation and soil change, but since vegetation responds faster than soil this results in boundary shifts between vegetation, soil and climate regimes. In terms of management planning, these changes in the process shows in discrepancies between vegetation and soil maps, where the vegetation does not follow the soil boundaries simply because the soil characteristics still reflect the previous climatic regime (Zonneveld 1989).

Thus landscapes function like a memory; processes that happened thousands or even millions of years in the past can have a direct impact on how the landscape works today, something known as the hereditary factors of a landscape (Zonneveld 1989). At the same time present-day processes such as climate and human activity influence and shape current landscape dynamics. These processes can be divided into two kinds of factors: Operational factors and Conditional factors (Zonneveld 1989). Operational factors are the description of variables, terms, or objects in terms of the specific process or set of validation tests used to determine its presence and quantity. Operational factors are difficult to measure directly. These include topoclimate, amount and availability of minerals for plant uptake, energy dynamics between water and soil particles, soil humidity on plant growth, and mutual biotic influences (Zonneveld 1989). Conditional factors are those variables, terms, or objects that are directly observable. Conditional factors include soil type, soil texture, slope, and aspect (Zonneveld 1989). It is the measuring and quantifying of conditional factors which are depended upon for almost all environmental studies (Zonneveld 1989). These influences of past and present processes work together to determine the extent and kind of biological communities that can be supported. This interplay also determines the shape and characteristics of the landscape that will develop in the future.

There are numerous features that can influence the development of biotic community within a landscape (Zonneveld 1989, Fu et al. 2004, Halabuk 2006); soil conditions, topography, landscape position, slope, aspect, elevation and existing biotic communities are some examples (Wondzell et al. 1996, Fu et al. 2004). All of these features work within the landscape to create conditions suitable for biotic communities to establish and maintain themselves.

Spatial scale in Landscape Analysis

Numerous studies have shown that ignoring the effects of scale when conducting research or making land management decisions is imprudent (Turner 1988, Zonneveld 1989, Wright 1997, Fu et al. 2004), since the level of scale greatly determines the type and quality of the information used to make planning decisions (Turner 1988, Scott and Jennings 1998, Karl et al. 2000, Bossenbroek et al. 2004). The level of accuracy of topographic features on numerous maps is almost entirely scale dependant (Frank Palmer and Robinson 1986, Wright 1997). Scale impacts the type of data collected in field work, and the results of any landscape analysis can change simply by changing the scale of the landscape studied (Gerrard and Robinson 1971, Turner 1988, Karl et al. 2000).

This problem of scale makes it difficult to make single designations about any landscape feature, since by changing the scale the designation becomes irrelevant or even inaccurate (Wood 1996). Gap analysis would appear to be the ideal solution to this dilemma, since it uses a multiple scale approach to landscape analysis and regional habitat modeling (Csuti and Kiester 1996, Karl et al. 2000). This is one of the strengths of the model; it enables planners to use a wide variety of map and information resources to conduct the modeling (Karl et al. 2000). However, just because the model allows the use of multiple resources at different scales does not mean they should be used. Studies have shown that there is a lack of knowledge on how the interactions of habitat information, levels of analysis and resolution of spatial data affect the performance of landscape analysis at varying spatial and temporal scales (Karl et al. 2000, Bossenbroek et al. 2004). Studies that have used Gap analysis modelling have reported differences in its effectiveness in landscape analysis. Some have found Gap analysis to be highly accurate (Scott Tear and Davis 1996), while other studies questioned its effectiveness as a management tool (Block et al. 1994). This suggests that the information requirements for accurate predictions using landscape-based models will differ with the level or scale of application (Karl et al. 2000). Being unaware of this can lead to Gap analysis being applied to situations which the model was not designed for (Wright 1997, Karl et al. 2000).

Acquiring small-scale (high definition) data is not always the best solution to this problem, since the smaller the scale, the more detail that can be found within the area (Zonneveld 1989, Bossenbroek et al. 2004). A lot of detail can create an increase in the amount of time and money spent on developing the model, and time and money are major constraints for most landscape planners. Too much detail can also unnecessarily complicate the model. Another problem is that since each study develops a map for each attribute (plant species, animal boundaries, etc) these maps would then have to be combined into a single mapping unit. Combining small-scale maps of each attribute causes multiple boundary issues, because the boundaries of most plant and animal species are not the same. For an effective landscape analysis to occur, these boundary issues would have to be resolved, a problem that is all too common in GIS (Zonneveld 1989). Cost, time and resource availability also impact the ability to acquire or use fine-scale information for landscape planning (Karl et al. 2000). Separate landscape-level models for each species can be developed, but time and cost render the exercise futile except for the most rare or threatened of species (Karl et al. 2000). All of these issues make it easier for planners to work with intermediate mapscales (1:250 000 to 1:500 000). At intermediate scales topographical boundaries tend to be obvious and easily correlated with both soils and vegetation (Zonneveld 1989).

Species do not respond or react to only one scale, they respond to numerous ecological processes occurring over a wide range of scales (Allen and Starr 1982, Wiens 1989, Karl et al. 2000, Cushman and McGarigal 2002, Bossenbroek et al. 2004). Explaining the variance within biological communities requires measuring environmental variables at multiple scales (Bossenbroek et al. 2004). Only by looking at the effects that environmental factors exert on species and communities at all scales (local, intermediate, large) can landscape analysts begin to understand how management plans will affect biological communities, and in turn how effective these management plans are in protecting biological communities.

As an example, plant population distribution is strongly correlated to large-scale changes in soil and climate, but plant distribution is also strongly correlated with small-scale variations in the soil and topography (Fu et al. 2004). These small-scale impacts can have a strong influence on the community structure and dynamics of plant populations within a region (Fu et al. 2004). Studies by Bossenbroek et al. (2004) on plant, bird and beetle communities showed that the composition of all three groups was influenced by environmental variables at three different scales (on-site, local, landscape). This showed that environmental factors at multiple scales are independent from the mobility of a taxonomic group in explaining community composition (Bossenbroek et al. 2004).

In landscape analysis, it is important to know the scale that will be used in order to develop an accurate model. Scale determines the number of observations that are needed to determine species abundance within an area (Karl et al. 2000). As a result it can become difficult to determine which scale is the most important to consider when looking at species distributions, and by extension, which areas to set aside for protection (Wiens 1989, Karl et al. 2000), especially when numerous species are being examined across different taxa. That is why these intermediate scales are so useful, they ignore the minor boundary discrepancies and overlaps between topographic and vegetation attributes that would inevitably occur on smaller, finer scales (Zonneveld 1989). This is the where GIS based landscape analysis such as enduring features gap analysis can prove to be the most useful. Caution must be exercised, since differences in scale have been shown to affect the accuracy of landscape analysis using Gap Analysis (Karl et al. 2000). A study on the impact of different scales on habitat-relationship models on Craig Mountain in Idaho showed that the degree of plant community heterogeneity within the landscape influenced how the model categorised the plant community (Karl et al. 2000). Simply put, at fine scales the model accurately showed the heterogeneous nature of the landscapes biological community, but as the scale coarsened the model simplified the community to the point that only the most dominant community type was recorded as being present in the landscape. Thus areas of high community complexity were simplified as the scale became coarser (Karl et al. 2000). On the other hand, increasing the complexity of landscape models when analysing homogenous communities increased the accuracy of the models (Karl et al. 2000). Overall, model accuracy increased with model complexity (Karl et al. 2000).

Scales are not just purely topographical, they can be political as well. Management decisions (scientific and political) for protected areas are made and carried out at the level of geopolitical units, the level at which legal and administrative instruments operate (Erasmus et al. 1999). In Manitoba there are multiple geopolitical units in existence: urban municipal, rural municipal, First Nation, Provincial, Federal, Territorial and International. Many of these jurisdictions overlap considerably, so that designating areas for protection becomes as much an issue of scale at the political level as it does at the landscape level. Problems with the use of political boundaries for determining conservation priorities mean improper fund allocation and overemphasis on peripheral populations (Hunter and Hutchinson 1994, Erasmus et al. 1999). For example, large amounts of money are spent on the conservation of timber wolves and bald eagles in the continental United States, even though both species are secure within Canada and Alaska (Hunter and Hutchinson 1994). Local conservation societies emphasise protection of locally rare species because they are based within political units (province, state, municipality) and not globally. Perceptions of people living within an area may be different from what is occurring on a national scale, fostering conservation or even over-utilisation of local species. A good example of this is the conflict on polar bear population numbers in Nunavut, specifically along the west coast of Hudson Bay. Native hunters claim that polar bear numbers are increasing, while scientists express doubt, citing declines of 22% since the early 1980's as a direct result of the earlier ice break-up on the Hudson Bay (Polar Bear International 1992). On the other hand, local conservation encourages the protection of local genetic diversity, local ecosystem function and local human values (Hunter and Hutchinson 1994, Erasmus et al. 1999). Such protection allows species to maintain the greatest possible genetic diversity, which increases the chances of the species to adapt to global changes, like climate change. In addition, the practice of using locally designed management models to protect threatened species works to prevent overall population declines (Hunter and Hutchinson 1994, Erasmus et al. 1999).

What is needed is to determine what the best level of scale is, in order to achieve planning or management objectives. The trickiest part of this procedure would be in determining how to best match the appropriate data sources with the best spatial data resolution into an appropriate analysis unit for the management purposes that are required (Karl et al. 2000).

Soil and Vegetation

Soil formation

Soils are one of the more direct influences on plant distribution and growth. Variation in soil types and soil nutrient levels at different spatial scales are common within landscapes and these variations are important in influencing the distribution of plants (Yonker et al. 1988, Fu et al. 2004). These variations in soil conditions: soil type, soil depth, organic content, nutrient level, and moisture retention, are all influenced by landscape features including topography, landscape position, slope gradient and elevation (Fu et al. 2004).

Soils are defined as the "naturally occurring, unconsolidated mineral or organic material at least 10 cm thick that occurs at the earth's surface and is capable of supporting plant growth" (Canadian System of Soil Classification 1998). "Naturally occurring" includes man-made disturbance of the surface such as cultivation and logging but not displaced materials such as gravel dumps and mine spoils (Canadian System of Soil Classification 1998).

Soils themselves are formed by five principle factors: climate, vegetation, drainage, parent material, and relief (Fraser et al. 1985). Thus the type of soil formed in any place on earth is a product of these five factors, all of which interact in varying degrees (Fraser et al. 1985). Two other considerations must be made when looking at soils, the length of time the factors have been operating, and any changes or modifications caused by man (Fraser et al. 1985, Štekauerová et al. 2006).

In Canada, soils are classified according to the Canadian System of Soil Classification (Canadian System of Soil Classification 1998). It is a taxonomic system, placing soils into classes based upon measurable soil properties that reflect processes of soil formation and environmental factors (Fraser et al. 1985). There are five classes of organisation, going from the largest grouping to the smallest: *Order, Great Group, Subgroup, Family,* and *Series*. Series are very often sub-divided into even smaller units known as *Phases*. The smallest unit of a soil sample representing a soil series is known as a Pedon. The size of a Pedon is somewhat arbitrary, due to the variable nature of soil properties (Fraser et al. 1985). Currently a Pedons' dimension are lateral 1.0 to 3.5 meters to a depth of 1.0 to 2.5 meters (Fraser et al. 1985). Pedons are used when sampling soil for research purposes, but are too small to be represented on a map.

Soils can be placed into two broad categories: organic soils and mineral soils. In reality organic soils are classified as a single Order, while mineral soils are classified into many different Orders. Soils of the Organic order are composed largely of organic materials; they include the soils commonly known as peat, muck, bog and fen soils. However, one group of Organic soils (Folisols) consists of upland organic materials, usually of forest origin (Canadian System of Soil Classification 1998). Mineral soils are classified into several Orders.

Properly identifying and classifying soils in the field is an important part of determining and classifying land units, since soils can determine both the character and the potential qualities of a land unit (Zonneveld 1989). Soils can also help with assessing land units based on climatic themes, but this could only be done if the climate regime has been relatively constant for at least several thousand years (Zonneveld 1989).

Soil Properties and vegetation (how do plants affect soil)

The relationship between soil and vegetation is fluid and bi-directional with vegetation (communities and individuals) and soil properties interacting and being interdependent upon one another (Power et al. 1981, Ata Seyed and Gilkes 2005). This interaction results in a wide mosaic of species assemblages, communities, and structures with an equally wide range of soil types and soil properties all within the same area (Ata Seyed and Gilkes 2005). This heterogeneity can be considered to be the reflection of a multiplicity of biotic and abiotic factors (Ata Seyed and Gilkes 2005). The interactions between soil properties and vegetation are strongly influenced and controlled by variation in landscape attributes, such as slope, aspect, and elevation. These attributes influence the interactions by affecting the distribution of energy within the system, the movement of water, the chemical and physical processes of soil, and the amount, type and pattern of precipitation (Buol Hole and McCracken 1989, Ata Seyed and Gilkes 2005).

The action of vegetation on the soil, whether through the creation of organic matter, removal of nutrients, or the physical action of roots within the soil (Halabuk 2006) all play a role in determining the properties of the soil, which in turn affect and influence vegetation growth. Studies on native rangelands have found that plant roots both exploit and develop soil structure, and in soil with good soil structure, root growth develops easily(Araujo 1999) . Other studies have shown that vegetation ground cover plays a stronger role in influencing soil conditions than the dominant tree stand (Flather et al. 1997, Jonathan and Gross 2005). Studies in semi-arid regions found a strong relationship between plant communities and soils or landforms. It seems that the patterns of plant communities resulted from a combination of soil properties on water availability and the distribution of water between landforms (Wondzell et al. 1996). Once again, these interactions were regulated between land-forms, geomorphic processes, soils, and plant communities. This resulted in the development of characteristic landforms and vegetation communities that repeat across the landscape (Wondzell et al. 1996).

However, there are many plant species and communities in which soil type does not play an important role in determining their distribution (Jonathan and Gross 2005). This was discovered in a study into riparian communities, where it was determined that land cover was not a reliable predictor of the distribution of tree and shrub species, species richness or riparian plant communities. It was also found that the shrub and tree layers responded in different ways to the same underlying environmental variables (Lyon and Gross 2005). These observations have been made in numerous other studies (Dunn and Stearns 1987, Sagers and Lyon 1997, Guillaume, 2002).

So while soil and landform play an important role in the development of biotic communities, it does not necessarily mean that all biological communities coincide with the underlying soil and topography – the enduring features (Noss 1995). Vegetation communities change in space and time in order to respond and adapt to environmental change (Zonneveld 1989). Since biological organisms respond more quickly to change than the geological processes underneath them, community and soil combinations can develop that never existed before. This results in spatial variability in soil properties, soil resource levels and plant communities (Schimel et al. 1985, Schimel et al. 1985, Aguilar and Heil 1988, Yonker et al. 1988, Fu et al. 2004). As a result, biodiversity and community structure control the amount and type of organic input in to the soil, thus affecting soil fertility (Yonker et al. 1988, Tilman et al. 1996, Fu et al. 2004).

Soil organic matter and vegetation

Soil Organic Matter (SOM) is an important component of the soil; it increases the capacity of the soil to retain moisture and heat and it is a critical factor for soil fertility (Power et al 1981, Fu et al. 2004). SOM contributes to soil structure by acting as a stabiliser in the formation of aggregates within the soil. SOM also contributes to the chemical and biological properties of the soil, and is both the source and the exchange site for most nutrients (Ata Seyed and Gilkes 2005). SOM has also been shown to be important in the formation and stabilisation of soil porosity, which allows for the easy development of roots which in their turn will make the soil thicker and maintain its porosity (Ata Seyed and Gilkes 2005).

SOM composition has been found to be strongly influenced by shrub coverage and ground vegetation (Fu et al. 2004). Topography, particularly elevation plays an important role on SOM variability (Fu et al. 2004). This has been shown in many studies where areas with high fertility often existed on the upper and gentler slopes while the lower and steeper slopes had greater disturbance and soil erosion in the research area. (Fu et al. 2004)

Soil and Landscape properties (how do landscape properties affect soil)

Topographic features (slope, elevation, and aspect) can determine where and how soil properties – both physical and chemical -- are maintained or lost (Jenny 1941, Ruhe 1956, Ata Seyed and Gilkes 2005). The variability of soil properties can be attributed to the dynamic interactions between the soil and environmental factors such as climate, parent material, vegetation, and topography; (Jenny 1941, Ata Seyed and Gilkes 2005). Some of the more important soil properties are: soil texture (the proportion sand, silt, and clay), soil structure (structural form, structural stability and strength, porosity, bulk density), organic matter, water content, aeration, and temperature.

Significant differences in the chemical and physical properties of soils can occur in very small areas simply due to landscape position, typically by providing micro-climates that support the growth of plant species with different characteristics from the surrounding community (Ata Seyed and Gilkes 2005). Soil properties such as soil surface layer thickness, bulk density, and soil structure continuously respond to natural soil formation factors and land management factors (erosion, exploitation, and conservation) (Power et al 1981, Ata Seyed and Gilkes 2005). These differences can occur even if the soils occur on the same geologic feature (Ata Seyed and Gilkes 2005). As an example, slope plays a role in soil fertility due to its effect on the accumulation of organic material, and slope (but not aspect or elevation) has been found to be significantly related to a soils ability to retain water (Ata Seyed and Gilkes 2005).

Soil Depth and Vegetation

Soil depth is an important factor that influences plants and plant communities, and it is known that there is a mutual dependence between soil profile development and the plant communities that grow on it (Jonathan and Gross 2005). Soil depth is considered an important factor in determining soil quality, since thick soils are capable of storing more available water and nutrients for plant use (Power et al. 1981, Ata Seyed and Gilkes 2005). So important is soil depth that in arid and semi-arid rangelands it is the thickness of soil depth that controls the type of vegetation and biomass production (Ata Seyed and Gilkes 2005).

The processes that work upon soil depth and plant species are complex because the processes are a combination of both biotic and abiotic factors that work in a mutually developed relationship between the vegetation and the soil (Jonathan and Gross 2005). Topography has long been known to strongly influence soil thickness (Power et al. 1981, Ata Seyed and Gilkes 2005). Aspect influences soil depth, simply because aspect determines canopy cover (Ata Seyed and Gilkes 2005), which in turn influences deposition of organic matter.

Soil depth has been found to be correlated to the distribution of tree species. For example, studies in Norway found that pine forests and forest grounds rich in lichens occurred more frequently on shallow soils (< 20cm), while spruce forests and forest grounds of grasses, herbs, and mosses tended to be found on the deep soils (Lag 1971). Studies in China have indicated that high soil fertility often existed on the gentle, upper, and south-facing slopes while the lower and steeper slope had greater disturbance and soil erosion (Fu et al. 2004).

Disturbance

Biotic communities are made up of a combination of species richness and community complexity. These two factors can be have an important impact on soil and landscape development by regulating soil fertility, moisture and heat retention, erosion control and the development of geomorphic processes within the landscape (Wondzell et al. 1996, Tilman et al. 1996, Fu et al. 2004). Disturbance events that alter or change vegetative cover and the composition of plant communities would affect the rates, types and patterns of erosion and soil development within landscapes (Wondzell et al. 1996). Because of disturbance events, community structure and biodiversity vary spatially throughout the landscape. Thus the heterogeneity of community types within a landscape are influenced by a combination of by both abiotic and biotic factors (Fu et al. 2004).

Regeneration of communities after disturbance assumes that all the factors that can allow for the regeneration are present. These factors are multiple, including but not limited too: suitable amount and type of soil, quality of the seed bank, climate conditions, impacts of invading/exotic or pioneer species, the type of disturbance, persistence and pattern of disturbance and presence or absence of similar nearby communities to allow for colonization.

Plant species respond to disturbance in different ways; it has been shown that different layers of a forest community will react differently to disturbance and environmental variables, suggesting that they behave independently from one another – the tree and shrub layers are uncoupled (Dunn and Stearns 1987, Sagers and Lyon 1997, Guillaume 2002, Lyon and Gross 2005). Lyon and Gross also found in their studies that high disturbance does not coincide with low diversity or susceptibility to invasive species.

Disturbances can be said to have several factors that can determine their impact on a community: scale, intensity/severity, persistence through time, and frequency. The main concern for protected areas planners is not disturbance due to natural reasons, for these disturbances have occurred before and the each biological community has their own adaptations to it. The concern is man-made disturbances in the area or the surrounding region.

It is important to remember when considering EFGA that the most fragile component of an Enduring Feature is the topsoil, since it can be easily removed under the right conditions. The most well-known example is erosion due to agricultural practices (plowing, irrigation, slash-and-burn farming). There are many places in the world whose ecosystems have been permanently destroyed due to soil erosion or salinisation, and all within a human lifetime. Areas like Easter Island, Greenland, and Iceland had very fragile ecosystems which were maintained solely by the presence of the biological community, and once that community was removed, the enduring features underneath it were quickly eroded or destroyed, thus preventing any re-establishment of the original ecosystem (Diamond 2005). Yet it is these disasters which are hoped to be avoided by using a community-based management approach to protected areas designation and management. So it now becomes a matter of deciding how effective EFGA can be, and the best way to do this is to identify what it is capable of, and ensuring that any weaknesses are addressed at the beginning of the process.

Objectives

The project has the following goals:

1) to assess if different enduring features had significantly different vegetation communities from one another. Part of this goal was achieved by conducting a series of botanical surveys in all of the major vegetation communities found within each enduring feature in the study area.

2) To conduct a soil analysis within each survey site to determine if the enduring features as identified by the Manitoba Conservation database matched with the enduring features identified at each site.

3) To compare the geomorphologies of enduring features at two different scales to determine what degree these geomorphological features may play in the ability of enduring features to differentiate vegetation communities, if at all.

Due to limitations in funding and the remoteness of the park reserve, only the northeast corner of the park reserve was sampled for the study. The area was chosen due to the presence of four of the six enduring features within a 20 km radius of a hydroline and cabin where the researchers could establish a basecamp.

Materials and Methods

Site Description

Chitek Lake Park Reserve is located within the Interlake region of Manitoba, approximately 350 km northwest of Winnipeg. It is 100,300 hectares in size, and located at Latitude 52° 25' 14" North and Longitude 99° 24' 12" West (**Figure 1**). The park reserve straddles two of Manitoba's natural regions. The southern area is a part of the Interlake plain ecoregion, while the north portion lies in the mid-boreal lowland ecoregion (Klassen 1928, Elson 1962, Fraser et al. 1985, Stock 2005). The Interlake plain is characterised by short warm summers and cold winters. The mean annual temp is 1.1°C, with an average growing season of 173 days. Annual precipitation is 510 mm, with one-quarter falling as snow (Smith et al. 1998). The mid-boreal lowland ecoregion is characterised by short, moderately warm summers and long cold winters. The mean annual temperature is 0.5C, with an average growing season of 166 days. Annual precipitation is 480mm, with one-quarter falling as snow (Smith et al. 1998). The landscape contains six enduring feature types and is home to five ungulate species: Elk (*Cervus elaphus*), Woodland Caribou (*Rangifer tarandus caribou*), Whitetail Deer (*Odocoileus virginianus*), Moose (*Alces alces*), and Wood Bison (*Bison bison athabascae*). Chitek Lake is located in the center of the park reserve and Lake Winnipegosis lies on its west side.

