A Geographic Information System Approach to Determine Connectivity between Duck Mountain Provincial Park and Forest and Riding Mountain National Park, Manitoba

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ABSTRACT

Four geographic information system methods were applied to determine connectivity and fragmentation for a corridor from Riding Mountain National Park to Duck Mountain Provincial Park and Forest. Least-cost path modelling showed that presently there is no corridor of continuous forest or corridor of undeveloped land between these two areas, of which developed land appears to fragment all possible paths. Maps generated from spatial graphs and least-cost path modelling show that undisturbed land and forest is concentrated in the western Bluewing Corridor. Due to its greater connectivity, the Bluewing corridor is the preferred route for a corridor between these conservation areas.

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GLOSSARY

- DM: Duck Mountain (used to describe DMPP and DMPF as a whole)
- DMPF: Duck Mountain Provincial Forest
- DMPP: Duck Mountain Provincial Park
- DMPPF: Duck Mountain Provincial Park and Forest
- DND: Undisturbed and disturbed
- ED: Euclidean Distance
- FNF: Forest and non-forest
- FRI: Forest Resource Inventory
- GIS: Geographic information systems
- LCC: Least-cost corridor(s)
- LCP: Least-cost path(s)
- LU/LC: Land use and land cover data
- MLI: Manitoba Land Initiative
- NCC: Nature Conservancy of Canada
- PG: Patch GRID
- PHP: Parkland Habitat Partnership
- RM: Riding Mountain (used together with DM to simplify things)
- RMNP: Riding Mountain National Park
- SG: Spatial graph(s)

CHAPTER 1: INTRODUCTION

1.1 Background

With the rising human population, wilderness is rapidly being converted to other land uses as a result, flora and fauna are confined to small patches of undeveloped areas, often surrounded by developed areas that lack biodiversity (Lussier et al., 2006). Development that encroaches upon wilderness results in habitat fragmentation and biodiversity loss, and can also undermine the survival of different species (Fleury & Brown, 1997).

Parks are designed to enhance biodiversity. However, when parks are surrounded by development and without corridors for travel of species their biodiversity is limited by the size of the park. The biodiversity in Duck Mountain Provincial Park and Forest (DMPPF) and Riding Mountain National Park (RMNP) are limited when agricultural development fragments the landscape without an official corridor. A corridor of undeveloped land can potentially link the habitat patches in these areas, and allow wildlife to move or migrate freely from one park to another (Bolger et al., 2001). The opposite of connectivity is habitat or patch isolation. Isolation refers to the spatial distance that one habitat patch is separated from another, which can negatively impact animal movement (Bender et al., 2003).

The development of a corridor between DMPPF and RMNP would connect isolated natural habitats. It can allow wildlife movement to occur on a regional scale for: 1) breeding, 2) enlarging home ranges, 3) finding food and water during the different seasons, 4) ensuring genetic variability, 5) maintaining wildlife populations over a wide, and 6) plant genetic movement (Drielsma et al., 2007; Fleury & Brown, 1997; Parks Canada, 2012; Vogt et al., 2009). This thesis explores the connectivity and fragmentation between these two areas to recommend a potential corridor.

1.2 Main Objectives

- To determine the current landscape conditions between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (this "between" region is hereafter termed RM and DM).
- To explore the connectivity of forested and undisturbed land in the western, central and eastern regions between RM and DM.
- To compare two identified corridors, specifically Bluewing and Rose Ridge, in terms of forested and undisturbed land.
- To determine the utility of a few selected geographical information system (GIS) methods in determining connectivity and fragmentation of forested and undisturbed land without animal data.

1.3 Study Area

The study area, which spans between RMNP and DMPPF, is approximately a 25-kilometer strip of land (NCC, 2008) with the edge of the mountains providing the boundary. This study area is situated in western Manitoba between the Manitoba-Saskatchewan border and Lake Manitoba-Lake Winnipegosis (Province of Manitoba, n.d.). In this section, the two park areas will be described, as well as the area between to provide the context for the corridor. The area between RM and DM is highly developed, particularly with agriculture.