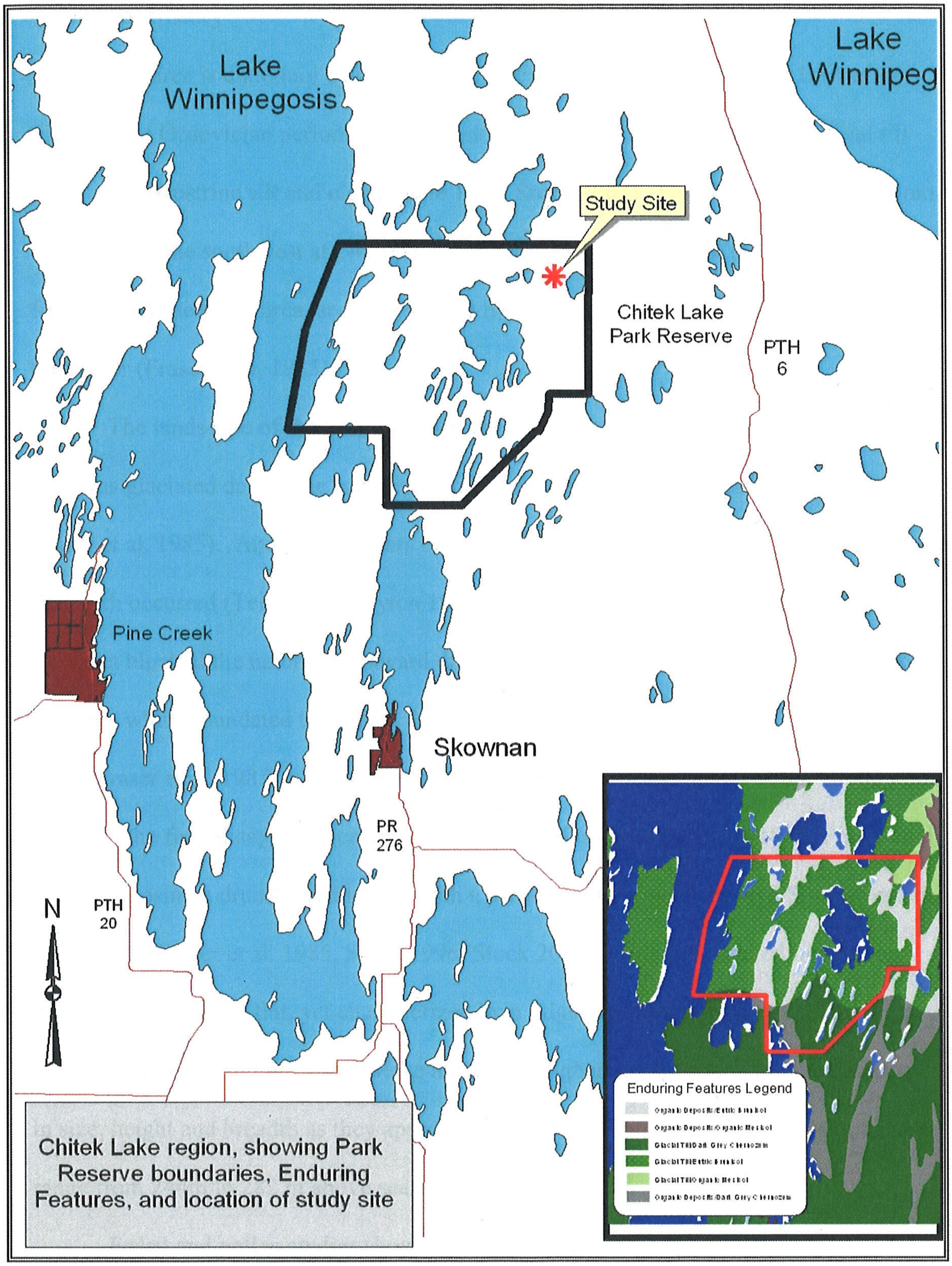

Figure 1: Location of the study site.

Geological History

The area is underlain by Paleozoic limestones and dolostones of the Devonian, Silurian and Ordovician periods (Berenzanski 1986), covered by deposits of glacial till and glacio-lacustrine silt and clay (Payne 1987, Stock 2005). Generally, these formations dip gently to the southwest at 2-4m per km^3. Silurian dolostones are the dominant formation in the study area, and they extend from north to south in a broad area through the center (Fraser et al. 1985).

The landscape of the Park Reserve was formed relatively recently, when the entire area was glaciated during the last ice age in the Pleistocene age (Teller and Clayton 1983, Fraser et al. 1985). About 9500 years before present the last recession of the icesheet to the north occurred (Teller and Clayton 1983, Fraser et al. 1985). During this retreat the ice sheet blocked the natural northward drainage resulting in the creation of glacial lake Agassiz, which inundated the region for about 1200 to 2000 years (Teller and Clayton 1983, Fraser et al. 1985). The present day land surface appeared about 7500 – 8000 years ago with the final disappearance of Lake Agassiz (Klassen 1928, Elson 1962, Fraser et al. 1985), exposing a drumlinised terrain with a predominantly North-eastern/South-western orientation (Fraser et al. 1985, Stock 1996, Stock 2005). This has resulted in a region that is predominantly flat, yet characterized by a ridge and swail topography. The ridges in the western part of the Park Reserve are larger, higher and broader and then decrease in size, height and breadth as they approach the east and southeast. Elevations in the area range from 244m to 282 m above sea level.

Fossil and pollen studies show that 6000 years ago the Waterhen-Chitek lake region was a parkland/prairie environment (Shay 1984), with only the extreme north of the Interlake Plain being covered by deciduous forest. Isostatic rebound along with a cooler and wetter climate allowed for the formation of lakes in the region (Fraser et al. 1985). By 5000 years ago it is believed that the Chitek Lake region had established its current-day forest community (Stock 2005).

Contemporary Soil

The study area is composed of the Interlake Plain, a physiographic subdivision within the Interlake region of Manitoba defined by a combination of surficial deposits and topography. The Interlake Plain is the largest of the subdivisions that occur within the entire Waterhen region (Fraser et al. 1985). It ranges from 244 meters to over 282 meters in elevation (Fraser et al. 1985, Berenzanski 1986, Stock 2005) and is characterised by undulating to gently undulating ground moraine deposits of loamy glacial till and organic deposits, of variable thicknesses, overlying the limestone bedrock (Fraser et al. 1985, Berenzanski 1986).

The southwestern section of the Interlake Plain, which is composed of Waterhen Lake and Chitek Lake, exhibits a strong drumlinized pattern in which long, broad north-northwest trending ridges are separated by broad parallel swales composed of shallow to deep organic deposits over glacial till (Fraser et al. 1985, Berenzanski 1986). The ridges are composed of two distinctive kinds of materials. The first consists of extremely calcareous loamy till materials mixed with moderately to strongly calcareous clayey glacial till (Fraser et al. 1985, Berenzanski 1986). The second material, which makes up the remainder of the area, is composed of extremely calcareous loamy till. These two distinctive tills indicate that there were two intervals of glaciation in the regions' past; the first glaciation event was characterised by ice flow from the northwest and the second by movement from the northeast (Fraser et al. 1985). In the drumlinized areas south of Chitek lake, drumlin crests generally occur at about 267 meters elevation on the extreme west side to more than 282 meters on the eastern portion of the drumlin field. These drumlins comprise the highest elevations in the Interlake Plain (Fraser et al. 1985).

The northern portion of the Interlake Plain, where the study occurred, is characterised by a strong ridge and swale topography with numerous large and small lakes. The uplands consist of extremely calcareous materials strongly mixed with loamy till, and moderately to strongly calcareous clayey glacial till deposits (Fraser et al. 1985). The many depressions randomly interspersed within these upland areas are filled with shallow to deep organic soils (Fraser et al. 1985).

The soils are composed of shallow luvisols and brunisols associated with gleysols and organic soils. These soils overlie bedrock or glacial deposits that occur no deeper than 40 to 160 cm from the surface (Fraser et al. 1985, Stock 2005).

Chitek Lake is part of the Nelson River drainage division. The general evenness of the land, along with the orientation of the drumlins (which lie almost perpendicular to the general fall of the land surface) contribute to very poor drainage (Fraser et al. 1985), with water commonly trapped within the swails in the numerous lakes, marshes, fens, and muskegs. Wetland communities vary from open fens to treed fens, bog-and-swamp landforms with black spruce and larch on peat lands to poorly drained mineral soils towards the north (Stock 2005). Much of the waters trapped within the swales is depleted by evapotranspiration (Fraser et al. 1985).

Climate

The climate of the Chitek Lake region is one of a continental climate, characterized by short cool summers and long cold winters (Fraser et al. 1985, Stock 2005). This is due to the area being beyond the moderating effects of any oceans. The climate of the region is primarily influenced by three air masses: the cold, dry air from the continental polar region; the cool and moist air from the Pacific; and warm and moist air from the gulf of Mexico (Fraser et al. 1985). The average lowest daily temperatures ranges from -25 °C in the winter to 11 °C in the summer, and the average highest daily temperature ranges from -16.3 °C in winter to 23 °C in summer. Average annual precipitation is 418mm, with precipitation being greatest in the late spring and summer (Fraser et al. 1985).

Vegetation

The vegetation community within the park reserve is largely heterogenous in nature due to the drumlinised terrain. In the northern half of the park reserve mixed coniferous forests of jack pine (*Pinus banksiana*), black spruce (*Picea mariana*) and tamarack (*Larix laricina*) dominate the ridges, interspersed with extensive wetlands comprised primarily of sedge (*Carex spp.*) fens, tamarack-sedge fens, black spruce muskeg and willow (*Salix spp.*) bogs (Fraser et al. 1985, Stock 1996, Stock 2005). In the southern end of the region deciduous-coniferous mixedwood forests of aspen (*Populus tremuloides*), jack pine, black spruce, white birch (*Betula papyrifera*) and balsam poplar (*Populus balsamifera*) occur on the sand and gravel ridges (Fraser et al. 1985, Stock

2005). Similar to the northern end, extensive fens, bogs and muskeg are found in the low-lying areas between ridges.

The underlying shrubs and ground cover are composed of a diverse mix of species, such as juniper (*Juniperus communis, Juniperus horizontalis*), dogwood (*Cornus stolonifera Cornus canadensis*), rose (*Rosa acicularis*), cinquefoil (*Potentilla fruticosa, Potentilla palustris*), violet (*Viola renifola*), wintergreen (*Pyrola asarifolia, Pyrola minor, Pyrola secunda*), and strawberry (*Fragaria virginiana*) on the ridges; and cattail (*Typha latifolia*), sphagnum, rushes (*Juncus* spp.), numerous orchids (*Orchidaceae*) and several carnivorous species (*Drosera rotundifolia*, *Drosera linearis, Sarracina purpurea*) on the low-lying wetlands.

Historical Occupation and Use

Archaeological studies show that as early as 6000 years ago Bison and people were occupying the area. Human use of the area was largely restricted to hunting activities; archaeological studies of the area showed that all artefacts and tools found there were restricted to hunting and a high mobility (Stock 1996, Stock 2005).

Human use of the area included hunting, trapping, fishing, plant and wood gathering. Small scale logging and cabin construction started with the fur trade (Stock 2005). Several small sawmills were built in the 1950's and 1960's. The soil qualities of the area make it poorly suited for intensive forestry or agriculture.

Traditional land-users practiced controlled burning along ridges to maintain travel routes up until WWII (Stock 1996, Stock 2005). The park reserve includes the traditional area of use for Skownan First Nation, who use the area for hunting, trapping, traditional plant gathering, and fishing. Chitek Lake is stocked with walleye each year and has a commercial fishery with an average yearly harvest of 40 000 kg.

Methodology

Study Sites

The study was conducted in and around the area of Atim lake, located in the north-east corner of Chitek Lake Park reserve (**Figure 2**). The study area was restricted to this region because there was not enough funding available to sample the entire park reserve, and because the greatest number of enduring features within a small area was available in the Atim Lake area. The sampling occurred from August 8^{th} to August 28^{th} in the summer of 2005 and from June 15 – July 18th in the summer of 2006. Access to the sites was achieved by the use of a hydro line that runs north-south through the study area and by several survey lines that run east-west. This allowed for relatively easy travel and access to sites throughout most of the area. Despite this, the large fens made travel slow and difficult and all survey sites had to be accessed by foot. As a result, the distance that could be travelled to each survey site was limited to a 10 km radius around the cabin where the research crew stayed.

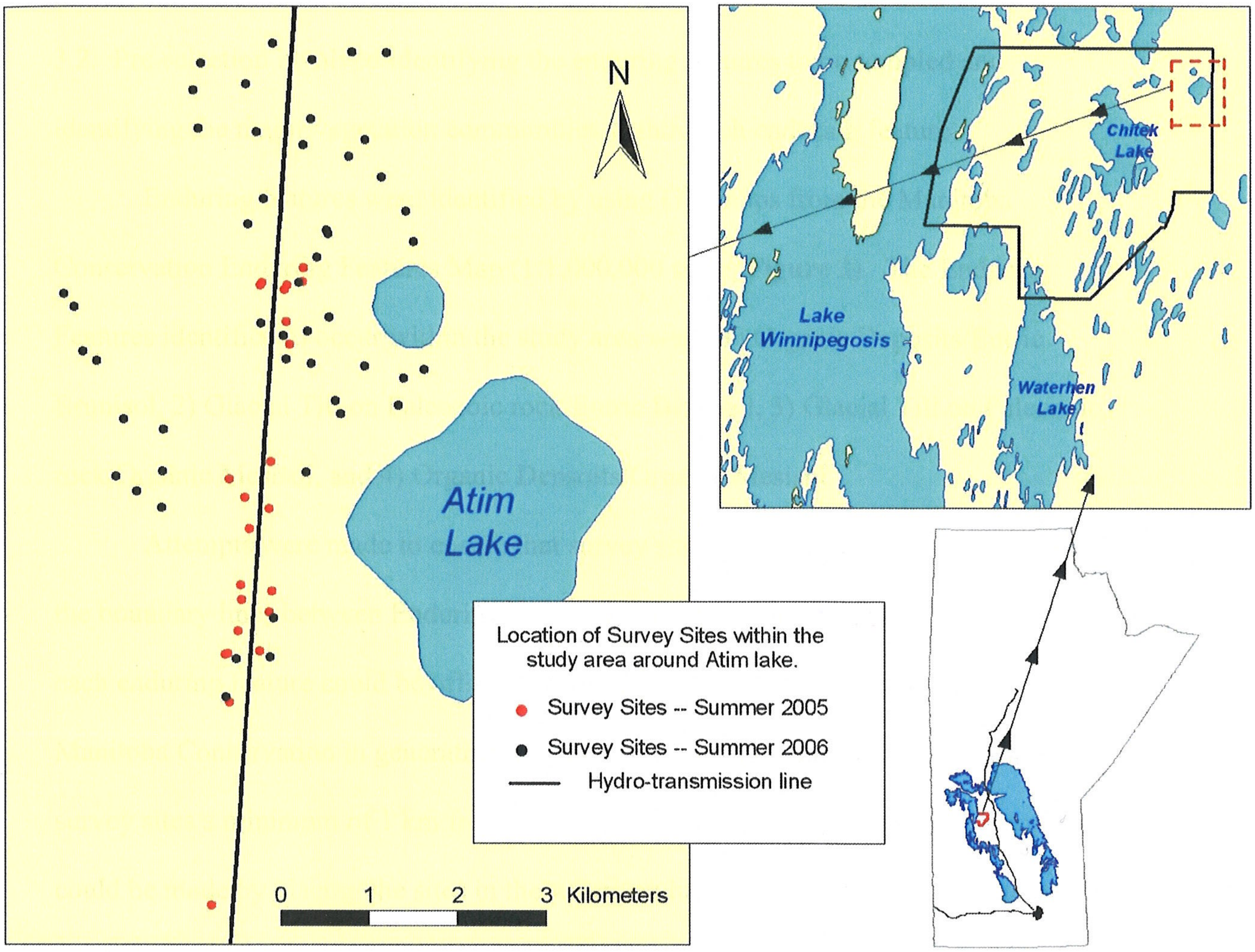

Figure 2: Location of Chitek Lake park reserve and study area at Atim Lake. Atim Lake study area magnified to show the location of all the survey sites within the study area.

All sample sites were pre-selected before going out into the field using ArcView 3.2. Pre-selection involved identifying the enduring features to be sampled and identifying the major vegetation communities within each enduring feature.

Enduring features were identified by using GIS maps from the Manitoba Conservation Enduring Features Map (1:1,000,000 scale, **Figure 3**). The Enduring Features identified to occur within the study area were: 1) Organic Deposits/Eutric Brunisol, 2) Glacial Till on Paleozoic rock/Eutric Brunisol, 3) Glacial Till on Paleozoic rock/Organic Mesisol, and 4) Organic Depsoits/Organic Mesisol.

Attempts were made to ensure that survey sites were located at least 1 km from the boundary lines between Enduring Features. This was done because the boundaries of each enduring feature could be offset by as much as 1km due to the scale used by Manitoba Conservation in generating the enduring features boundaries. Locating the survey sites a minimum of 1 km from the boundaries prevented any potential error that could be made by placing the sites in the wrong enduring feature. This made it impossible to sample the small Organic Deposits/Organic Mesisol enduring feature, since its total size was smaller than 1 km^2.

Within each enduring feature, major vegetation communities were identified and selected for the vegetation survey, for a total of 20 survey sites for each enduring feature, equalling a total potential sample size of 80 survey sites. Communities were selected by using the Forest Management Unit (FMU) inventory map for the area. A community was defined by the dominant tree cover and moisture regime. The initial vegetation communities identified from the forest inventory map were 1) *Pinus banksiana* dominated softwood forest, 2) *Picea mariana* muskeg, 3) Fen, 4) Mixedwood forest, and

5) *Populus tremuloides* dominated hardwood forest. Once the communities within an enduring feature were identified, the twenty survey sites were evenly divided up between them. On average, each vegetation community had five vegetation surveys within each enduring feature.

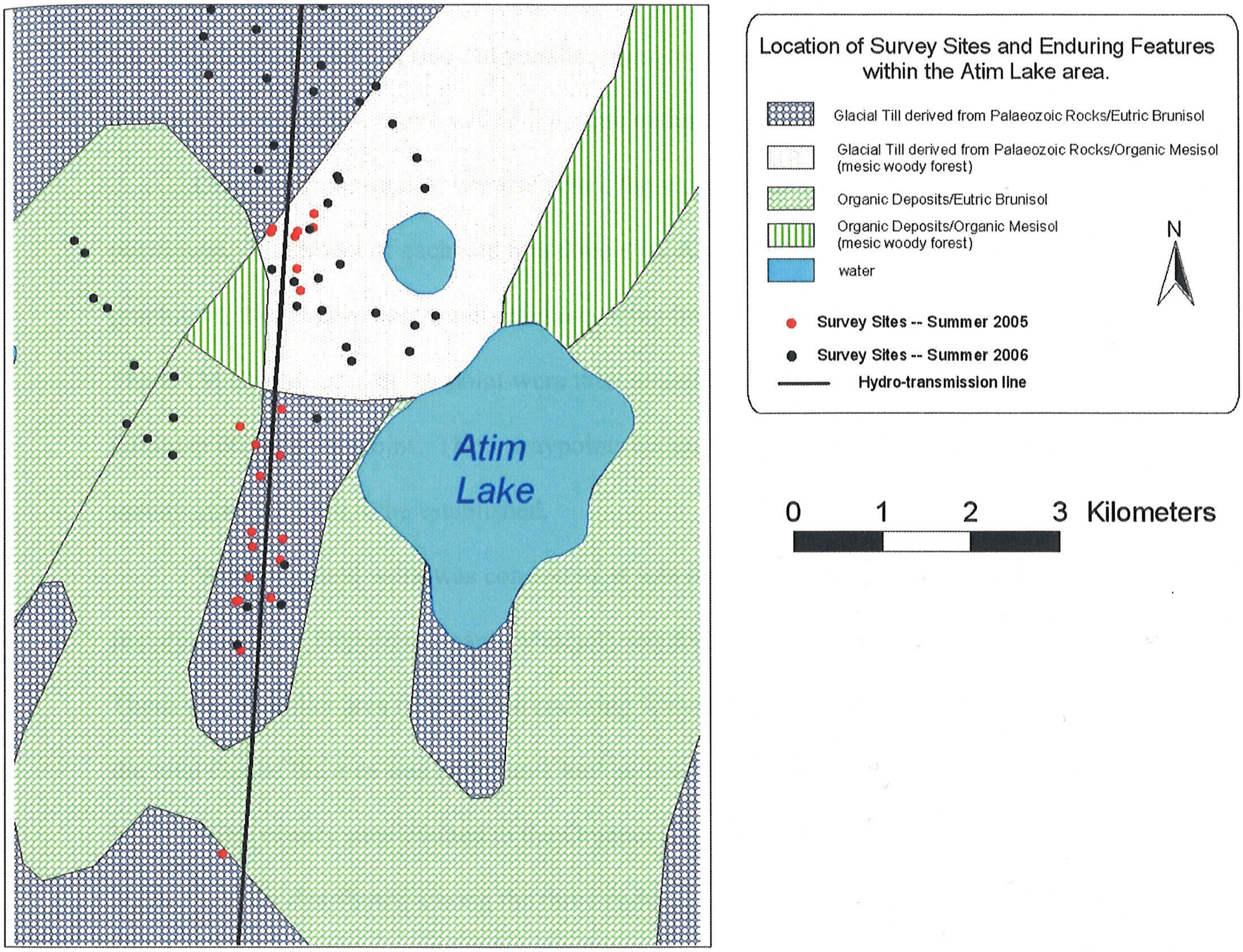

Figure 3: Enduring features of study area at Atim Lake showing the location of all the survey sites within the study area.

The purpose for doing this was twofold: it allowed the study to measure the degree of change within similar plant communities between different enduring features, and it enabled the study to rule out whether plant community change was due to a difference in moisture regime within the same enduring feature.

Once the communities were selected, the survey sites within the community were positioned. Placement of each site was done with ArcView 3.2 by placing a *point* graphic on the selected community and recording the UTM co-ordinates of the point. The UTM co-ordinates of the point were then recorded within a GPS unit (Garmin GPSmap 60) as a waypoint. These waypoints became the location where the vegetation survey quadrats were to be established.

When the field work was conducted, it was discovered that one of the enduring features (Organic Deposits/Organic Mesisol) was too difficult to gain safe access to. There was a smaller area of the same enduring feature that could be easily accessed, but the total size of the area was less than 1 km^2 so it was disregarded (the reasons outlined below). The twenty sites allotted to the Organic Deposits/Organic Mesisol enduring feature were re-distributed among the three enduring features that could be accessed. In total 76 sites were surveyed in three different enduring features. Time constraints prevented the remaining four sites from being surveyed. An additional three survey sites had to be excluded from the analysis due to the GPS unit being unable to fix a location and record their UTM co-ordinates (**Table 1**).

Table 1: List of all Survey Sites with their associated Enduring features and Vegetation Communities. The first column is the site, the second column is the enduring features as defined by the Manitoba Conservation database, the third is the enduring features identified at each survey site, and the fourth column the vegetation community identified at each survey site.

Site	Enduring Features Manitoba Conservation	Enduring Features Defined at Survey Site	Vegetation Community
Site 1	N/A (No GPS co-ordinates)	Glacial Till/Eutric Brunisol	Mixed wood Forest
Site 2	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 3	Glacial Till/Eutric Brunisol	Glacial Till/Organic Deposits	Coniferous Muskeg
Site 4	N/A (No GPS co-ordinates)	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 5	N/A (No GPS co-ordinates)	Glacial Till/Eutric Brunisol	Mixed wood Forest
Site 6	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 7	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 8	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 9	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 10	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 11	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 12	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 13	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 14	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 15	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 16	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 17	Glacial Till/Eutric Brunisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 18	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 19	Glacial Till/Eutric Brunisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 20	Glacial Till/Eutric Brunisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 21	Glacial Till/Eutric Brunisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 22	Organic Deposits/Eutric Brunisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 23	Glacial Till/Eutric Brunisol	Organic Deposits	Treed Fen
Site 24	Glacial Till/Eutric Brunisol	Organic Deposits	Coniferous Muskeg

Site	Enduring Features Manitoba Conservation	Enduring Features Defined at Survey Site	Vegetation Community
Site 25	Glacial Till/Eutric Brunisol	Organic Mesisol	Coniferous Muskeg
Site 26	Glacial Till/Eutric Brunisol	Organic Deposits	Treed Fen
Site 27	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 28	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 29	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 30	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 31	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 32	Glacial Till/Organic Mesisol	Glacial Till/Organic Mesisol	Coniferous Dry
Site 33	Glacial Till/Organic Mesisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 34	Glacial Till/Organic Mesisol	Glacial Till/Organic Mesisol	Treed Fen
Site 35	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Deciduous
Site 36	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 37	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Deciduous
Site 38	Glacial Till/Eutric Brunisol	Organic Deposits	Treeless Fen
Site 39	Glacial Till/Organic Mesisol	Organic Deposits	Treed Fen
Site 40	Glacial Till/Organic Mesisol	Organic Deposits	Treeless Fen
Site 41	Glacial Till/Organic Mesisol	Organic Deposits	Treeless Fen
Site 42	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 43	Glacial Till/Organic Mesisol	Glacial Till/Organic Mesisol	Coniferous Muskeg
Site 44			Treed Fen
Site 45	Glacial Till/Organic Mesisol	Glacial Till/Eutric Brunisol	Deciduous
Site 46	Glacial Till/Organic Mesisol	Organic Deposits	Treed Fen
Site 47	Glacial Till/Organic Mesisol	Glacial Till/Organic Mesisol	Mixedwood Forest
Site 48	Glacial Till/Organic Mesisol	Glacial Till/Organic Deposits	Treed Fen
Site 49	Glacial Till/Organic Mesisol	Organic Deposits	Treed Fen
Site 50	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 51	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 52	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 53	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 54	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Deciduous
Site 55	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 56	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 57	Glacial Till/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 58	Glacial Till/Eutric Brunisol	Organic Deposits	Treed Fen
Site 59	Glacial Till/Eutric Brunisol	Glacial Till/Organic	Coniferous Dry

		Mesisol	
Site	**Enduring Features Manitoba Conservation**	**Enduring Features Defined at Survey Site**	**Vegetation Community**
Site 60	Glacial Till/Eutric Brunisol	Organic Deposits	Treed Fen
Site 61	Glacial Till/Eutric Brunisol	Organic Deposits	Treeless Fen
Site 62	Glacial Till/Eutric Brunisol	Organic Deposits	Treeless Fen
Site 63	Glacial Till/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Muskeg
Site 64	Glacial Till/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 65	Glacial Till/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 66	Glacial Till/Eutric Brunisol	Glacial Till/Organic Deposits	Coniferous Muskeg
Site 67	Organic Deposits/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 68	Organic Deposits/Eutric Brunisol	Organic Deposits/Eutric Brunisol	Treeless Fen
Site 69	Organic Deposits/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 70	Organic Deposits/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 71	Organic Deposits/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 72	Organic Deposits/Eutric Brunisol	Organic Deposits	Treed Fen
Site 73	Organic Deposits/Eutric Brunisol	Organic Deposits	Coniferous Muskeg
Site 74	Organic Deposits/Eutric Brunisol	Glacial Till/Eutric Brunisol	Coniferous Dry
Site 75	Organic Deposits/Eutric Brunisol	Glacial Till/Eutric Brunisol	Mixedwood Forest
Site 76	Organic Deposits/Eutric Brunisol	Organic Deposits	Treed Fen

Vegetation Sampling

Within each survey site five vegetation quadrats were established. Attempts were made to ensure the quadrats were always established in the most representative area of the community, which sometimes required placing the quadrats up to 300 m away from the initial selected point. The five quadrats of the survey were composed of one quadrat for trees, one quadrat for shrub species, and three quadrats for herbs. Mosses were not sampled in any of the quadrats due to time constraints in the field. Tree species were sampled using a 20 m x 20 m quadrat. Sampling recorded each tree species present. Within the 20 m x 20 m quadrat the presence or absence of lichen species was also recorded. The 10 m x 10 m shrub quadrat and the three 1 m x 1 m herb quadrats were randomly distributed within the 20 m x 20 m quadrat. The shrub layer was sampled using a single contiguous 10 m x 10 m area. Herbs were sampled in three 1 m x 1 m quadrats. Species abundance for shrubs and herbs was determined using visual estimation of their cover within each survey quadrat. Lichens could not be estimated in this way due to the arboreal habit of 80% of the species recorded. Therefore only their presence was noted.

Specimens which were difficult to identify were collected and brought to the lab for identification. Lichens were identified by using physical characteristics and chemical tests, using *Lichens of North America* (Brodo et al. 2001). Voucher specimens of herbs and shrubs were placed at the University of Manitoba Herbarium, with Voucher specimens for lichens being kept at the University of Manitoba Cryptogamic Herbarium.

Soil Sampling

A location for a single soil pit within each survey site was randomly selected within the 20 m x 20 m quadrat and dug to a minimum width of 50 cm, a minimum depth of 30 cm, and to a depth of 70 cm where possible. Soil analysis identified the type and depth of organic material over each pit, and also determined the percentage of Ca^{+} in the soil via the use of 10% HCl (Skinner et al, 1959). Soil classes were determined on-site using both the Canadian System of Soil Classification and the definitions of enduring features as described by Manitoba Conservation. Classifying the soils was necessary to identify the enduring features on each site, since the enduring features were classified by a combination of soil type (class) and underlying parent material. As an example, to determine if an area was the enduring feature Glacial Till/Eutric Brunisol, the soil was analysed to determine whether its class was a Eutric Brunisol. Eutric Brunisols are identified as occurring primarily on parent materials with a high base status under forest or shrub vegetation in a wide range of climates. Eutric Brunisols have a relatively high level of base (Ca+) saturation and lack a well-developed mineral-organic surface horizon (CSSC, 1998). Once the soil class was determined, the soil pit was deepened to see what kind of underlying soil was present. If glacial till was found and the till layer went down to a depth greater than 70 cm (or as deep as could be dug up to a maximum of 70 cm), the area was defined as a Glacial Till/Eutric Brunisol enduring feature. If instead there was a layer of organic soil whose depth was greater than 70cm, the area was defined as an Organic Deposit/Eutric Brunisol enduring feature. Organic soils were described only down to the Great Groups, as either fibric or mesic. Fibric (fibrisols) soils are primarily composed of relatively undecomposed organic material. Fibric soils are usually classified on the van Post scale of decomposition as classes 1-4 (Appendix). Fibric soils occur extensively in Canada, especially in peat deposits dominated by sphagnum mosses (CSSC, 1998). Mesic (mesisol) soils are primarily composed of organic material that is intermediate in its decomposition between fibric and humic soils. Mesic soils are usually classified on the van Post scale of decomposition as class 5 or 6 (Appendix; CSSC, 1998). Organic soils were further classified on the composition of the organic materials, the three types found were fibric soils composed primarily of sphagnum moss, fibric soils composed primarily of sedge, and mesic soils composed of forest materials (twigs, leaves, needles, wood).

The soil classification was performed in order to ensure that the enduring feature recorded for the site corresponded to the actual soil type present. After the soils were initially classified they were further analysed by determining the percentage that each silt, clay, and sand component made in each soil sample (hereafter referred to as the soil fraction) by hand, following the testing guidelines of the soil texture triangle (U.S. Department of Agriculture, 2007). The organic soils were initially classified by their material of origin (sedge, moss, mesic forest) but were eventually classed together as one group for ease of analysis.

Soil data from each site was cross-checked with the Canada Soils Report No 23 (Soils of the Waterhen Area) to confirm accuracy and to acquire further soil information on depths greater than 70 cm. Discrepancies between the soil analysis and what was described in the Manitoba Conservation enduring features database and the Canada Soils Report No 23 were recorded within the dataset.

Photos of each site and soil pit were taken (**Figure 4**), GPS co-ordinates were recorded, and a site description of the area, detailing community structure, presence or absence or rare species, amount of light, gaps in the canopy, or any information to note the community structure of the area were recorded.

Coniferous Dry

Coniferous Dry, Glacial Till/Eutric Brunisol

MixedWood

MixedWood, Glacial Till/Eutric Brunisol

Deciduous

Deciduous, Glacial Till/Eutric Brunisol

Coniferous Muskeg

Coniferous Muskeg, Glacial Till/Organic Mesisol

Treed Fen

Treed Fen, Organic Deposits

Treeless Fen

Treeless Fen, Organic Deposits

Figure 4: Examples of each major vegetation community found within the study area, and the most common enduring feature found in each community.

Digital Elevation Model (DEM) analysis

The ENVI image processing software package was used to extract a Digital Elevation Model (DEM) of the Chitek Lake park reserve area. The DEM model was created to look at the topographic values of the study area at two different scales: a coarse scale of 1:1,000,000 and a resolution of 90 m. The DEM was made using the topographic data collected by the Shuttle Radar Topography Mission (SRTM) (Rodriguez et al. 2005).

The topographic slope and feature values of the DEM were modeled in ENVI using the built-in topographic modeling functions (Wood 1996). The model was then brought into ArcView 3.2 and converted to a grid. The locations of all of the survey sites and the associated Enduring Features GIS layers were then overlaid onto the DEM model of the area. The mean slope values for the vegetation survey sites and the Manitoba Conservation enduring features polygons were then extracted using the Summarise Zones function in Spatial Analyst.

For each site and enduring feature overlaid on the DEM model, a parameterisation of the surface features was conducted. This was done in order to characterize these features as they were associated with each of the sites and enduring features. Parameterisation is described as "a set of measurements that describe topographic form well enough to distinguish topographically disparate landscapes" (Chambers, 1990; Wood, 1996).

The purpose of using this analysis method was to describe the geomorphometry of the study area. This allows for a more quantifiable way of characterising the landscape since most studies focus on identifying specific geomorphic features, such as ridges or hills. For this study, the analytical method used to parameterise the data follows Woods' methodology (Wood, 1996). The data, in the form of individual landform variables, is described statistically and geometrically as a series of parameters. Wood defines parameters as "a line or quantity which serves to determine a point, line, figure, or quantity in a class of such things" (Wood, 1996). Another way of defining parameters are as quantities that define certain characteristics of systems or functions. The purpose of his model was to emphasise the identification of unique and defining properties of a surface model while also ensuring that there are as few surface parameters as possible, and at the same time conveying the maximum amount of information and be as widely applicable as possible.

The methodology that Wood developed placed focus upon six subdivisions of all surface features that would be considered characteristic of any surface. These six subdivisions are: *pits, peaks, channels, ridges, passes* and *planes* (**Table 2**). Within each subdivision are five parameters; each parameter is defined by a quadratic equation (derivative) (**Table 3**). These parameters provide a complete set of conditions for describing all six morphometric features. These parameters are: cross-sectional curvature (*crosc*), longitudinal curvature (*longc*), slope, maximum convexity (*maxic*) and minimum convexity (*minic*).

Table 2: The six morphometric feature types. Taken from Wood, 1996.

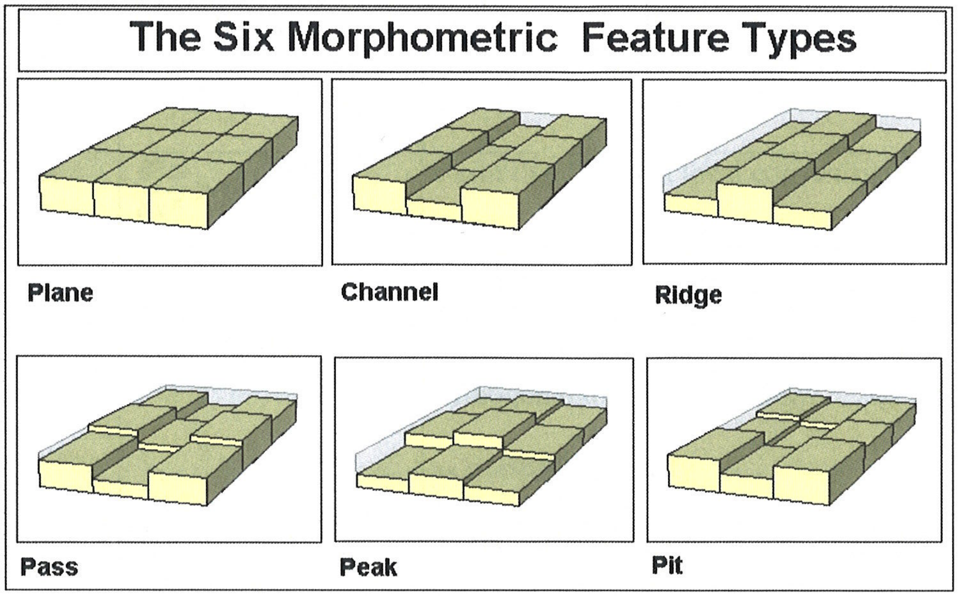

Table 3: Morphometric features described by second derivatives. Taken from Wood, 1996.

Feature	Derivative Expression	Description
Peak	$\frac{\delta^2 z}{\delta x^2} > 0, \frac{\delta^2 z}{\delta y^2} > 0$	Point that lies on a local convexity in all directions (all neighbours lower)
Ridge	$\frac{\delta^2 z}{\delta x^2} > 0, \frac{\delta^2 z}{\delta y^2} = 0$	Point that lies on a local convexity that is orthogonal to a line with no convexity/concavity
Pass	$\frac{\delta^2 z}{\delta x^2} > 0, \frac{\delta^2 z}{\delta y^2} < 0$	Point that lies on a local convexity that is orthogonal to a local concavity
Plane	$\frac{\delta^2 z}{\delta x^2} = 0, \frac{\delta^2 z}{\delta y^2} = 0$	Points that do not lie on any surface concavity or convexity
Channel	$\frac{\delta^2 z}{\delta x^2} < 0, \frac{\delta^2 z}{\delta y^2} = 0$	Point that lies in a local concavity that is orthogonal to a line with no concavity/convexity
Pit	$\frac{\delta^2 z}{\delta x^2} < 0, \frac{\delta^2 z}{\delta y^2} < 0$	Point that lies in a local concavity in all directions (all neighbours higher)

This technique is accomplished by analysing the derivative of each parameter. Each derivative characterises a single point in the surface feature, and returns a series of numbers that describe the kind of feature but also its rate of change as it moves from one point to the next. Each derivative can be used on its own to describe a feature, or combined with another derivative to describe a related but different feature. For example, for a point with a non-zero slope channels have a negative *crosc*, ridges a positive *crosc*, and (sloping) planes a *crosc* of zero. When the longitudinal curvature is measured in addition, then the three remaining feature types can also be defined. Pits have a negative *crosc* and *longc*, peaks a positive *crosc* and *longc*, and passes *crosc* and *longc* with opposite signs. What this form of analysis does is to recognise that one parameter alone is not sufficient to describe a surface feature (**Table 4**).

Table 4: Morphometric features defined by the sign of five morphometric parameters. # indicates undefined, or not part of selection criteria. Taken from Wood, 1996.

Feature	slope	crosc	longc	maxic	minic
Peak	0	#	#	+ve	+ve
	+ve	+ve	+ve	#	#
Ridge	0	#	#	+ve	0
	+ve	+ve	0	#	#
	+ve	0	+ve	#	#
Pass	0	#	#	+ve	-ve
	+ve	+ve	-ve	#	#
	+ve	-ve	+ve	#	#
Plane	0	#	#	0	0
	+ve	0	0	#	#
Channel	0	#	#	0	-ve
	+ve	-ve	0	#	#
	+ve	0	-ve	#	#
Pit	0	#	#	-ve	-ve
	+ve	-ve	-ve	#	#

These surface features (pits, peaks, channels, ridges, passes and planes) can be thought of as *morphometric* features rather than *geomorphometric* features. This is because morphometric features can be applied to any surface, whether that surface is a landscape or a manmade structure such as a road or building, whereas geomorphometric features deal specifically with landscape features, such as watersheds, drainages, hillslopes or any other feature of a landscape. One of the advantages of using this technique is that it treats each subdivision not just as a feature in itself, but also as a way of describing each feature in terms of rates of change. It is also a method of analysis that is independent of both size and scale, a factor which is very important in this study since the information used comes from two very different scales.

By conducting a parameterisation of the surface data, each of the morphometric features within the study region could be correlated to the sites, soils and enduring features at each site. This provided a single dataset that contained all of the variables under study for each survey site: enduring features, species, soil analysis and morphometric features. By using this data it became possible to see if enduring features could be differentiated by specific morphometric features.

Statistical Analysis

In preparing the data for analysis, species that were recorded on three sites or fewer during the entire study were removed from the dataset. This was done to prevent outgroups in the multivariate analysis, thus biasing the data. Other species were grouped by genera, due to a combination of rare (three or less occurrences) and singular occurrences within the dataset. They were also grouped due to the difficulty involved in identifying many of these species. By combining species into a single genera it was possible to retain these species for the analysis. Species grouped were the willows (*Salix*), sedges (*Carex*), ladies-slippers (*Cypridium*), and the wintergreens (*Pyrola*). At the beginning of the study, each survey site was classified into a vegetation community, based upon moisture regime and dominant tree species composition as described by the

FMU. Once the survey was finished and the data analysed, the communities were reclassified based upon the community structure, moisture regime, and dominant canopy cover found at each survey site (**Table 1**). They are: 1) Coniferous Dry (*Pinus banksiana, Larix laricina, Picea mariana*), 2) Mixedwood (equal mix of *Populus tremuloides, Populus balsamifera, Pinus banksiana, Larix laricina and Picea mariana*), 3) Deciduous (*Populus tremuloides, Populus balsamifera* dominated forests), 4) Coniferous Muskeg (*Picea mariana* with sphagnum as the dominant groundcover and primary constituent of organic soil, water level below surface), 5) Treed Fen (*Larix laricina*, *Carex* spp. as dominant groundcover and primary constituent of organic soil, water level at surface), and 6) Treeless Fen (*Carex* spp. dominated, *Carex* primary constituent of organic soil, water level at surface).

Vegetation communities, plant species, soil classes particle size fractions, and enduring features were analyzed using multivariate and ordination statistical methods. Canonical Correspondence Analysis (CCA) ordination was performed on enduring features–communities-species matrices and soil fraction-communities-species matrices (ter Braak 1986). By performing these two analyses it became possible to compare between the soil fractions and the enduring features on how the species and vegetation communities were distributed. Principal Components Analysis (PCA) was performed on geomorphometric parameters (landform variables) at each site (90 m scale), geomorphometric parameters (landform variables) in polygons (1:1,000,000 scale) and soils fractions for each site. By doing a PCE of these three groups, any patterns within these datasets could be identified and expressed in a way that would highlight their similarities and differences (Smith 2002, McCune and Mefford 1999). For each PCA, a Pearsons correlation, Kendall correlation and Monte-Carlo tests were performed.

Species richness was used to classify and characterize the enduring features. It also allowed for a comparison between the enduring features to determine if they had significant differences in species richness. Species richness was split into trees, herbs, shrubs and lichens. Tables were created to compare the agreement between the soil analysis conducted within each site to the boundaries of the Enduring Features that was generated by the Manitoba Conservation database.

Analysis and Results

Comparison of Enduring Features

According to the database developed by Manitoba Conservation, there were three enduring features in the survey area; these were Glacial Till /Organic Mesisol, Glacial Till/Eutric Brunisol, and Organic Deposits/ Eutric Brunisol. The soil analysis conducted within each survey site revealed six enduring features within the study area. These six are: Glacial Till/Eutric Brunisol, Glacial Till/Organic Deposits, Glacial Till/Organic Mesisol, Organic Deposits, Organic Deposits/Organic Mesisol, and Organic Deposits/Eutric Brunisol.

When the enduring features boundaries generated by Manitoba Conservation were compared with the enduring features identified on the survey sites, it was found that the enduring features described on each site (hereafter known as on-site) did not match the enduring features described by the Manitoba Conservation database (**Table 5**). Only in the Glacial Till/Eutric Brunisol enduring feature was there any significant agreement being the two datasets.

Table 5: Comparison showing the level of agreement between the enduring features found on-site to the enduring features described in the Manitoba Conservation database. The numbers in bold indicate where both the Manitoba Database and on-site analysis agree with one another.

MC Database \ On-Site Soil Analysis	Glacial Till/Eutric Brunisol	Organic Deposits	Organic Deposits/ Eutric Brunisol	Glacial Till /Organic Deposits	Glacial Till/ Organic Mesisol	Organic Mesisol	Grand Total
Organic Deposits/ Eutric Brunisol	5	5	**1**		1		12
Glacial Till/Eutric Brunisol	**14**	11		2	5	1	33
Glacial Till /Organic Mesisol	16	5		2	**5**		28
Grand Total	35	21	1	4	11	1	73

Analysis of Manitoba Conservation enduring features boundaries.

DEM Landforms Analysis

Analysis of the landform variables looked at how the enduring features as defined by Manitoba Conservation correlated with the landform variables. The analysis was conducted at a 1:1,000,000 scale and encompassed the entire Chitek Lake park reserve.

Table 6 shows the average of each geomorphological parameter for each of the enduring features polygons. In the table, it is not the numbers that are important, instead it is whether they are positive or negative. The combination of positive and negatives parameters then determine which geomorphological feature each enduring feature most closely characterises (see **Table 4**, Methodology).

Those enduring features that appeared to characterise the geomorphological feature of a peak were the Glacial Till/Organic Mesisol, Glacial Till/Dark Grey Chernozem, and the Organic Deposits/Eutric Brunisol. None of the enduring features characterised the features of ridges, channels, passes or planes. This is because none of the enduring features had zero in their average in any of the geomorphological parameters. None of the enduring features studied had a zero slope. The minimum curvature and maximum curvature was therefore not needed to characterise them.

Figure 5 is a Principal Components Analysis (PCA) between the Manitoba Conservation enduring features boundaries (polygons) and the DEM landform variables. Each polygon was correlated with their relationship to each of the landform variables, and then colour-coded according to the enduring features that the polygon was located on. Since the analysis encompassed the entire park reserve, many of the polygons extracted were water polygons. These water polygons were removed from the dataset prior to analysis, since water is not considered an enduring feature. All of the enduring features found within the Chitek Lake park reserve were included in this analysis; this includes enduring features which were not found within the study area. Those enduring features which were found within the study area have been circled.

The spread of the points on the graph suggest that there is some weak correlation between enduring features and landform variables. There is a significant amount of overlap between the three circled enduring features, with the Glacial Till/Organic Mesisol enduring feature being contained completely within the Glacial Till/Eutric Brunisol and

Organic Deposits/Eutric Brunisol two enduring features. Also, all but one of the datapoints of the Organic deposits/Eutric Brunisol enduring feature were contained within the encircled areas of the Glacial Till/Organic Mesisol and Glacial Till/Eutric Brunisol enduring features. The Glaical Till/Eutric Brunisol enduring feature had less overlap than the other two, but still had a little over half of all datapoints within the other circled areas.