The Parkland region is utilized commercially for livestock, grain production and other agriculture (Brierley & Todd, 1990). Also mining, hydroelectricity and forestry are other ways that serve to diversify the Manitoba economy (Hum & Simpson, 2009; Wellstead, 2007).

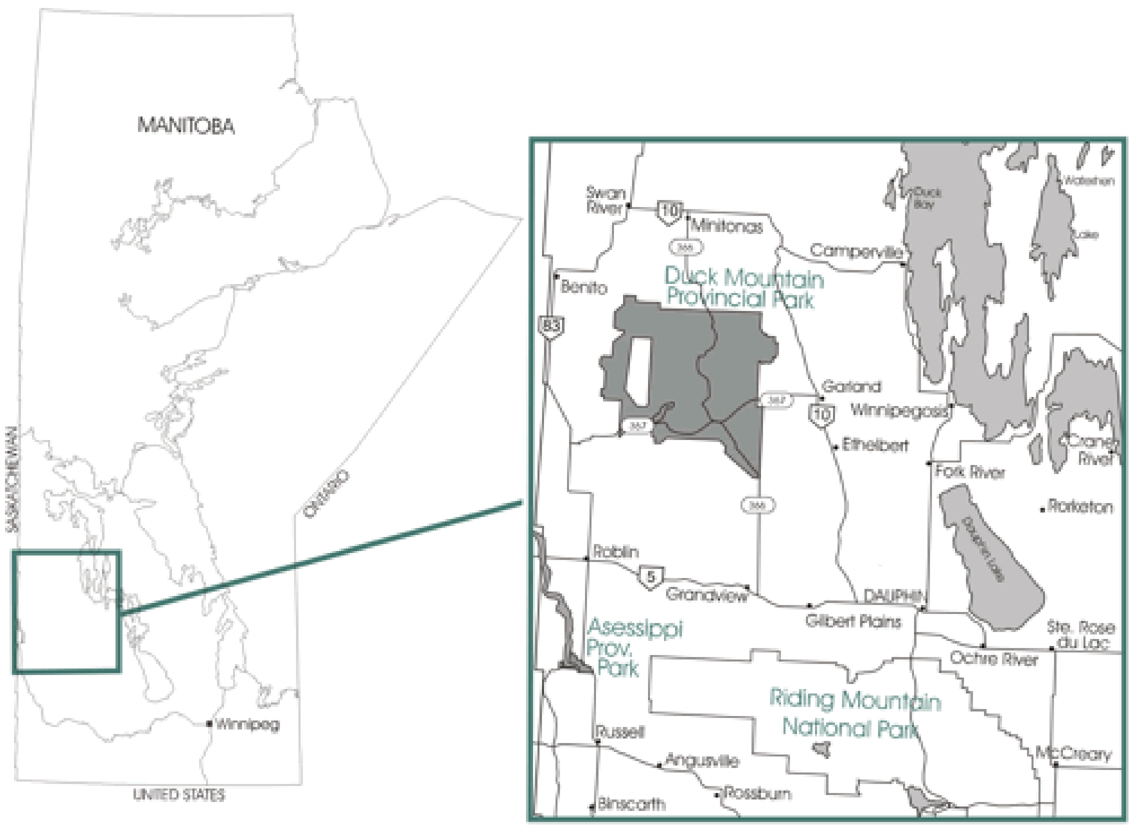

Figure 1: The Area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest in a larger Context (Manitoba Conservation, 2007)