The Glacial Till/Eutric Brunisol enduring feature appears to be positively correlated with elevation, minimum curvature and plan convexity, but negatively associated with slope and maximum curvature. The Organic Deposits/Eutric Brunisol was positively correlated with cross-sectional convexity, elevation, profile convexity and longitudinal convexity, but negatively associated with maximum/minimum curvature and slope. The Organic Deposits/Chernozem are positively correlated with cross-sectional convexity and negatively associated with elevation. The Glacial Till/Organic Mesisol is positively correlated with elevation, minimum curvature and cross-sectional convexity. The remaining enduring features have too few observations to determine any potential trends.

In general, the results in **Figure 5** agree with the results seen in **Table 6**. Although there are some differences between the two results, these are due to the averaging of all the geomorphological parameters of each enduring feature in **Table 6**. In **Figure 5** each of the individual points was represented, allowing for the graph to show all the variation within each enduring feature.

Table 6: Average of geomorphological parameters for each enduring feature polygon (1:1,000,000).

Man EF	elev	Crossc x 10^{-3}	Longc x 10^{-3}	Maxic x 10^{-3}	Minic x 10^{-3}	Plancon x 10^{-3}	Profcon x 10^{-3}	slope
Glacial Till/ Organic Mesisol	267.14	3.905	0.412	18.426	-13.323	-142.727	0.093	0.431
Glacial Till/Eutric Brunisol	266.836	1.438	-0.231	15.798	-14.785	-42.881	-5.08849	0.363
Glacial Till/ Dark Grey Chernozem	264.29	2.371	1.308	21.089	-17.792	-74.827	0.290	0.587
Organic Deposits/ Organic Mesisol	264.701	4.840	-3.443	18.866	-17.616	-116.369	-0.764	0.451
Organic deposits/ Dark Grey Chernozem	262.041	2.399	-1.777	17.473	-17.609	-68.134	-0.395	0.506
Organic Deposits/ Eutric Brunisol	267.14	3.905	0.412	18.426	-13.323	-142.727	0.093	0.431

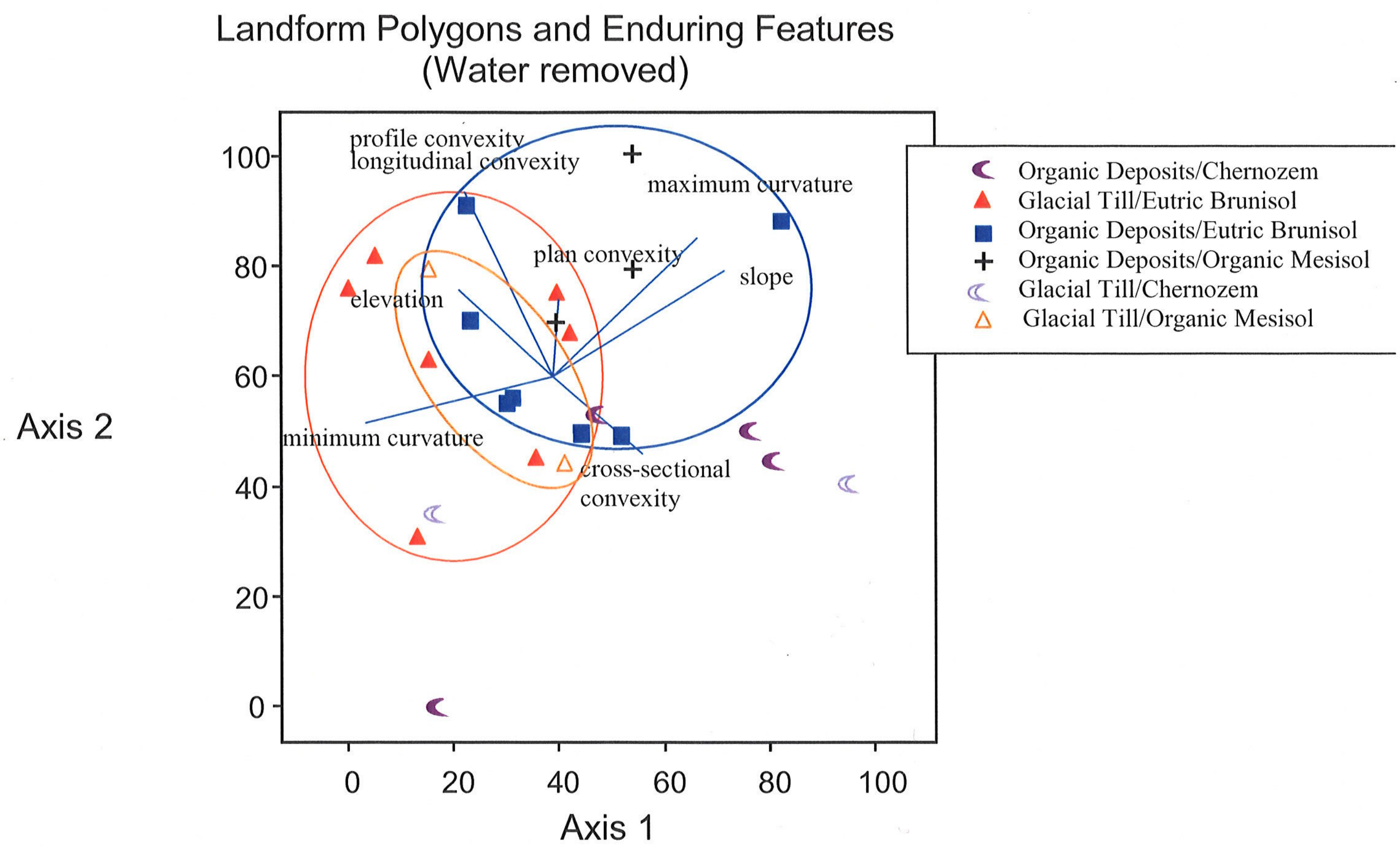

Figure 5: PCA showing the distribution of enduring features by the landform polygon variables (graphed proportion to max %). Enduring Features were based upon the boundaries determined by Manitoba Conservation. Circles represent those enduring features sampled within the study area. Analysis shows that axis 1 accounted for 36.28% of all variance noted among the sites. The second axis explained 31.20% of variance. The third axis accounted for 21.26% of variance, with the fourth axis explaining 8.84% of variance.

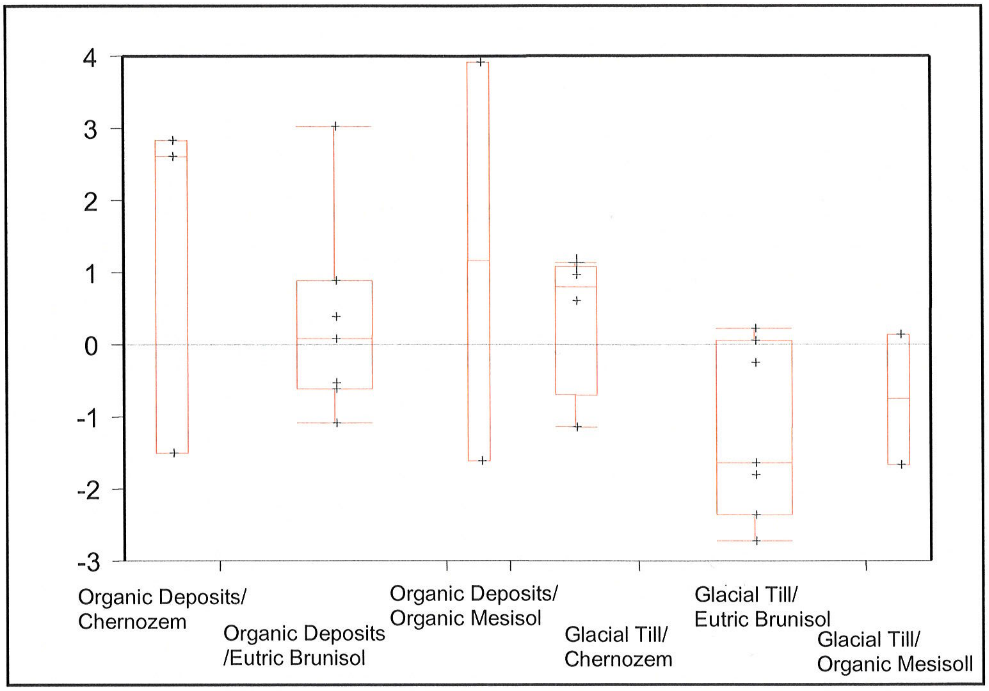

Figure 6: Boxplot of Landform Variable Scores (Axis 1) and Manitoba Conservation enduring features. The widths of the boxes are proportional to the number of data points in each set.

Figure 6 is a boxplot of the first Axis scores of the landform variables in **Figure 5** and the Manitoba Conservation enduring features. Most of the scores for each of the enduring features overlap with one another. The Glacial Till/Eutric Brunisol scores in the 25% Quantile has diverse enough scores to make it different from the other enduring features, but it still shared many similar scores. The Organic Deposits/Eutric Brunisol enduring feature has the one score that could be an outlier, since it is located at the top of the 90% Quantile.

Vegetation Analysis

Table 7 shows the distribution of vegetation communities within the enduring features identified in each of the survey sites. Over half of the sites within the Glaical Till/Eutric Brunisol enduring feature had the Coniferous Muskeg and Coniferous Dry communities, with an even spread among the remaining communities. Both the Glacial Till/Organic Mesisol and Organic Deposits/Eutric Brunisol enduring features had a relatively uniform distribution of the different communities within them. Overall, each of the enduring features had representatives from all of the vegetation communities, with the exception of the Deciduous community in the Organic Deposits/Eutric Brunisol enduring feature.

Table 7: Enduring features as determined by Manitoba Conservation database and vegetation community type as assessed in the field.

Manitoba EF	Coniferous Dry	Mixedwood	Deciduous	Coniferous Muskeg	Treed Fen	Fen	Total
Glacial Till/Organic Mesisol	10	6	2	2	6	2	**28**
Glacial Till/Eutric Brunisol	9	4	2	12	4	3	**34**
Organic Deposits/Eutric Brunisol	1	3	0	4	2	1	**11**

Analysis of the On-Site enduring features.

Soil Analysis

Table 8 shows the distribution of the different soil types among the enduring features. The Organic Deposits enduring feature showed no soil type within the table because there were no mineral components. The Glacial Till/Eutric Brunisol enduring feature had almost all soil types, while the Glacial Till/Organic Mesisol enduring feature has examples in six of the ten soil types, although four of the examples have only one observation. As with the results in previous tables, a small number of observations in most of the enduring features limits the analysis and any results that stem from the analysis.

Table 8: Distribution of soil type among on-site enduring features, with organic soils excluded.

Soil Type	Glacial Till/Eutric Brunisol	Organic Deposits	Organic Deposits / Eutric` Brunisol	Glacial Till /Organic Deposits	Glacial Till/ Organic Mesisol	Organic Mesisol	**Grand Total**
Clay	2		1	3	4	1	**11**
Clay Loam	5						**5**
Clay/ Rocks					1		**1**
Loam	9				1		**10**
Loamy Sand	8						**8**
Sandy Clay					1		**1**
Sandy Loam	4				1		**5**
Silt	4						**4**
Silty loam	3						**3**
Silty Clay					3		**3**
Grand Total	**35**	**0**	**1**	**3**	**11**	**1**	**51**

The PCA (**Figure 7**) shows the distribution and relationship of each site based upon the soil fractions found at the sites. All of the sites that are predominantly mineral in composition are more strongly related to each other than to those sites that are composed of organic soil, which is shown as an outlier to the other soils. It was found that those sites comprised strongly of sand were relatively independent of their distribution and relationship to other sites. To study the relationship between the mineral fractions only, the organic fraction and sites with only organic fractions were removed and the PCA re-run (**Figure 8**). With the organic component removed, the two strongest factors in the composition of the soil fractions on the sites are Clay (55%) and Silt (44%). Sand appeared to have no influence.

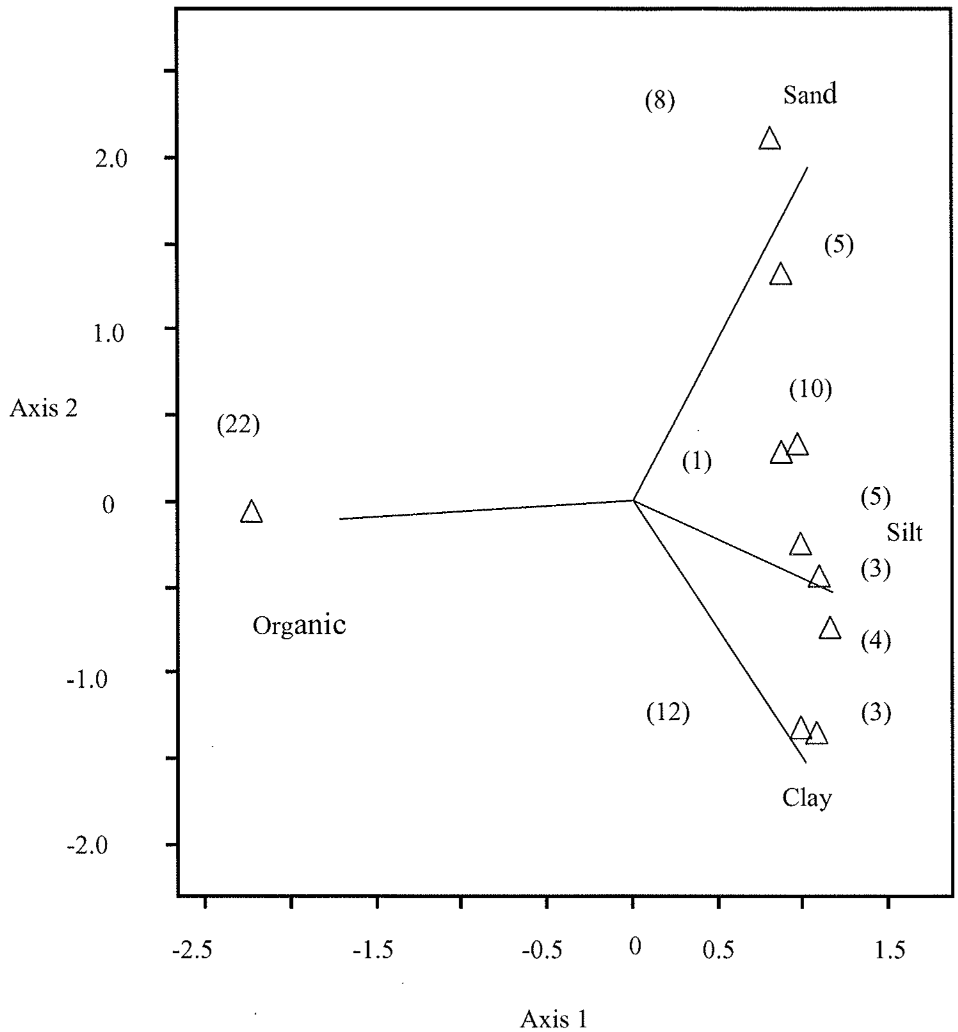

Figure 7: PCA showing the distribution of survey sites by the fraction of clay, silt, sand and organic components in each soil survey. Clay fraction explains 53% of the variance, followed by silt (25%), then sand (20%). Organic soils are seen as an outlier. Parentheses indicate the number of sites that overlap, due to similarities in sand, silt and clay composition.

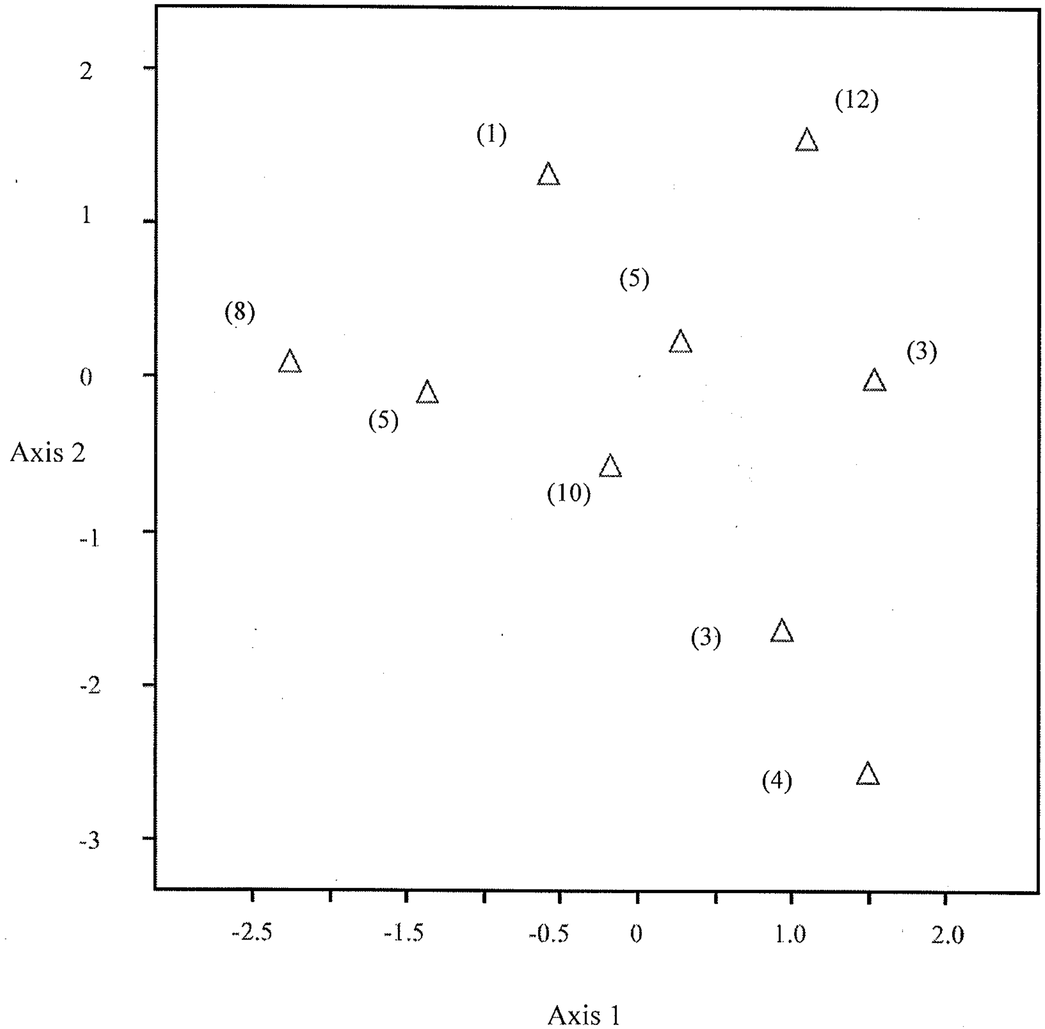

Figure 8: PCA showing the distribution of survey sites by the fraction of clay, silt, and sand components in each soil survey with the organic fraction removed. Clay fraction makes up the first axis and explains 55% of the variance, followed by silt on the second axis at 44% of variance explained. Sand explained 0% of the variance. Parentheses indicate the number of sites that overlap, due to similarities in sand, silt and clay composition.

DEM Landforms Analysis

Analysis of the landform variables looked at how the on-site enduring features as determined using the soil analysis correlated with the landform variables. The analysis was conducted at a 90 m resolution and encompassed only the Atim Lake study area.

Table 9 shows the average of each geomorphological parameter for each of the on-site enduring features. It is similar to **Table 6** in that it is the positive or negative aspects of the numbers that are important as opposed to their numerical value. The combination of positive and negatives parameters then determine which geomorphological feature each enduring feature most closely characterises (see **Table 4**, Methodology).

Those enduring features that appeared to characterise the geomorphological feature of a peak were the Glaicial Till/Organic Mesisol and the Organic Deposits/Eutric Brunisol . None of the enduring features characterised the features of ridges, channels, passes or planes. This is because none of the enduring features had zero in their average in any of the geomorphological parameters. Since none of the enduring features studied had a zero slope, the minimum curvature and maximum curvature was not needed.

Figure 9 shows a PCA conducted between the on-site enduring features and the landform variables extracted from each survey site. Each site was correlated with their relationship to each of the landform variables, and then coloured according to the enduring features that the site was located on. Those enduring features that were also found within the landform-polygon analysis (**Figure 5**) were circled.

The spread of the site points in **Figure 5** suggests none of the enduring features are strongly correlated to any of the axes. There seems to be no specific landform variable or combination of landform variables that are strongly correlated with a specific enduring feature. This is seen in the circled areas, the Glacial Till/Eutric Brunisol encompasses nearly the entire graph area. All of the circled areas greatly overlap one another or are contained completely within another circled area. Part of the analysis is hampered by the fact that there is only one observation each for the Organic Deposits/Eutric Brunisol and Organic Mesisol enduring features, and only four observations for the Glacial Till/Organic deposits enduring feature.

Figure 10 is a Boxplot of the first Axis scores of the landform variables in **Figure 9** and the on-site enduring features. Similar to what was seen in **Figure 9**, there is a lot of overlap in the scores between the enduring features. The Glacial Till/Eutric Brunisol and Organic Depsoits enduring features are the most different, with only the scores of the upper Quantile of the former and the scores of the lower Quantile of the latter having any overlap. The other two enduring features are overlapped completely by all of the other enduring features.

Table 9: Average of geomorphological parameters for each on-site enduring feature (90 m resolution).

	aspect	**crossc**	**longc**	**maxic**	**minic**	**plancon**	**profcon**	**slope**
Organic Deposits/ Eutric Brunisol	207.644	0.001727	0.002336	0.024563	-0.020509	-0.310255	0.0005364	0.660
Glacial Till/Eutric Brunisol	174.505	-0.001029	0.007512	0.020394	-0.011062	0.022874	0.0016706	0.396
Glacial Till /Organic Mesisol	149.306	0.004179	0.002336	0.027039	-0.02215	-0.14595	0.0005143	0.498

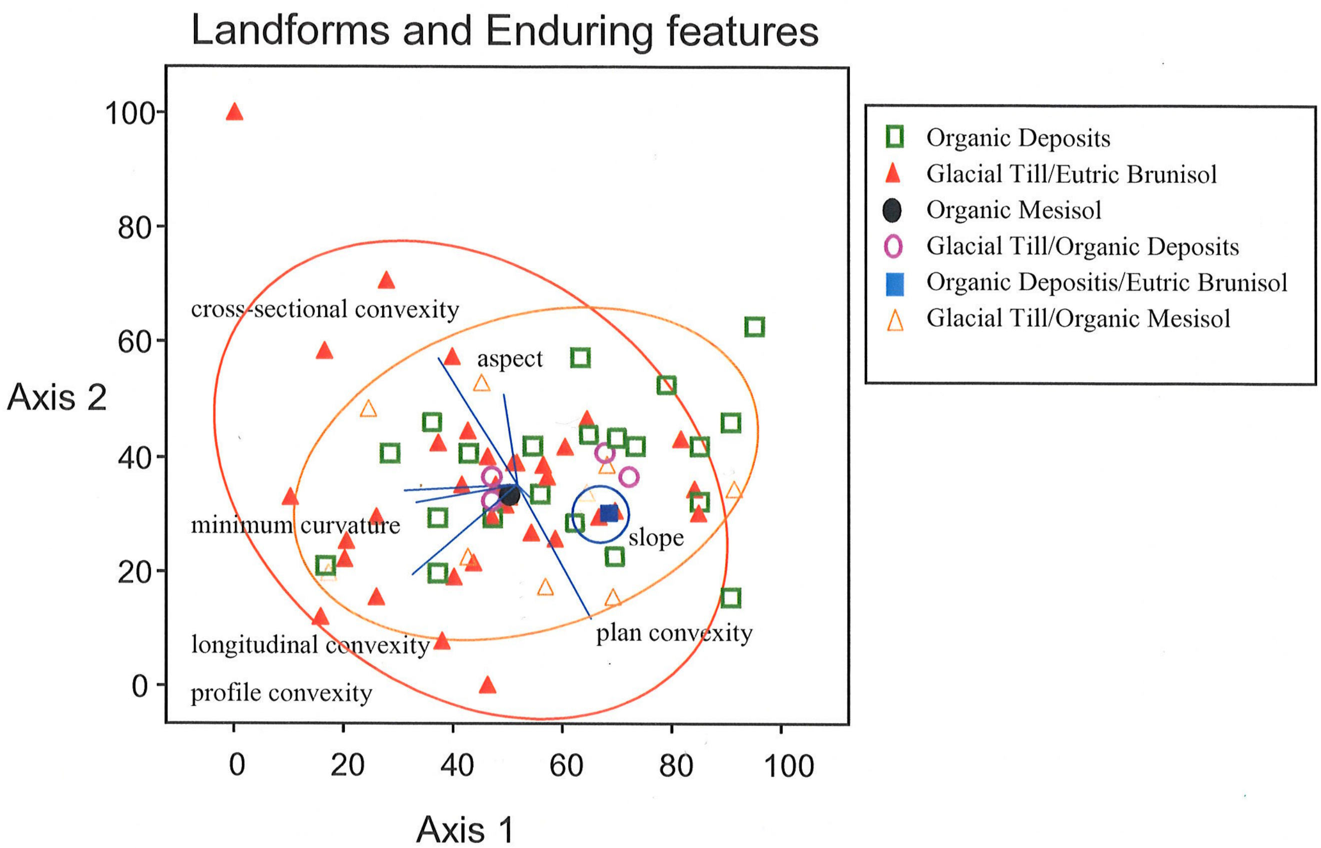

Figure 9: PCA of the landform variables (graphed proportion to max %) showing the distribution of on-site enduring features among the landform variables. Circles represent those enduring features sampled within the study area. Analysis shows that the first axis accounted for 45.21% of all variance noted among the sites. The second axis explained 23.60% of variance. Monte Carlo test for species-environment correlations is p= 0.0050.

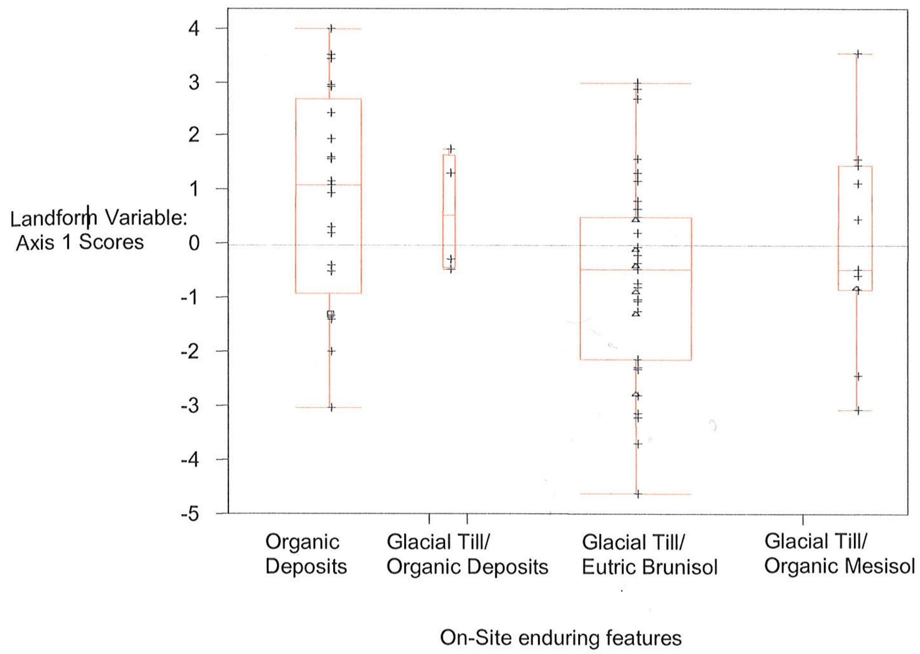

Figure 10: Boxplot of PCA landform variable scores (Axis 1) and on-site enduring features. The Organic Deposits/Eutric Brunisol and Organic Mesisol enduring features were removed. Width of the boxes are proportional to the number of data points in each set.

Vegetation Analysis

Table 10 summarises the species richness for each of the enduring features. Glacial Till/Eutric Brunisol had the highest species richness for trees, shrubs, herbs and lichens. Glacial Till/Organic Mesisol had the next highest in species richness for all four groups, with Organic Deposits being the last. Although Organic Deposits had the lowest species richness, it was the highest for presence of rare species. The other three enduring features studied have been listed but are being excluded from the analysis due to low sample size.

Table 10: List of species richness by tree, shrub, herb and lichen for each enduring feature. Rare species are those species categorised as S1 to S3 by the Manitoba Conservation Data Centre. Uncommon species are those species that had three or fewer recordings within the entire study area, and have no classification within the Manitoba Conservation Data Centre or have a classification of S4 and S5. Species richness is the total of all species found in all sites within the same enduring feature.

Species Richness by Enduring Feature (On-site analysis)					
		Trees	**Shrubs**	**Herbs**	**Lichens**
Glacial Till/Organic Mesisol n=11	average	2.5	6.5	8.6	9
	Range per site	2-4	1-14	4-12	0-14
	uncommon species	6			
	rare species	0			
	Species Richness	4	25	34	26
Glacial Till/Eutric Brunisol n= 35	Average	3.3	6.5	9.7	10.6
	Range (per site)	2-5	1-15	4-18	0-19
	uncommon species	22			
	rare species	1			
	Species Richness	5	29	49	44
Glacial Till/ Organic Deposits n= 4	Average	2	5.5	5.75	11.25
	Range per site	2	3-8	4-7	4-18
	uncommon species	1			
	rare species	0			
	Species Richness	2	14	15	22
Organic Deposits n= 21	Average	1.7	4.4	6.4	9.6
	Range per site	1-2	2-10	1-10	0-21
	uncommon species	4			
	rare species	3			
	Species Richness	2	18	33	35
Organic Deposits/ Eutric Brunisol n= 1	Average	1	1	6	7
	Range per site	1	1	6	7
	uncommon species	1			
	rare species	0			
	Species Richness	1	1	6	7
Organic Mesisol n= 1	Average	2	5	1	0
	Range per site	2	5	1	0
	uncommon species	0			
	rare species	0			
	Species Richness	2	5	1	0

Table 11: List of rare and uncommon species by enduring feature

	Rare	Uncommon
Glacial Till /Organic Mesisol		*Ribes lacustre (Bristly black current)* *Salix bebbiana (beaked willow)* *Salix maccalliana (velvet fruited willow)* *Salix glauca* *Peltigera malacea* *Lonicera dioica var glauescens (twining honeysuckle)*
Glacial Till /Eutric Brunisol	*Liparis loeselii (loesels twayblade)*	*Ribes lacustre (Bristly black current)* *Salix bebbiana (beaked willow)* *Salix lutea (yellow willow)* *Salix maccalliana (velvet fruited willow)* *Salix planifolia (diamondleaf willow)* *Symphoricarpus occidentalis (western snowberry)* *Astragalus canadensis (canadian milkvetch)* *Cirsium arvense* *Deschampsia caespitose (tufted hair grass)* *Habernaria hyperborea (Northern mannagrass)* *Lomatogonium rotatum (Marsh Felwort)* *Parnassia palustris (Northern Grass of Parnassus)* *Cladonia phyllophore* *Cladonia stellaris* *Cladonia symphycarpia* *Cladonia uncialis* *Cladonia verticillata* *Parmelopsis ambigua* *Peltigera neopolydactyla* *Phaeophysica hispidula* *Tuckermannopsis chlorophylla* *Usnea glabrescens*
Glacial Till/ Organic Deposits		*Salix candida (sageleaf willow)*
Organic Deposits	*Cypripedium reginae (showy ladies slippers)* *Malaxis unifolia (green adders mouth)* *Platanthera orbiculata (Round-leaved rein-orchid)*	*Lonicera dioica var glauescens (twining honeysuckle)* *Parnassia palustris (Northern Grass of Parnassus)* *Cladonia ochrochlora* *Phaeophysica hispidula* *Physica caesia*
Organic Deposits/ Eutric Brunisol		*Physica caesia*

The next table looks at the relationship between the enduring features and the major vegetation communities within the study area. **Table 12** shows the distribution of vegetation communities within the enduring features identified on-site. It is seen that the vegetation communities are more strongly associated with specific enduring features or specific components of enduring features (such as organic deposits) than in the Manitoba Conservation database. In all the sites that had the Glaical Till/Eutric Brunisol enduring feature, 86% were composed of Coniferous Dry/Mixedwood communities. The other two enduring features with a glacial till and organic component (Glacial Till/Organic MesisolGlacial Till/Organic Deposits) had predominantly Coniferous Muskeg/Treed Fen communities. However, these last two enduring features had small sample sizes. The enduring features that were predominately organic in composition (Organic Deposits/Eutric Brunisol Organic Mesisol, Organic Deposits) had only Coniferous Muskeg/Treed Fen/Fen communities. However, the enduring features Organic Deposits/Eutric Brunisol and Organic Mesisol had a sample size of one.

It can be seen between the two tables (**Table 7** and **Table 12**) that the enduring features defined by Manitoba Conservation did not appear to represent or predict specific vegetation communities as well as the enduring features determined on-site.

Table 12: Enduring features as determined by on-site soil analysis and Community type.

On-Site EF	Coniferous Dry	Mixedwood	Deciduous	Coniferous Muskeg	Treed Fen	Fen	Total
Glacial Till/Organic Mesisol	2	1	0	**7**	1	0	**11**
Glacial Till/Eutric Brunisol	**18**	**12**	4	1	0	0	**35**
Glacial Till/Organic Deposits	0	0	0	2	2	0	**4**
Organic Deposits	0	0	0	**7**	**9**	5	**21**
Organic Mesisol	0	0	0	1	0	0	**1**
Organic Deposits/Eutric Brunisol	0	0	0	0	0	1	**1**

All of the enduring features used in the Canonical Correlation Analysis (CCA) were based upon the on-site enduring features. Analysis was focused on correlations between the vegetation communities, the vegetation layers within communities (trees, shrubs and herbs), and the species composition of the study area within the enduring features. Pearson Correlations and Kendall Correlations were calculated for the first three axis in each of the CCA.

Figure 11 shows the Canonical Correlation Analysis (CCA) between the vegetation communities and the on-site enduring features. Only the Organic Deposits, Glacial Till/Organic Mesisol and GlacialTill/Eutric Brunisol enduring features showed a large enough influence on the distribution of communities to be represented on the CCA graph.

The results show that vegetation communities are correlated with enduring features. Treed Fens and Treeless Fens were strongly associated with the Organic Deposits. The Coniferous Muskeg was strongly correlated with the Glacial Till/Organic Mesisol enduring features, but also showed some affinity to the Organic Deposits as well. The Coniferous Dry, Mixedwood and Deciduous vegetation communities were correlated to the Glacial Till/Eutric Brunisol enduring features. The mixedwood communities showed the greatest spread along both the Glacial Till/Eutric Brunisol and Glacial Till/Organic Mesisol enduring features, while the Coniferous Dry were more strongly associated with the enduring features that had no organic components. There was significant overlap between the Mixedwood, Coniferous Dry, and Deciduous communities within the Glacial Till/Eutric Brunisol and Glacial Till/Organic Mesisol enduring features. There was also some overlap between the Treed Fen and Treeless Fen communities in the Organic Deposits enduring feature. The overlap between these two communities was not as extreme is with the other three communities. The only community which had very little overlap was the Coniferous Muskeg community.

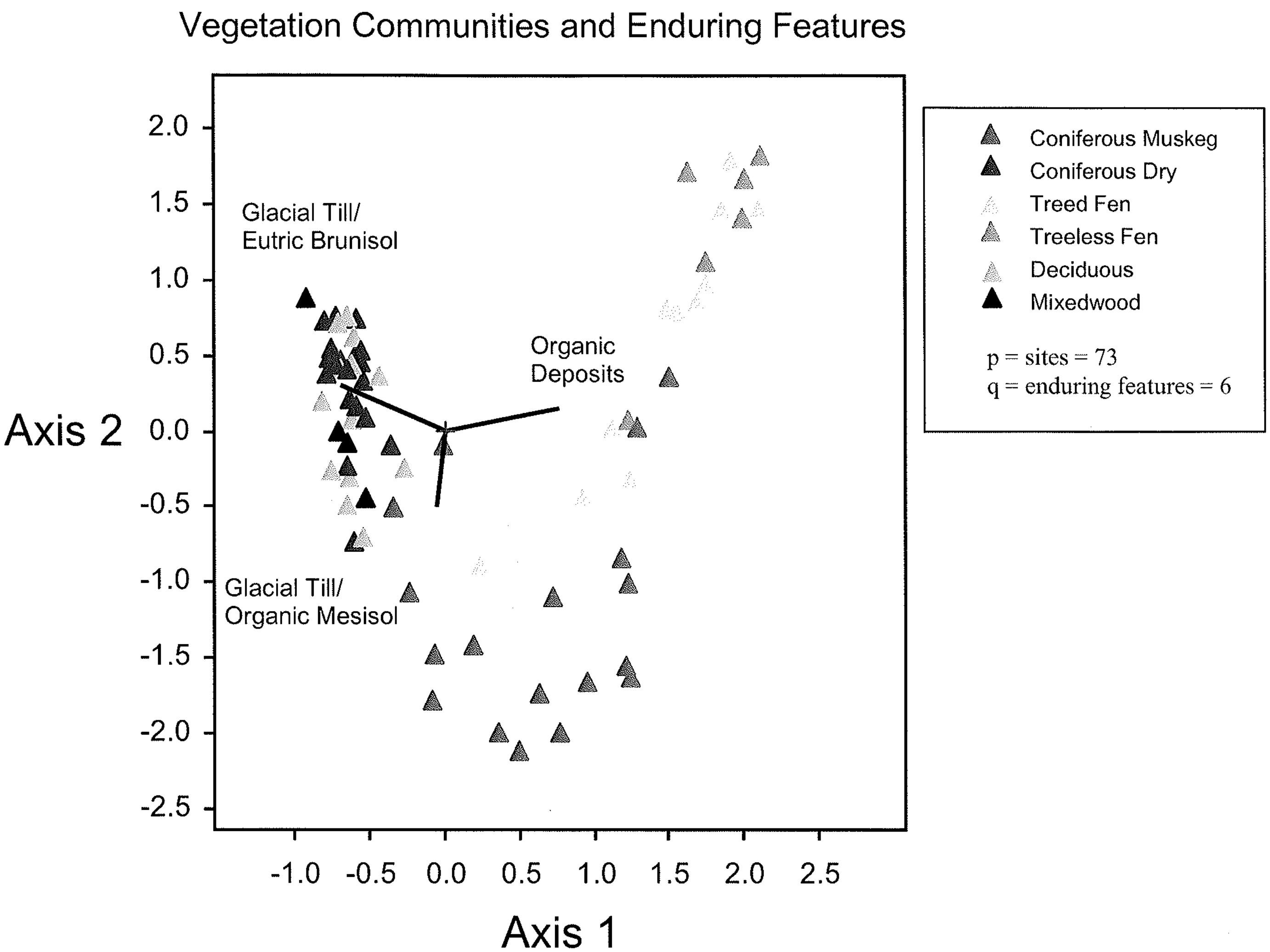

Figure 11: CCA showing the distribution of vegetation communities within the study site in relation to the on-site enduring features. The first axis describes 16.1% of the variance, with the second axis accounting for 3.1% and the third axis 1.5% of the variance. Pearsons Correlation for the first axis is 0.952, the second axis 0.657, and the third 0.693. Kendall (Rank) Correlation for the first axis is 0.747, the second axis 0.409, and the third 0.382. Monte Carlo test for species-environment correlations and eigenvalues is $p = 0.0010$. P is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values.

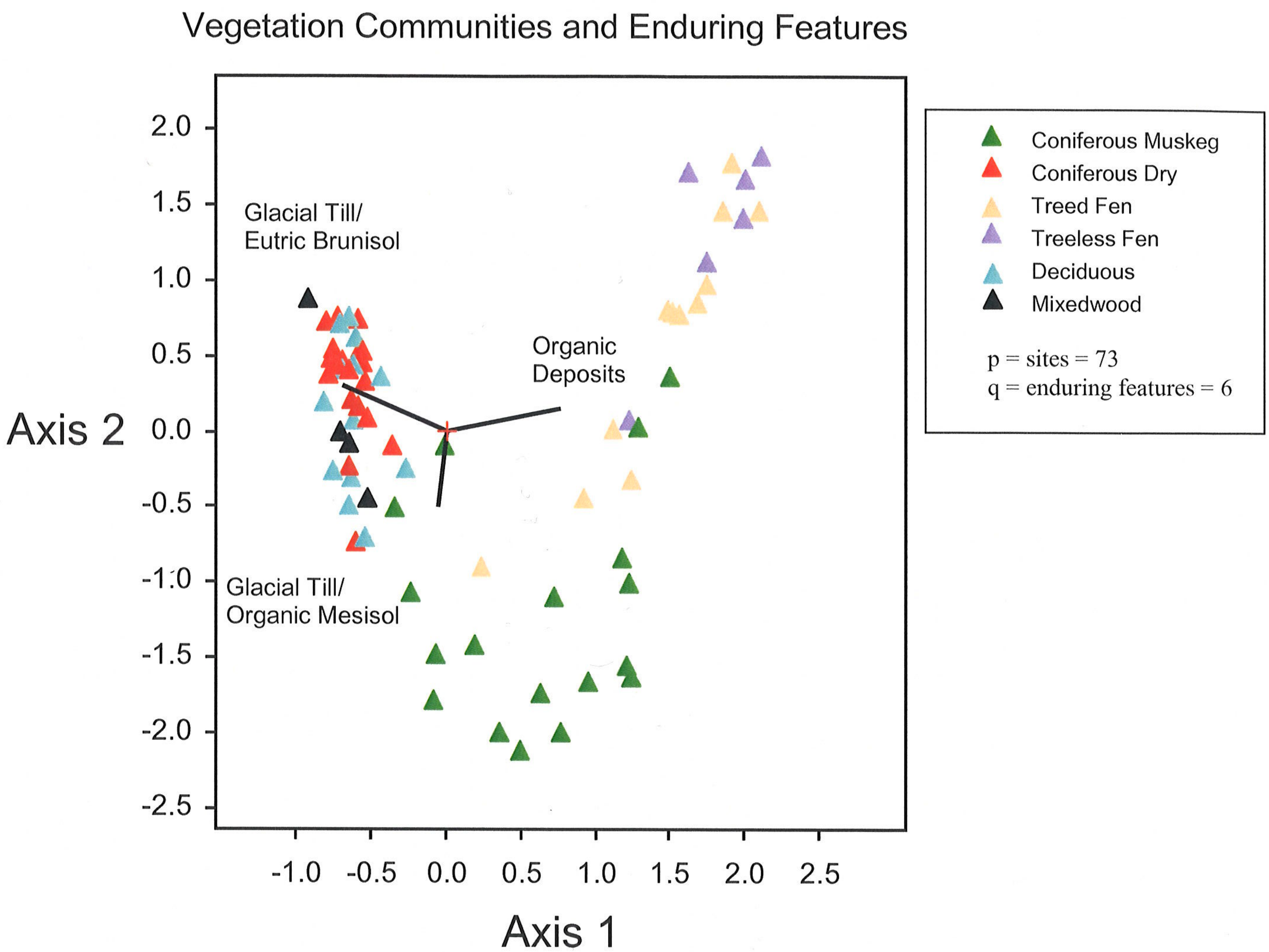

Figure 11: CCA showing the distribution of vegetation communities within the study site in relation to the on-site enduring features. The first axis describes 16.1% of the variance, with the second axis accounting for 3.1% and the third axis 1.5% of the variance. Pearsons Correlation for the first axis is 0.952, the second axis 0.657, and the third 0.693. Kendall (Rank) Correlation for the first axis is 0.747, the second axis 0.409, and the third 0.382. Monte Carlo test for species-environment correlations and eigenvalues is $p = 0.0010$. P is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values.

Figure 12 shows a CCA between all the vegetation species surveyed and the enduring features that the species were located on. *Equesitum* spp. were found to occur only in organic and very wet conditions, so they were most strongly associated with the enduring features that had an organic component in them. Two species, *Picea mariana* and *Larix laricina* were found to not have any strong relationships with any of the enduring features, although *L. laricina* was more closely associated with the organic-based enduring features than *P. mariana*.

Figure 13 shows the first of three CCA on each of the community levels (trees, shrubs and herbs). **Figure 13** showed that only two enduring features -- Organic Deposits and Glacial Till/Eutric Brunisol) -- were responsible for 31% of the variance. *Pinus banksiana* showed a strong relationship to Till/Eutric Brunisol, while *P. mariana* appeared to not have any correlation to any of the enduring features. This is similar to what was seen in **Figure 12**. *L. laricina* shows a stronger relationship with the Organic Deposits enduring feature, but its position on the graph shows that this preference is due to the fact that *L. laricina* was the only tree found growing within pure organic soils. The same can be said for *P. mariana*, whose growth habit is even less determined by the enduring feature it is found on.

Lichens were excluded because over 80% of the species surveyed required wood as their substrate. This resulted in a predominantly arboreal habit for these species. Because the distribution of these lichens was dependant upon the presence or absence of the substrate (wood) they grew on and not the soil type, it was felt that the enduring feature would have had very little effect on their distribution. A CCA looking at the lichen-enduring feature relationship resulted in only 2% of the variance being explained by the first axis.

Both the shrubs species and the herb species show similar trends in their relationship to enduring features (**Figure 14** and **Figure 15**). There are strong relationships between species and the enduring features that correspond most closely to the type of soil conditions they require. Species whose growth requires organic soils, such as *Andromeda polifolia, Vaccinium myrtilloides, Betula pumila var glandulifera* and *Oxycoccus microcarpus* show a stronger correlation to the organic based enduring features and are not found growing on other types of enduring features. Those species that depend upon a mineral soil such as *Juniperus communis, Arctostophylos uva-ursi, Shepherdia canadensis*, *Potentila fruticosa* and *Rubus idaeus* are more widely distributed among the enduring features that have a mineral composition, such as Glacial Till/Eutric Brunisol. Most of the species whose growth habit requires a mineral component show less fidelity to a specific enduring feature than those species that are found within organic-based enduring features. For example, *Cornus canadensis, Lathyrus venosus, Fragaria virginiana,* and *Galium boreale,* have been found to occur within a wide range of communities, which is reflected in the graph by their placement between the two enduring features with a glacial till component in them. Other species such as *Rubus acaulis, Potentilla palustris* and *Sarracina purpurea* are found to be clustered more strongly around the Organic Deposits enduring feature, and nowhere else.

When looking at **Figure 14** and **Figure 15** it can be seen that there are two groups; one group is composed of those species found only in enduring features with organic deposits. These species appear to be strongly correlated with a specific enduring feature. The second group is made of species assemblages that are associated with the Glacial Tills and/or Eutric Brunisols. This second group has more species than the first, and the spread of species suggests that they have less fidelity to a specific enduring feature than the first group does.

Vegetation with soil fraction

Figure 16 shows similar trends among the vegetation communities and soil fractions that were seen between the vegetation communities and enduring features. Treed Fens and Treeless Fens showed a strong correlation for the organic soils. Coniferous Muskeg tended to be found in soils that had both an organic and clay fraction. The remaining vegetation communities showed strong associations with the silt and sand fraction of the soil. There appears to be a correlation between the Deciduous community and the sand/silt fraction, but the overlap between the Coniferous Dry, Mixedwood and Deciduous communities suggest that these communities show no preference for one soil fraction over another.

Species distributions among the soil fractions (**Figure 17**) shows strong relationships among most of the species and their association with a soil fraction. The largest number of species tended to congregate around the silt/sand fraction, with fewer species around the organic soil fractions. This trend is seen again when comparing each community level to the soil fractions (**Figures 18, 19** and **20**). Many of the correlations seen between the species and the soil fractions appear to match the trends seen among the species distributions and enduring features.

There is a clear distribution within the tree species among the organic and sand soil fractions, with black spruce showing no strong correlation with any of the soil fractions and larch showing a weak correlation with the organic fraction. The herbs and shrubs show similar groupings around specific soil fractions. Like the trees, there were some species that did not seem to be limited or influenced by soil fraction. There were more herb species that showed no preference for one kind of soil fraction over another than in the other two groups, but this could be due to the larger sample size for herbs.

Despite these strong correlations, there must be some caution exercised in these results. In the tree-soil fraction CCA only two soil fractions showed a variance strong enough to be represented on the graph. Since these two axis represent the extreme ends of the physical and chemical properties of soils, it is expected to find such a clear trend. In many of the CCA the total variance represented on the graphs rarely exceed 40%, this means that over half of all variance could not be explained within the CCA.

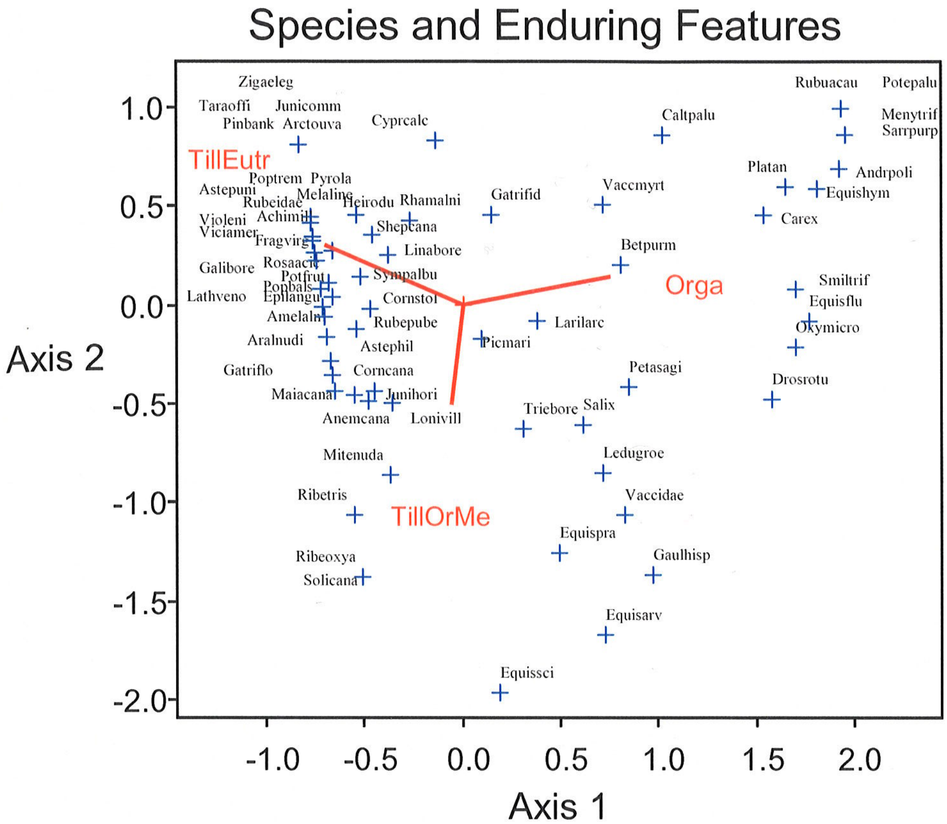

Figure 12: CCA showing the relationships between vegetation species and the on-site enduring features within the study area. p =68 species, q =6 enduring features. The first axis describes 16.1% of the variance, with the second axis accounting for 3.1% and the third axis 1.5% of the variance. Pearsons Correlation for the first axis is 0.952, the second axis 0.657, and the third 0.693. Kendall (Rank) Correlation for the first axis is 0.747, the second axis 0.409, and the third 0.382. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010. Species codes are listed in table 13.

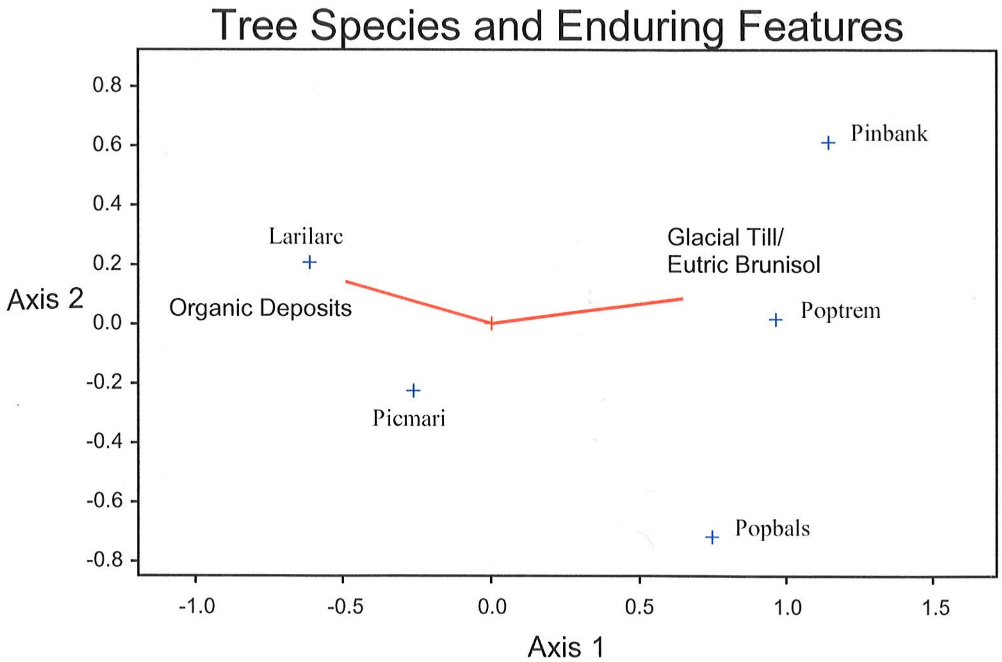

Figure 13: CCA showing the relationships between tree species and the on-site enduring features within the study area. p =5 species, q =6 enduring features. The first axis describes 29.3% of the variance, with the second axis accounting for 1.8%. Pearsons Correlation for the first axis is 0.815, the second axis 0.271. Kendall (Rank) Correlation for the first axis is 0.753, the second axis 0.253. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010.

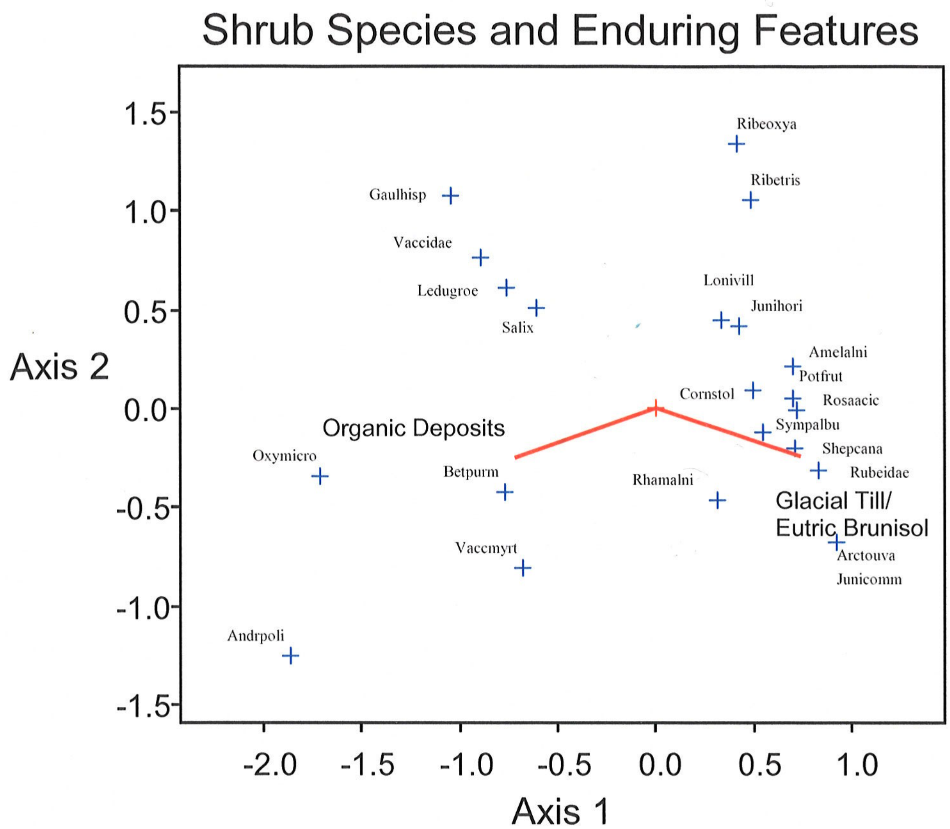

Figure 14: CCA showing the relationships between shrub species and the on-site enduring features within the study area. p =22 species, q =6 enduring features. The first axis describes 17.5% of the variance, with the second axis accounting for 3.5% and the third axis only 1.0% of the variance. Pearsons Correlation for the first axis is 0.942, the second axis 0.590, and the third 0.513. Kendall (Rank) Correlation for the first axis is 0.733, the second axis 0.459, and the third 0.149. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010.

Herb Species and Enduring Features

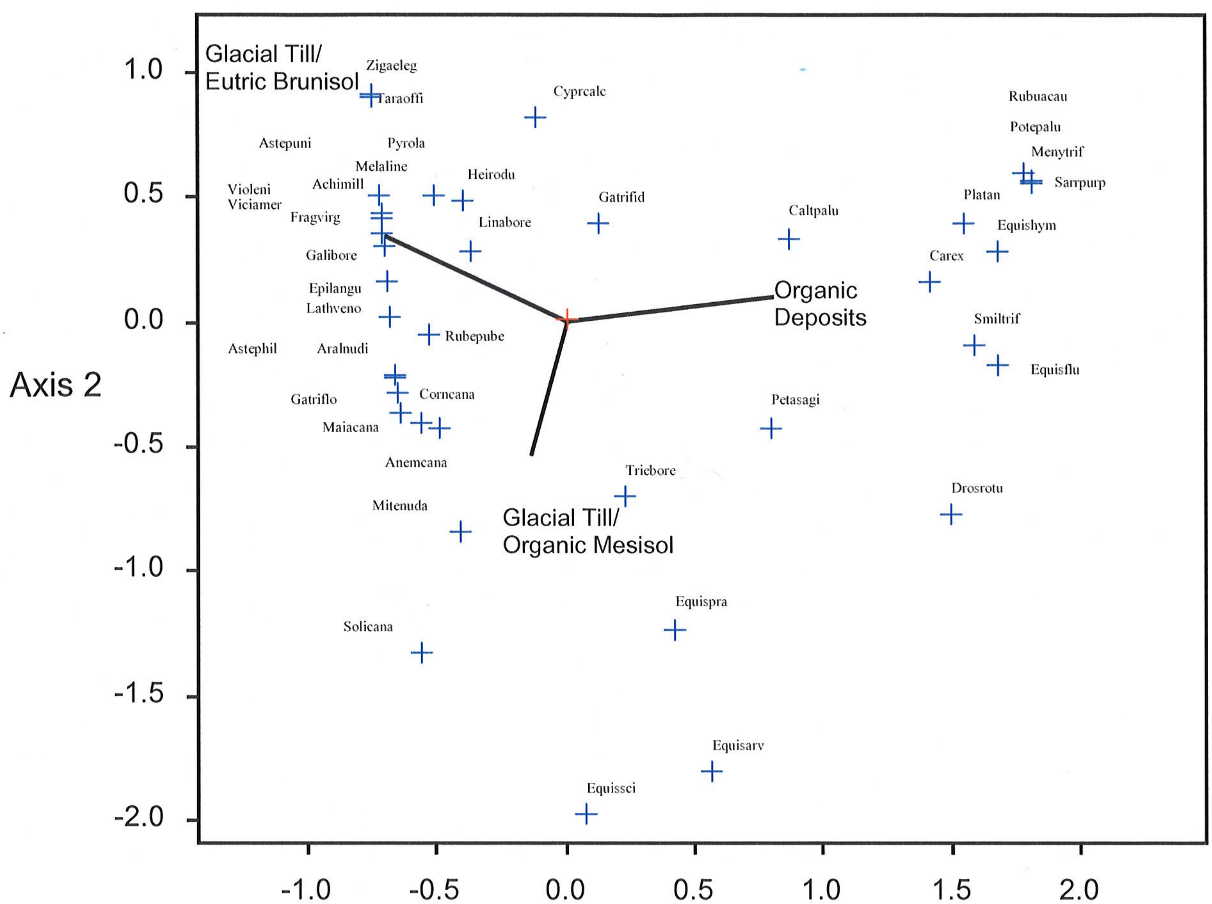

Figure 15: CCA showing the relationships between herb species and the on-site enduring features within the study area. p =41 species, q =6 enduring features. The first axis describes 15.8% of the variance within the dataset, with the second axis accounting for 2.7% and the third axis 1.8% of the variance. Pearsons Correlation for the first axis is 0.948, the second axis 0.549, and the third 0.558. Kendall (Rank) Correlation for the first axis is 0.732, the second axis 0.323, and the third 0.405. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010.

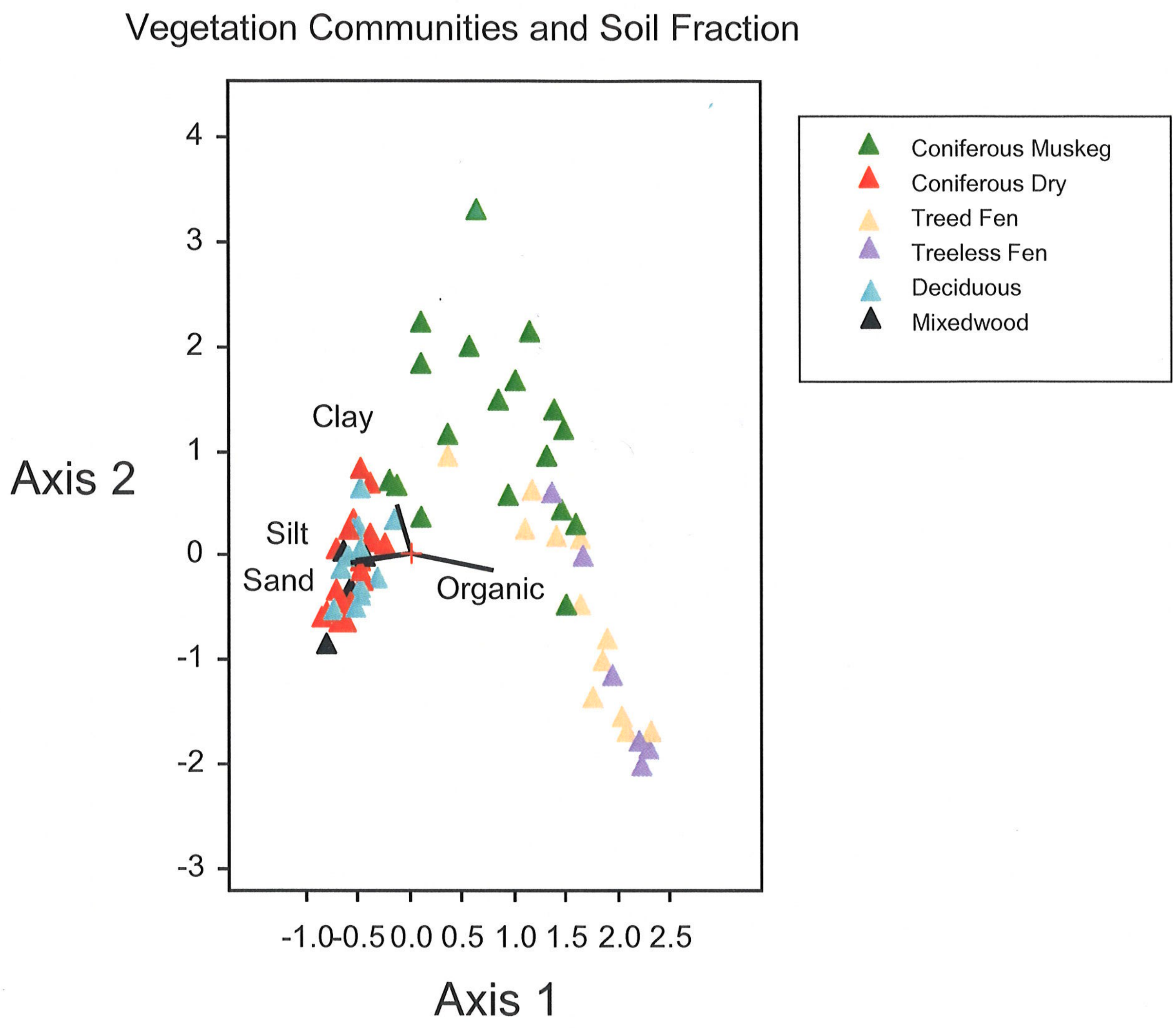

Figure 16: CCA showing relationship between vegetation communities and soil fraction. The first axis describes 14.3 % of the variance, with the second axis accounting for 1.8 % and the third axis only 1.1% of the variance. Pearsons Correlation for the first axis is 0.900, the second axis 0.594, and the third 0.518. Kendall (Rank) Correlation for the first axis is 0.621, the second axis 0.334, and the third 0.295. Monte Carlo test for species-environment correlations and eigenvalues is $p = 0.0010$.

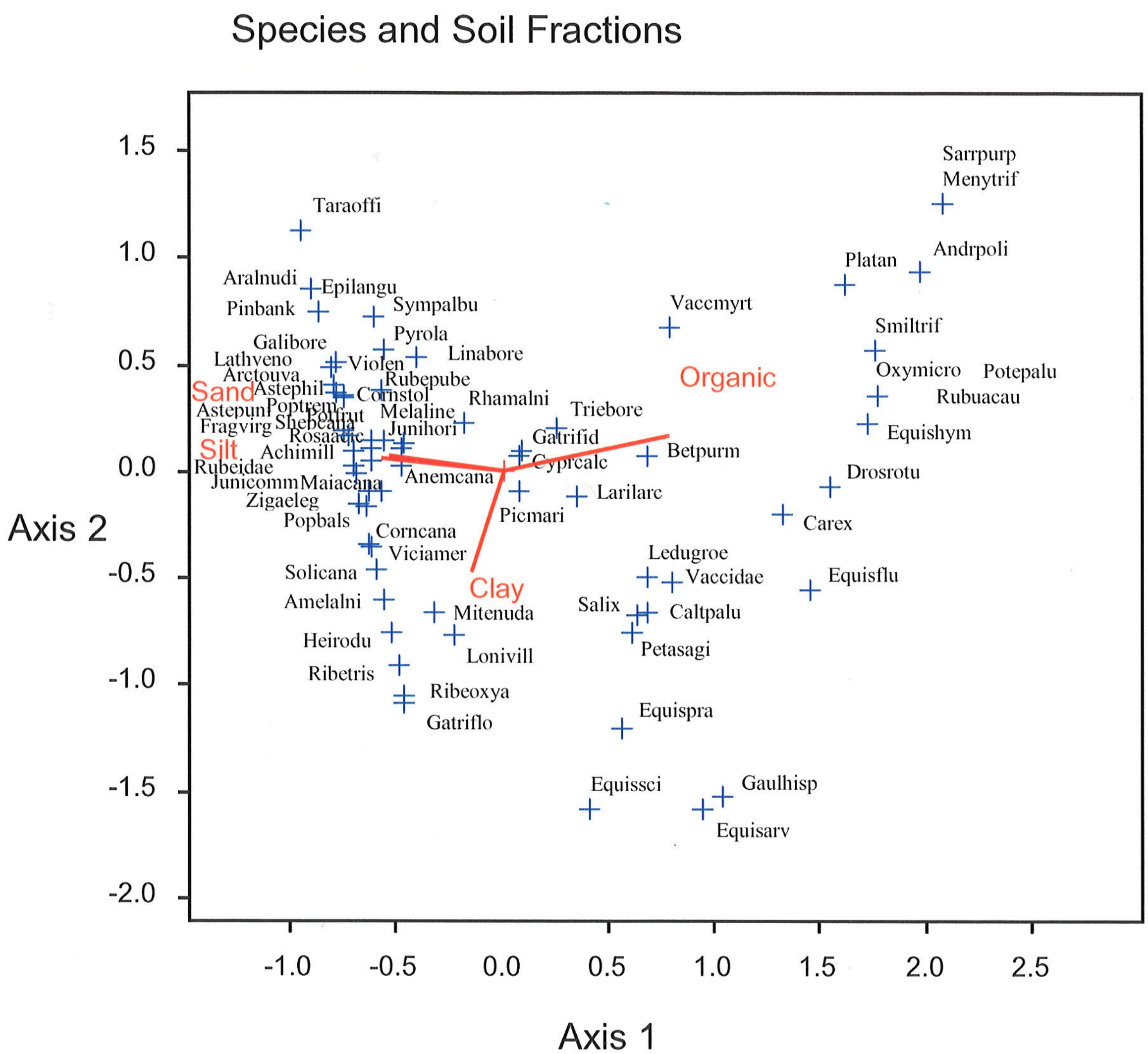

Figure 17: CCA showing relationship between species and soil fractions within the study area. p =68 species, q =4 soil fractions. The first axis describes 14.3% of the variance, with the second axis accounting for 1.8% and the third axis only 1.1% of the variance. Pearsons Correlation for the first axis is 0.900, the second axis 0.594, and the third 0.518.Kendall (Rank) Correlation for the first axis is 0.621, the second axis 0.334, and the third 0.295. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010. Species codes are listed in table 13.

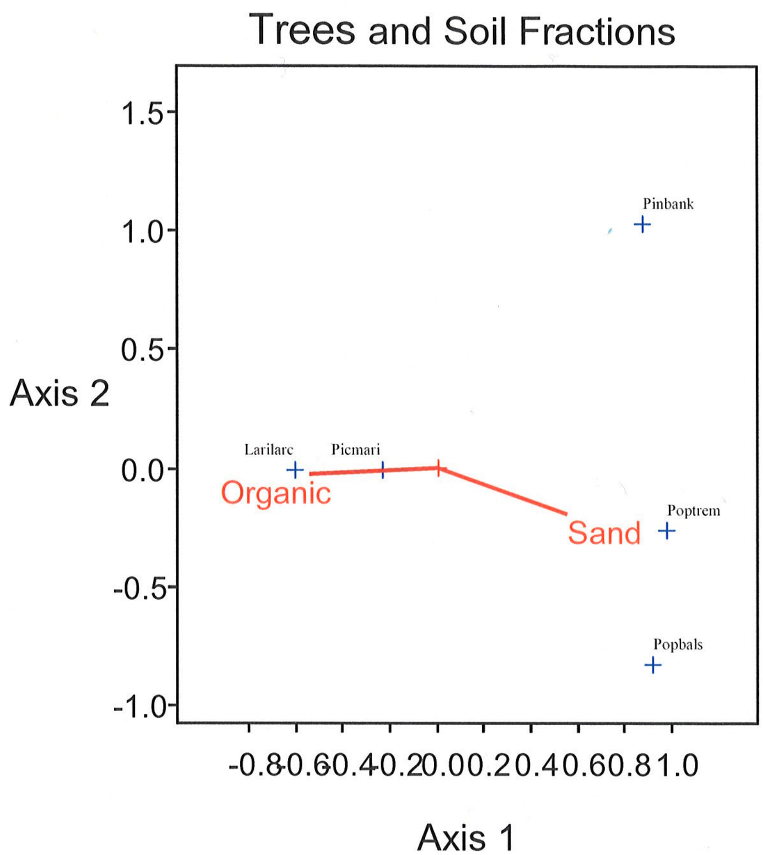

Figure 18: CCA showing relationship between tree species and soil fractions within the study area. p =5 species, q =4 soil fractions. The first axis describes 24.5% of the variance, with the second axis accounting for 4.4% and the third axis 0.1% of the variance. Pearsons Correlation for the first axis is 0.730, the second axis 0.351, and the third 0.098. Kendall (Rank) Correlation for the first axis is 0.610, the second axis 0.219, and the third 0.084. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010.

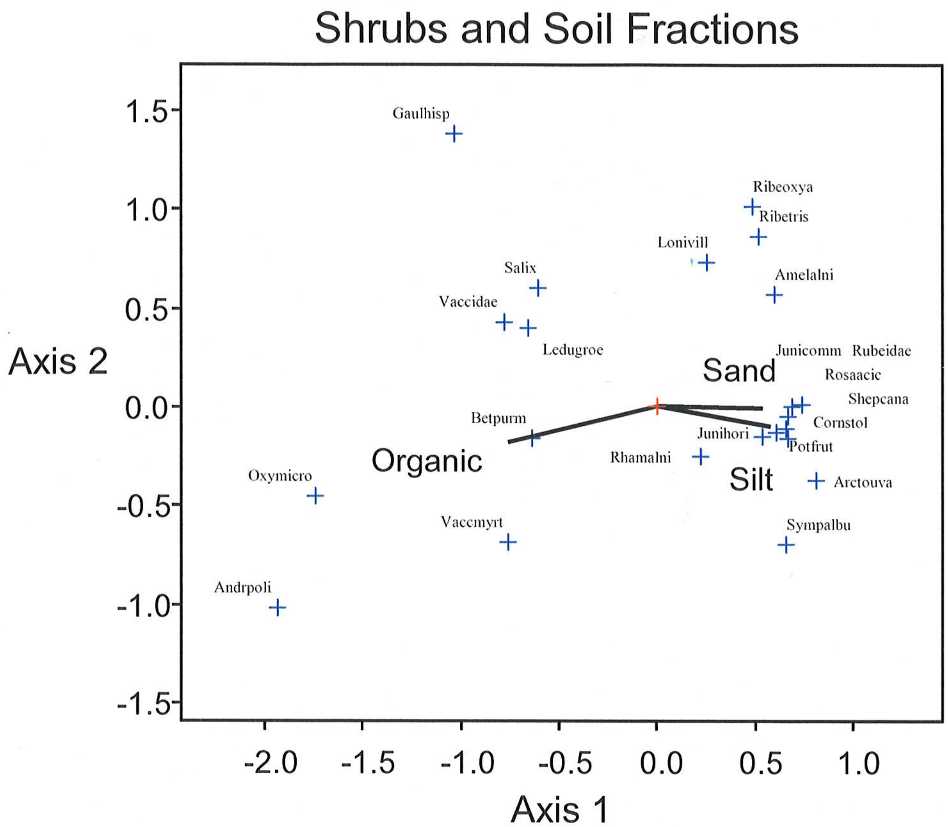

Figure 19: CCA showing relationship between shrub species and soil fractions within the study area. p =22 species, q =4 soil fractions. The first axis describes 15.4% of the variance, with the second axis accounting for 2.1% and the third axis only 1.1% of the variance. Pearsons Correlation for the first axis is 0.885, the second axis 0.487, and the third 0.405. Kendall (Rank) Correlation for the first axis is 0.613, the second axis 0.305, and the third 0.254. Monte Carlo test for species-environment correlations and eigenvalues is $p = 0.0010$.

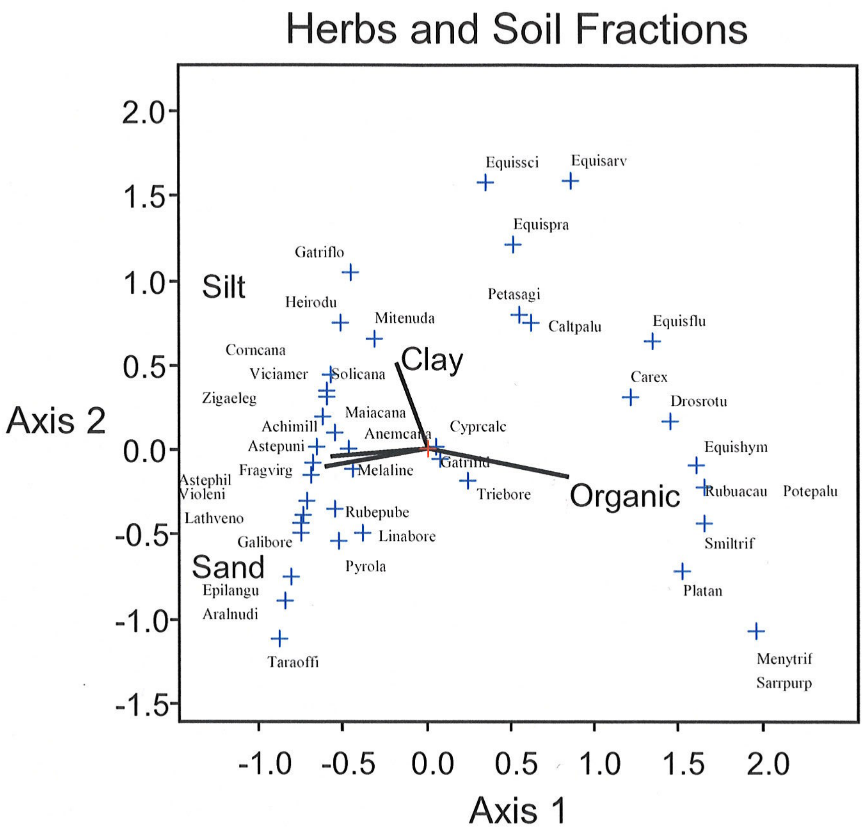

Figure 20: CCA showing relationship between herb species and soil fractions within the study area. p =41 species, q =4 soil fractions. The first axis describes 13.8% of the variance, with the second axis accounting for 1.7% and the third axis only 0.7% of the variance. Pearsons Correlation for the first axis is 0.893, the second axis 0.598, and the third 0.444. Kendall (Rank) Correlation for the first axis is 0.629, the second axis 0.329, and the third 0.255. Monte Carlo test for species-environment correlations and eigenvalues is p = 0.0010.

Table 13: List of codes for each species used in the analysis.

Trees

Larilarc *Larix laricina* (tamarack)
Picmari *Picea mariana* (black spruce)
Pinbank *Pinus banksiana* (Jack Pine)
Popbals *Populus balsamifera* (balsam poplar)
Poptrem *Populus tremuloides* (trembling aspen)

Shrubs

Amelalni *Amelanchier alnifolia* (saskatoon
Andrpoli *Andromeda polifolia* (bog rosemary)
Arctouva *Arctostophylos uva-ursi* (bearberry)
Betpurm *Betula pumila var glandulifera*
Cornstol *Cornus stolonifera* (red-osier dogwood)
Gaulhisp *Gaultheria hispidula* (creeping snowberry)
Junicomm *Juniperus communis* (common juniper)
Juniho - *Juniperus horizontalis* (creeping juniper)
Ledugroe *Ledum groenlandicum* (Labrador Tea)
Lonivillo *Lonicera villosa* (fly honeysuckle)
Oxymicro *Oxycoccus microcarpus* (small cranberry)
Potfrut *Potentila fruticosa* (cinquefoil)
Rhamalni *Rhamnus alnifolia* (alder-leaved buckthorn)
Ribeoxya *Ribes oxyacanthiodes* (Canadian Gooseberry)
Ribetris *Ribes triste* (Wild Red current)
Rosaacic *Rosa acicularis* (prickly rose)
Rubeidae *Rubus idaeus* (wild red raspberry
Salix Willows
Shepcana *Shepherdia canadensis* (buffaloberry)
Sympalbu *Symphoricarpus albus* (common snowberry)
Vaccmyrti *Vaccinium myrtilloides* (velvetleaf blueberry)
Vaccidae *Vaccinium vitis-idaea* (bog cranberry)

Herbs

Achimill *Achillium millefolium* (common yarrow)
Anemcana *Anemone canadensis* (Canada anemone)
Aralnudi *Aralia nudicaulis* (wild sasparilla)
Astephil *Aster philadelphicus* (Philadelphea fleabane)
Astepuni *Aster puniceus* (purple-stemmed aster)
Caltpalu *Caltha palustris* (marsh marigold)
Carex sedge family

Corncana *Cornus canadensis* (bunchberry)
Cyprcalc *Cypripedium calcaolus var pubescens* (yellow ladies slipper)
Drosrotu *Drosera rotundifolia* (round leaved sundew)
Epilangu *Epilobium angustifolium* (fireweed)
Equisarv *Equisetum arvense* (common horsetail)
Equisflu *Equisetum fluviatile* (water horsetail)
Equishym *Equisetum hymenale* (scouring rush)
Equispra *Equisetum pratense* (meadow horsetail)
Equissci *Equisetum scirpoides* (Dwarf scouring rush)
Fragvirg *Fragaria virginiana* (common strawberry)
Galibore *Galium boreale* (northern bedstraw)
Gatrifid *Galium trifidum* (small northern bedstraw)
Gatriflo *Galium trifloram* (sweet-scented bedstraw)
Heirodu *Heirochloe odurata* (sweetgrass)
Lathveno *Lathyrus venosus* (veiny pea)
Linabore *Linaeus borealis* (Twinflower)
Maiacana *Maianthemum canadensis* (wild lily-of-the-valley)
Melaline *Melampyrum lineare (*cow-wheat)
Menytrif *Menyanthes trifoliata* (buckbean)
Mitenuda *Mitella nuda* (bishops cap)
Petasagi *Petasites sagittatus* (Sweet coltsfoot)
Platan *Platanthera family* (bog orchid)
Potepalu *Potentilla palustris* (marsh cinquefoil)
Pyrola wintergreens
Rubepube *Rubus pubescens* (dwarf red raspberry, dewberry)
Rubuacau *Rubus acaulis* (dwarf raspberry)
Sarrpurp *Sarracina purpurea* (pitcher plant)
Smiltrif *Smilacina trifolia* (three leaved soloman seal)
Solicana *Solidago canadensis* (Canada Goldenrod)
Taraoffi *Taraxacum officinaia* (Common Dandelion)
Triebore *Trientalis borealis* (Northern starflower)
Viciamer *Vicia americana* (American vetch)
Violeni *Viola renifola* (kidneyleaf violet)
Zigaeleg *Zigadenus elegans* (White Camas)

Discussion

The first objective of this study was to determine if different enduring features had significantly different vegetation communities from one another. One method used to accomplish this objective was by looking at the effectiveness of enduring features at the boundaries designed by Manitoba Conservation at the 1:1,000,000 mapscale using the DEM and a scale of 1:1 (vegetation/soil) using field surveys. The second objective of the study was to determine if the enduring feature that occurred at each site was the same as the enduring feature that the Manitoba Conservation database reported as being present. Finally, the third objective was to look at the effectiveness of the geomorphological features in differentiating enduring features at a resolution of 90 m and a scale of 1:1000000. The reason for defining the objectives in this way and for conducting the study and analysis by this methodology is that it became apparent that two different results were emerging, and these differences in results appeared to be primarily due to scale.

Prior to entering the field, there were three enduring features to be studied. At the end of the study, six enduring features were confirmed to be present from the field surveys. Comparing the two groups showed that there was a low level of agreement between the enduring features designated by Manitoba Conservation and the on-site enduring features (**Table 5**). The explanation for this discrepancy can be attributed to issues of scale and to two scale-related factors. One of the factors relates to the way that Manitoba Conservation designed the enduring features map, the second factor has to do with the geophysical nature of the soil itself. The enduring features map was developed with several limitations to its design. One of these limitations has to do with the way the boundary lines were generated; by a union overlay of themes in a GIS program using 1: 1,000,000 soil maps. This large scale resulted in a margin of error as large as 1 km on each of the boundaries (William Watson, personal communication), which meant that enduring features with a size smaller than 1 km^2 would be considered artefacts of the Union overlay theme. It was these issues with boundaries which required the study to have all of the survey sites located a minimum of 1 km away from all of the boundaries. The second limitation was that each enduring feature was classified based upon the dominant soil type in the region, with a dominant soil being defined as any one soil class that comprises 51% or greater of the enduring feature polygon (Watkins, personal communication). This meant that up to 49% of an enduring feature polygon could be composed of at least one, if not more, entirely different soil classes. These limitations were always known when the enduring features map was created. Because of these problems each enduring feature polygon was to be treated as a hypothetical unit until confirmed on the ground. The idea was to use enduring features as a focus for the study of new parks in areas that contained features not adequately represented in the existing park system, and was not intended for setting park reserve boundaries (Watkins et al. 1994, Noss 1995).

The second factor, the geophysical nature of soil, is such that soil types tend to change gradually from one type to the other. Soils are highly sensitive to microsite conditions, such that it is possible to have two very different soil types within meters of one another (Fraser et al. 1985, CSSC 1998). Because of the highly variable nature of soils it is difficult to characterise an area for one kind of soil type, especially when the sampling scale is small. It does not prevent areas from being classified into particular soil types, but these classifications are made with the understanding that this inherent variation in soil type will always prevent 100% accuracy in soil maps. What matters most is the accuracy for the scale that the mapping was conducted at, with the knowledge that the accuracy of the soil map will diminish if a study is conducted at a scale that is smaller or larger than the soil map.

These reasons of map generation and soil property explains why there was so little agreement between the enduring features as described on the Manitoba Conservation database and the enduring features that were described for each survey site. The sampling scales were too widely different, and the potential error due to the limitations created by the map generation too great to allow for any significant correlation between the Manitoba Conservation-derived enduring features and the enduring features identified on-site. Because of this, the bulk of the analysis was conducted using the enduring features identified on-site since the purpose of this paper is to determine the effectiveness of enduring features as a proxy for biological diversity. Comparisons between the enduring features at the two different mapscales will be used to draw attention to the role that scale plays on interpreting the effectiveness of enduring features as a proxy for biological diversity.

Vegetation

Community Analysis

In the community analysis the relationship between the enduring features and the major vegetation communities within the study area was studied. **Table 7** describes the distribution of vegetation communities within the enduring features defined by Manitoba Conservation. The spread of the communities showed that each of the enduring features had representatives from all of the vegetation communities, with the exception of the Deciduous community in the Organic Deposits/Eutric Brunisol enduring feature.

It can be inferred from these results that enduring features when defined at the 1:1,000,000 scale are not effective at discriminating between communities. However, the enduring features defined on-site and the vegetation communities found in each of those enduring features (**Table 11**) are more strongly associated with one another.

The results seen in **Table 11** are supported in **Figure 11,** which show that vegetation communities are correlated with the on-site enduring features. Those communities that are found in wet habitats, such as Treed Fens and Treeless Fens were associated with the Organic Deposits. Those communities which are found in dry regions (Coniferous Dry, Mixedwood and Deciduous) were found primarily in the Glacial Till/Eutric Brunisol enduring features. The remaining community - Coniferous Muskeg -- was found straddling a range of enduring features, although it was correlated most strongly with the Glacial Till/Organic Mesisol enduring features. The correlations between the vegetation communities and the enduring features are not perfect, but they are clear enough to differentiate into discreet groups.

Similar trends were seen among the CCA conducted between the vegetation communities and soil fractions (**Figure 16**). The organic fraction had fen communities, while the mineral fractions supported the Deciduous, Mixedwood and Coniferous Dry communities. The only difference was that there was more overlap between the Treed

Fen and Treeless Fen communities in the soil fractions than was seen in the enduring features.

All of these trends in community distribution support the conclusion about scale which was inferred from the results in **Table 5**. The scale at which the enduring features are designed are just as important for predicting vegetation communities as the enduring features themselves. It also explains why the on-site enduring features were more effective at differentiating the vegetation communities than the enduring features derived by Manitoba Conservation. Smaller scales appear to be more effective in increasing the ability of the enduring features to adequately proxy for the biological communities that are within them. Since gap analysis was originally designed to work at intermediate to small scales, from 1:20,000 to 1:250,000, it should not be surprising that the smaller scale has been shown to be more effective. Even so, some caution should be exercised with this result since there was only one observation recorded for each of the Organic Deposits/Eutric Brunisol and Organic Mesisol enduring features.

Species Analysis

Table 10 summarises the species richness for each of the enduring features. The enduring features with a glacial till component (Glacial Till/Eutric Brunisol and Glacial Till/Organic Mesisol) supported a higher average species richness than the enduring features with an Organic component, although the Glacial Tills had the fewest rare species. Organic Deposits had the lowest average species richness but was the highest for presence of rare species. The Glacial Till/Eutric Brunisol enduring feature was correlated with the greatest number of species overall (**Figure 12**), and the greatest number of shrubs and herbs (**Figures 14** and **15**). This shows that these species have a distinct preference for the landform and soil combination that this enduring feature is comprised of. Further CCA ordinations looking at the individual soil fractions also show that these same species are correlated with the clay and silt components of the soil, indicating that these species preferentially establish themselves in these soil fractions or combinations of soil fractions. Similar trends can be seen between those species found within the Organic Deposits enduring feature and the organic fraction of the soil.

What was also found were several species that were independent of the enduring features and the soil fractions. Soil type appeared to have had no influence on their distribution within the study site. *L. laricina* and *P. mariana* were found to not be correlated to any specific soil fraction or enduring feature. This characteristic would be especially true of *P. mariana*, which is a common specie and is tolerant in almost all kinds of moisture regimes and soil types within the study area. *L. laricina* showed a stronger correlation with the Organic Deposits enduring feature, but this is because *L. laricina* was the only tree to be found growing in the fens, it being an extremely water-tolerant tree and able to grow within pure organic soils. This should not be interpreted to mean that *L. laricina* prefers organic soils, since it was found growing vigorously in all other enduring features in almost every survey site.

Overall, each of the CCA ordinations showed that there is a correlation between individual species, vegetation communities, and the type of soil and enduring features that these species and communities occur on. This finding is not new, it simply confirms what has long been known and supported in the scientific literature, specific plants and communities have adapted themselves to survive on specific soil types (Wondzell et al. 1996, Štekauerová et al. 2006, Schimel et al. 1985a, Lyon et al. 2005). However, within these trends variations in the distribution of species and communities can be observed. The largest trend being that individual species are less constrained in their distribution by enduring features or soil fraction than are entire communities.

There are several reasons why species are less constrained than plant communities. Each species has a range of tolerance for the many environmental variables that it encounters. This flexibility allows it to adapt to the growing conditions that it is found in. These tolerance ranges are the product of both genetic and environmental factors, resulting in both morphological and physiological responses from the plant (Silvertown 1998). This is known as *phenotypic plasticity*, and it is what allows plants to grow and adapt to environmental variables, such as soil type, light levels and moisture regime. Since communities are composed of a wide range of species with different growth habits, the ability of a specific biological community to adapt to different soil types are constrained by the tolerance range of all the individual species within the community. An example within the study area was the distinct vegetation communities that developed under similar canopy species, *L. laricina* and *P. mariana*. Both of these species have proven to be able to grow under an extremely wide range of growing conditions, and canopy species exert a strong influence on the kinds of communities that develop. However, the type of community that develops also rests strongly on the soil and topography. Based upon the vegetation surveys conducted at each site and the observations made at each survey site an *L. laricina* and *P. mariana* dominated community that is established on a dry mineral soil has a significantly different structure and species composition than a community established under these two species in an organic soil. This is because soil and topography determine how water moves within a landscape; and water movement, water level and water availability are one of the key influences on the distribution of a plant species -- which in turn influences soil development. This interplay of landscape and water determines the distribution of species throughout the landscape, so that species like *Andromeda polifolia* and *Oxycoccus microcarpus* were only found in regions of high water and organic soil content, while species like *Arctostophylos uva-ursi* and *Shepherdia canadensis* were only found on mineral soils in well-drained ridges. These limitations in the growth requirements of each species explains why two different communities can form under the same dominant canopy species, such as *L. laricina* and *P. mariana,* even though the canopy species may be able to grow in any soil type or moisture regime.

There can also be variations in the extent of constraints on species and communities. Within the study area it was shown that on organic soils, the distribution of species and communities were more constrained than the distribution of those species and communities found on mineral soils. Treed fens and treeless fens were found to be strongly correlated to those organic soils that had no mineral component to them, while coniferous muskeg were found were somewhat more versatile, being found in a mixture of organic soils with a clay component. On mineral soils the deciduous, mixedwood and coniferous dry communities showed no preference for one type of mineral soil fraction over another, and always overlapped. These same trends were observed in the enduring features, with both of the fen communities and the coniferous muskeg showing a distinct relationship with specific enduring features (Organic Deposits and Glacial Till/Organic

Mesisol respectively). On the enduring features with a mineral component (glacial till/eutric brunisol and glacial till/organic mesisol) the deciduous, mixedwood and coniferous dry communities were found to overlap with one another.

These constraints can be explained in the interaction between soil type and plant adaptation. The conditions that create organic soils require cool temperatures and high water tables. The result is slow decomposition rates and these soils are very low in available nutrients as a rule. For plant species to survive in these soil conditions they had to become specialised, *Sarracina purpurea* (pitcher plant) is an excellent example. Specialization enabled these species to survive in soil conditions that would be considered too difficult for most other species. This was done by the development of physical structures or biochemical pathways that enabled these species to survive in soils that are nutrient poor. In the case of *Sarracina purpurea* it was by developing a carnivorous habit which enabled the plant to acquire the necessary nutrients from insect prey. However, specialization comes at a price. That price is often the inability to grow in any other kind of soil type. This can explain why throughout the dataset two distinct groups can be discerned: one group is composed of those species found only in enduring features with Organic Deposits while the second group is made of species that are associated with the Glacial Tills and/or Eutric Brunisols. Most importantly, it was seen that those species found within an organic soil type had a far stronger fidelity to the organic soils and organic deposits enduring feature than the second group had to the mineral component. This is supported in the list of species recorded for each survey site, many of the species found in the organic deposits enduing feature and organic soils were never found in any other soil type or enduring feature. Examples of some of these species are the pitcher plant (*Sarracina purpurea*), bog rosemary (*Andromeda polifolia*), dwarf raspberry (*Rubus acaulis*), and buckbean (*Menyanthes trifoliate*).

The constraints due to habitat specialization and site fidelity within each species will naturally lead to similar constraints among larger plant communities. The ridge and swail topography of the study area allowed for these observations of community constraints. Within the study area, the changes from one organic soil to the next were abrupt. This resulted in the formation of distinct vegetation communities only meters away from one another, because of the species that are adapted to grow in these different kinds of organic soils. As a result the boundaries between a sphagnum bog and a sedge fen were obvious and easily observable. This distinction between these two groups was reflected in the data by the distinct grouping of the communities, in both soils and enduring features (**Figure 11** and **Figure 16**). Specifically, three combinations of community types could be discerned within both graphs: 1) Treed Fens/Treeless Fens, 2) Coniferous Muskeg, and 3) Coniferous Dry/Mixedwood/Deciduous. Using the enduring features to separate the sites (**Figure 11**) the distinctions between these community groupings was better developed; there was less overlap between the different groups as opposed to using soil fractions to separate the sites, which showed more overlap between the Coniferous Muskeg and Treed Fen/Treeless Fen group. The reason that there was less overlap between community combinations in the enduring features is probably because the enduring features are composed of both the soil type and underlying topography. Both of these features would account for a greater number of the environmental variables (slope, elevation, soil type, water movement, etc) that would influence the development of vegetation communities (Zonneveld 1989, Araujo 1999, Fu et al. 2004).

The differences seen in community type from one enduring feature to another does have limits. While the Coniferous Muskeg and Fen communities showed a distinct difference between the soil type and enduring features that they were located in, the same distinction did not occur between the Treed Fen and Treeless Fen communities, which overlapped considerably with one another within the Organic Deposits enduring feature. On mineral soils it was observed that the individual plant species and plant communities (Coniferous Dry, Mixedwood, Deciduous) had a greater degree of overlap within and between the different mineral soil fractions and associated enduring features than was seen between the individual plant species and plant communities that occurred in the organic soil fraction. This could be due to the extreme variability seen in mineral soils and their formation (Jenny 1941).

Part of the explanation for these overlaps could be understood by looking more closely at the soil fractions, and trying to understand how the soil fractions and the distribution of the plant species within each soil fraction can influence plant community development and distribution within a landscape (Schimel et al. 1985b, Schimel et al. 1985a, Ruhe 1956, Lag 1971). In the PCA analysis of the soil fractions (**Figures 7 and 8**) it was seen that the Organic fractions were an outlier, forcing the mineral components closer together. Even so, the sand fraction appeared to have less of a relationship to the silt and clay fractions (**Figure 7**). When the organic fraction was removed it was seen that the silt and clay components were grouped together closely, appearing to be very similar in their influence on the distribution (**Figure 8**). Sand appeared to have no influence in the relationship between the different sites, and could be interpreted as being independent from the other two components. The sandiest soils were found on the drumlins, which is where the Glacial Till/Eutric Brunisol enduring features were located. The higher elevation, greater exposure to wind and greater slope of the drumlins allowed water to drain away quickly and to prevent the ground from retaining moisture. Without sufficient soil moisture, many of the processes that would allow for the accumulation of organic matter would be slowed or even halted. All of these factors would work to ensure that the sandier soils would remain distinct and maintain their "independence" from the other areas.

Plants and vegetation communities on mineral soils would thus have to be more flexible and tolerant of the varying nature of mineral soils. This is not to ignore the role that other variables such as moisture, light, soil nutrients, and competition have in determining the establishment of certain vegetation communities over others. It is merely showing that plant establishment and soil development is a two-way relationship. Those communities that grew on mineral soils appeared to be more versatile in the kind of enduring features and the soil fractions that they could be found on.

Landforms

The landform analysis showed similar results in all of the enduring features studied, whether studied at the 1:1,000,000 scale or the 90 m scale.

In the polygon analysis, the results seen in both **Table 6** and **Figure 5** generally agree with one another in that the averages generated in **Table 6** closely reflect the spread of datapoints seen in **Figure 5**. When looking at all of the geomorphological parameters within each polygon of the same enduring feature, differences between the results seen in **Table 6** and **Figure 5** show there is some variation within each polygon. These variations are reflected in the spread of datapoints in **Figure 5.** These variations are not seen in **Table 6** because of the averaging of each geomorphological parameter for each of the enduring features polygons. In each of the enduring features, the geomorphological features as defined by their parameters appear to be restricted to passes and peaks. None of the other geomorphological features (planes, channels, ridges, pits) are represented. It is possible that this lack of the other features is representative of the ridge and swail topography of the area. Those enduring features that had peaks were composed of topographic features typical of high areas, namely glacial till and Eutric Brunisol. The enduring features that had an organic component were characteristic of a pass, which would be expected since those regions are low-lying, wet areas. But as was seen in **Table 7**, the Glacial Till/Eutric Brunisol enduring feature had almost all vegetation communities represented in it, and numerically possessed more Fen and Muskeg communities than mixedwood or coniferous i.e., the dry communities. Thus at the polygon (1:1,000,000) scale, it was found that the Glacial Till/Eutric Brunisol enduring feature contained all of the geomorphological parameters that would allow it to possess this wide variety of vegetation communities.

The results seen in both **Table 6** and **Figure 5** reflect this. There was a significant amount of overlap between the three circled enduring features in the Polygons analysis. The overlapping between these three enduring features suggests that they all share similar landforms. Even the Glacial Till/Eutric Brunisol enduring feature had a little over half of all datapoints within the other circled areas. What this may indicate is that these enduring features share so many geomorphological parameters that they are not significantly different from one another.

In the end, it is probably a little unwise to put too much interpretation into the numbers generated for **Table 6** since they are an average of many datapoints. The PCA in **figure 5** showed that while there may be some weak correlation between the enduring features and landform variables at the 1:1,000,000 (polygon) scale, there is too much overlap between all of the enduring features to reliably conclude that there is any particular relationship between them and the geomorphological parameters.

This overlap in parameters can be attributed to the 1:1,000,000 scale of the polygons. During the DEM analysis, all of the geomorphological parameters within each polygon were averaged together; this averaging would have flattened out or hidden any geomorphological features that would characterise geomorphological features within the polygon as more unique or distinct from the surrounding landscape. The result is that at such a large scale, the enduring features are not sufficiently distinct from one another based on geomorphological features alone.

This suggests that this would also happen when making landscape planning decisions at the same scale. Any unique geomorphological characteristics would be blurred into the background, or hidden among larger features. Since the purpose of enduring features are to find and protect all the biological diversity represented by different topographical and soil features this can prove to be a problem. In the boreal forests of Canada areas of high biological diversity tend to be located within and around areas known as *Hotspots* (Myers et al. 2000). Examples of hotspots would be forest/prairie interfaces, land/water boundaries, or slight deviations in the landscape, such as ridges, depressions, inclines/declines. Hotspots are also areas that possess unique species assemblages that are found nowhere else within a region or landscape. These kinds of hotspots are not necessarily species rich, but have species that are endemic to that region only. An example of this type of hotspot within Manitoba would be the salt springs located around Lake Winnipegosis, currently protected as the Lake Winnipegosis Salt Flats ecological reserve. Hotspots allow for a wider diversity of organisms or communities to establish themselves, because new niches are created due to the different microsite conditions that have developed as a result of the differences in the topography, compared to the surrounding landscape. Enduring features can reliably determine the location and importance of these areas, but because many hotspots can be very small in size enduring features would only be effective at a scale small enough to pick out these changes in the landscape.

Future studies would need to look at landform variables and enduring features at an intermediate scale or even a fine scale, 1:20,000 to 1:250,000 to see if the correlations seen in **figure 5** would be strengthened and the amount of overlap between the enduring features reduced.

Similar results were seen in the analysis of the landform variables at the 90 m scale. It was seen that those enduring features that appeared to characterise the geomorphological feature of a peak were the Glacial Till/Organic Mesisol and the Organic Deposits/Eutric Brunisol. The remaining enduring feature -- Glacial Till/Eutric Brunisol -- had geomorphological parameters that characterised the feature of a pass.

Like the analysis of the polygon landforms, none of the other geomorphological features (planes, channels, ridges, pits) were found.

In the PCA conducted between the on-site enduring features and the landform variables from each survey site (**figure 9**), the spread of the datapoints in the graph shows that none of the enduring features are strongly correlated to any of the axis. This is seen in the enduring features that were circled, the Glacial Till/Eutric Brunisol encompasses nearly the entire graph area. The datapoints for the Organic Deposits enduring feature were also spread throughout the graph, with no clear pattern. All of the circled areas greatly overlapped one another or are contained completely within another circled area. It should be mentioned that although the above analysis is useful for showing patterns among the dataset, it must be remembered that PCA is not an analytical method that is designed for use in group discrimination.

There appears to be no correlation between the enduring features identified on-site with the landform variables. One of the reasons for this result could be due to the low number of observations for three of the six enduring features. There was only one observation each for the Organic Deposits/Eutric Brunisol and Organic Mesisol enduring features, and only four observations for the Glacial Till/Organic deposits enduring feature.

Looking at only those enduring features that have a large number of observations, one explanation for the lack of correlation could be due to the fact that enduring features were designed to be used at landscape level processes. As has been explained earlier, scale is important when considering the impact of landscape variables on biological communities. At the on-site level, it is quite possible that there was no correlation with the enduring features because the enduring features were never intended to be used at such a small scale. They are used for landscape-level processes, and the PCA for the groundsite landforms was used to look at relations between the sites based on those variables that are most important at the local (groundsite) level. Thus there was no correlation simply because the scale of analysis was too small to make any association with the enduring features.

The conclusions made on these results between landform variables and enduring features emphasises the importance of scale when studying landscapes or making landscape-level management decisions. Numerous studies have shown that ignoring the effects of scale when conducting research or making land management decisions is imprudent (Wood 1996, Zonneveld 1989, Fu et al. 2004), since the level of scale greatly determines the type and quality of the information used to make planning decisions. The level of accuracy of topographic features on numerous maps is almost entirely scale dependant (Frank et al. 1986, Wood 1996). Scale impacts the type of data collected in field work, and the results of any landscape analysis can change simply by changing the scale of the landscape studied (Gerrard and Robinson 1971). This problem of scale makes it difficult to make single designations about any landscape feature, since by changing the scale the designation becomes irrelevant or even inaccurate (Wood 1996). But the answer is not to seek small-scale (high definition) data, since the smaller the scale, the more differences that can be found to occur within the area (Zonneveld 1989). Instead what is needed is to determine what the best level of scale is, in order to achieve planning or management objectives.

An example of the importance of scale would be to look at slope. When enduring features gap analysis was developed for use in Manitoba, slope was not included as one of the primary features of representation, with the exception of the escarpments and the beach ridges. It was felt that Manitoba was too flat a landscape for slope to play a significant role (Watkins et al. 1994). The importance of slope at the landscape level as opposed to a local level can be seen in the geological history of the area. Glacial movement scraped out the lower lying areas and deposited large amounts of silt and gravel, forming the ridges (Stock 2005). Following the retreat of the glaciers, inundation of the region by Lake Agassiz created a large standing body of water. This high amount of water, combined with the cool climate and the gradual change of elevation from Chitek Lake to the waters of Lake Winnipeg, created an area of high water and poor drainage.

These conditions allowed even minor variations in slope to have an impact on the movement of water and thus the development of the soil. So for the Chitek Lake region, the high gravel ridges allowed for quick and easy runoff of water into the low-lying land. Meanwhile the cool boreal climate created an accumulation of organic matter in these low-lying areas, which acted to slow the movement of water and allowed for the formation of fens and muskeg. This resulted in the creation of at least two distinct communities; the first is the jack pine/tamarack forest, located only on the high till ridges. The other is the sedge-dominated fens which were found in the low-lying lands. In between these two extremes is a community mixture determined largely by slight deviations in slope and elevation (pass and peak). This observation has been confirmed in other studies, which have also concluded the importance of landscape features (topography, landscape position, slope gradient, elevation) in influencing plant communities and soil conditions (Schimel et al. 1985, Aguilar and Heil 1988, Fu et al. 2004).

Conclusion

By using Enduring Features Gap Analysis, Manitoba Conservation hopes to: 1) to protect biodiversity by protecting representative areas and the processes that maintain them, 2) to protect landscape level processes and biodiversity, instead of only individual species and, 3) to have a planning system that relates protection standards to the criterion of ecological integrity. The primary goal of Manitoba Conservations protected areas management is to maintain a state of equilibrium within the protected area, usually via pure conservation or by prevention of deterioration through use (Zonneveld 1989).

The problem is how to best determine what size and scale to conduct the planning. This must be done in order to have the greatest relevance in conservation regarding the protecting of unique or important communities. At intermediate scales, topographical boundaries tend to be obvious and easily correlated with both soils and vegetation, since they ignore the minor boundary discrepancies and overlaps between topographic and vegetation attributes that would inevitably occur on smaller, finer scales (Zonneveld 1989). Intermediate scales are often the best scale for planners, since a greater importance is placed on landscape characteristics than minor deviations in boundaries. This is the strength behind the use of GIS based landscape analysis such as enduring features gap analysis.

The results of this study have shown that while enduring features are mostly effective in determining the distribution and composition of biological communities, there is doubt as to whether EFGA at the map scale that Manitoba Conservation currently works at is an effective one. It has also been shown that while most species and vegetation community distribution is correlated with the underlying enduring features there are some species, most notably black spruce and tamarack, whose distribution is not determined by enduring features, soils or landform. It has also been shown that enduring features with a mineral component did not perform as well in differentiating vegetation communities than those enduring features which are defined by an organic component. As a result caution should be exercised when using EFGA, to ensure that these factors are taken into account when doing protected areas planning.

Of course, not everything in park establishment has to do with enduring features or ecological criteria. Politics, industry, other stakeholder interests, First Nations, and financial limitations all play a part in determining the size, boundaries, contents and purpose of a protected area. But with a practical analytical technique based upon sound management ethics, one more barrier to the conservation of our future will be removed.

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Appendix

List of species richness by tree, shrub, herb and lichen for each survey site.

Species Richness by Site						
Site	On-Site Enduring Feature	Species Richness				Vegetation Community
		Trees	**Shrubs**	**Herbs**	**Lichens**	
Site 2	Glacial Till/Eutric Brunisol	3	5	5	14	Coniferous Dry
Site 3	Glacial Till/Organic Deposits	2	3	4	4	Coniferous Muskeg
Site 6	Glacial Till/Eutric Brunisol	3	8	10	9	Coniferous Dry
Site 7	Glacial Till/Eutric Brunisol	4	10	7	7	Mixedwood Forest
Site 8	Glacial Till/Eutric Brunisol	3	6	10	11	Coniferous Dry
Site 9	Glacial Till/Eutric Brunisol	4	4	13	9	Coniferous Dry
Site 10	Glacial Till/Eutric Brunisol	4	6	10	8	Mixedwood Forest
Site 11	Glacial Till/Eutric Brunisol	3	6	7	7	Coniferous Dry
Site 12	Glacial Till/Eutric Brunisol	4	8	7	10	Mixedwood Forest
Site 13	Glacial Till/Eutric Brunisol	3	9	10	11	Coniferous Dry
Site 14	Glacial Till/Eutric Brunisol	4	15	8	5	Mixedwood Forest
Site 15	Glacial Till/Eutric Brunisol	2	5	9	9	Coniferous Dry
Site 16	Glacial Till/Eutric Brunisol	4	9	8	8	Mixedwood Forest
Site 17	Glacial Till/Organic Mesisol	2	10	12	10	Coniferous Muskeg
Site 18	Glacial Till/Eutric Brunisol	2	9	7	0	Coniferous Dry
Site 19	Glacial Till/Organic Mesisol	2	6	10	0	Coniferous Muskeg
Site 20	Glacial Till/Organic Mesisol	2	6	7	10	Coniferous Muskeg
Site 21	Glacial Till/Organic Mesisol	2	6	5	12	Coniferous Muskeg
Site 22	Glacial Till/Organic Mesisol	2	14	6	0	Coniferous Muskeg
Site 23	Organic Deposits	2	7	4	7	Treed Fen
Site 24	Organic Deposits	2	6	5	10	Coniferous Muskeg
Site 25	Organic Mesisol	2	5	1	0	Coniferous Muskeg
Site 26	Organic Deposits	2	10	9	6	Treed Fen
Site 27	Glacial Till/Eutric Brunisol	2	5	4	14	Coniferous Dry
Site 28	Glacial Till/Eutric Brunisol	4	6	6	8	Mixedwood Forest
Site 29	Glacial Till/Eutric Brunisol	5	8	11	8	Coniferous Dry
Site 30	Glacial Till/Eutric Brunisol	3	6	7	11	Coniferous Dry
Site 31	Glacial Till/Eutric Brunisol	3	9	16	11	Coniferous Dry
Site 32	Glacial Till/Organic Mesisol	4	8	10	7	Coniferous Dry
Site 33	Glacial Till/Organic Mesisol	2	8	10	13	Coniferous Muskeg
Site 34	Glacial Till/Organic Mesisol	4	5	4	9	Treed Fen
Site 35	Glacial Till/Eutric Brunisol	3	4	8	8	Deciduous
Site 36	Glacial Till/Eutric Brunisol	3	6	13	8	Coniferous Dry
Site 37	Glacial Till/Eutric Brunisol	3	5	16	3	Deciduous
Site 38	Organic Deposits	1	4	2	0	Treeless Fen
Site 39	Organic Deposits	2	4	5	8	Treed Fen
Site 40	Organic Deposits	1	2	3	4	Treeless Fen
Site 41	Organic Deposits	1	2	6	6	Treeless Fen
Site 42	Glacial Till/Eutric Brunisol	4	4	11	17	Mixedwood Forest

Species Richness by Site						
Site	On-Site Enduring Feature	Species Richness				Vegetation Community
		Trees	Shrubs	Herbs	Lichens	
Site 43	Glacial Till/Organic Mesisol	2	5	11	14	Coniferous Muskeg
Site 44	Glacial Till/Organic Deposits	2	5	7	12	Treed Fen
Site 45	Glacial Till/Eutric Brunisol	3	5	12	8	Deciduous
Site 46	Organic Deposits	1	2	7	6	Treed Fen
Site 47	Glacial Till/Organic Mesisol	3	1	10	11	Mixedwood Forest
Site 48	Glacial Till/Organic Deposits	2	6	6	11	Treed Fen
Site 49	Organic Deposits	1	2	5	9	Treed Fen
Site 50	Glacial Till/Eutric Brunisol	2	8	7	17	Coniferous Dry
Site 51	Glacial Till/Eutric Brunisol	4	7	8	13	Mixedwood Forest
Site 52	Glacial Till/Eutric Brunisol	4	8	10	12	Coniferous Dry
Site 53	Glacial Till/Eutric Brunisol	3	1	10	19	Coniferous Dry
Site 54	Glacial Till/Eutric Brunisol	3	1	10	12	Deciduous
Site 55	Glacial Till/Eutric Brunisol	5	8	9	16	Coniferous Dry
Site 56	Glacial Till/Eutric Brunisol	2	3	10	13	Mixedwood Forest
Site 57	Organic Deposits	2	5	7	13	Coniferous Muskeg
Site 58	Organic Deposits	2	3	8	13	Treed Fen
Site 59	Glacial Till/Organic Mesisol	2	3	10	13	Coniferous Dry
Site 60	Organic Deposits	2	4	10	11	Treed Fen
Site 61	Organic Deposits	2	4	8	7	Treeless Fen
Site 62	Organic Deposits	2	2	8	11	Treeless Fen
Site 63	Glacial Till/Eutric Brunisol	2	6	12	13	Coniferous Muskeg
Site 64	Organic Deposits	2	4	7	13	Coniferous Muskeg
Site 65	Organic Deposits	2	4	1	21	Coniferous Muskeg
Site 66	Glacial Till/Organic Deposits	2	8	6	18	Coniferous Muskeg
Site 67	Organic Deposits	2	7	9	19	Coniferous Muskeg
Site 68	Organic Deposits/Eutric Brunisol	1	1	6	7	Treeless Fen
Site 69	Glacial Till/Eutric Brunisol	4	4	18	13	Mixedwood Forest
Site 70	Glacial Till/Eutric Brunisol	4	8	15	10	Mixedwood Forest
Site 71	Organic Deposits	2	8	8	13	Coniferous Muskeg
Site 72	Organic Deposits	2	8	9	7	Treed Fen
Site 73	Organic Deposits	2	3	7	14	Coniferous Muskeg
Site 74	Glacial Till/Eutric Brunisol	3	6	8	12	Coniferous Dry
Site 75	Glacial Till/Eutric Brunisol	5	10	8	18	Mixedwood Forest
Site 76	Organic Deposits	1	2	7	4	Treed Fen

Von Post scale of decomposition. Taken from CSSC, 1998.

The field test involves squeezing a sample of the organic material within the closed hand. Classification is determined by observing the color of the solution that is expressed between the fingers, the nature of the fibers, and the proportion of the original sample that remains in the hand. Ten classes are defined as follows:

1	Undecomposed; plant structure unaltered; yields only clear water coloured light yellow-brown.
2	Almost undecomposed; plant structure distinct; yields only clear water coloured light yellow-brown.
3	Very weakly decomposed; plant structure distinct; yields distinctly turbid brown water, no peat substance passes between the fingers, residue not mushy.
4	Weakly decomposed; plant structure distinct; yields strongly turbid water, no peat substance escapes between the fingers, residue rather mushy.
5	Moderately decomposed; plant structure clear but becoming indistinct; yields much turbid brown water, some peat escapes between the fingers, residue very mushy.
6	Strongly decomposed; plant structure somewhat indistinct but clearer in the squeezed residue than in the undisturbed peat; about one-third of the peat escapes between the fingers, residue strongly mushy.
7	Strongly decomposed; plant structure indistinct but recognizable; about half the peat escapes between the fingers.
8	Very strongly decomposed; plant structure very indistinct; about two-thirds of the peat escapes between the fingers, residue almost entirely resistant remnants such as root fibres and wood.
9	Almost completely decomposed; plant structure almost unrecognizable; nearly all the peat escapes between the fingers.
10	Completely decomposed; plant structure unrecognizable; all the peat escapes between the fingers.

Morphometric features defined by the sign of five morphometric parameters. # indicates undefined, or not part of selection criteria. Taken from Wood, 1996.

Feature	slope	crosc	longc	maxic	minic
Peak	0	#	#	+ve	+ve
	+ve	+ve	+ve	#	#
Ridge	0	#	#	+ve	0
	+ve	+ve	0	#	#
	+ve	0	+ve	#	#
Pass	0	#	#	+ve	-ve
	+ve	+ve	-ve	#	#
	+ve	-ve	+ve	#	#
Plane	0	#	#	0	0
	+ve	0	0	#	#
Channel	0	#	#	0	-ve
	+ve	-ve	0	#	#
	+ve	0	-ve	#	#
Pit	0	#	#	-ve	-ve
	+ve	-ve	-ve	#	#