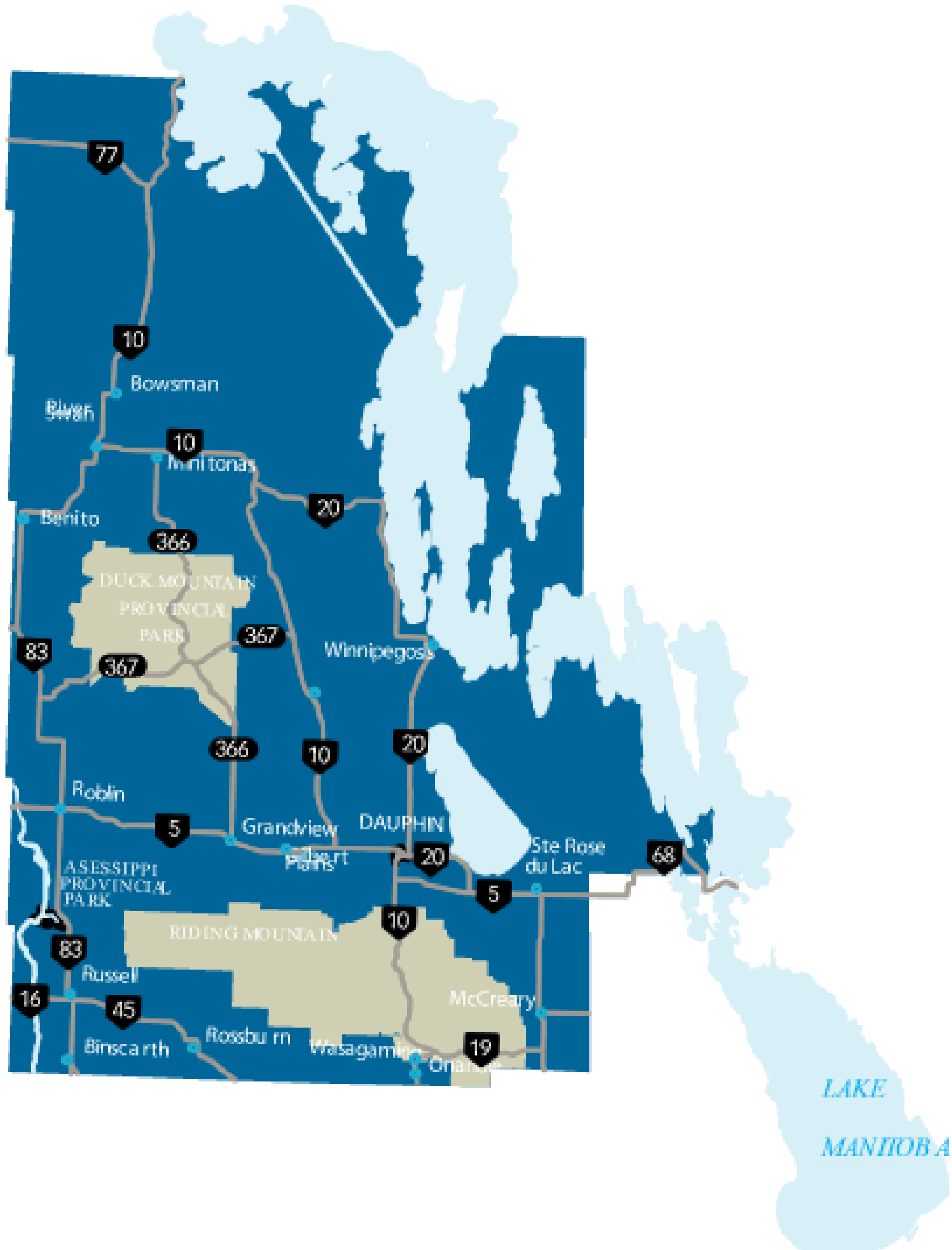

Figure 2: Detailed Map of between Riding Mountain National Park and Duck Mountain Provincial Park and Forest shown within the Parkland Region (Watchable Wildlife, n.d.).

1.3.1 Corridors between Riding Mountain National Park and Duck Mountain Provincial Park and Forest

Two potential corridors exist between the mountains, namely the Rose Ridge (RR) Corridor (also known as the Grandview corridor) and the Bluewing (BW) Corridor (Aidnell, 2006; CPAWS, 2004; NCC, 2008). These two potential corridors lack data to characterize their biodiversity or connectivity. They are situated in the rural municipalities of Hillsburg, Shellmouth-Boulton and Grandville (Figure 1, Figure 2, Figure 3 and Figure 4). The BW Corridor is on the west side almost touching the Manitoba-Saskatchewan border. In contrast, the RR Corridor is to the east, adjacent to a First Nation Indian Reserve. Both the RR and BW corridors have distinct forest cover and habitat (NCC, 2008), and allow wildlife travel such as wolves, moose and elk (Aidnell, 2006; Brook, 2008; Charney, 2006; NCC, 2008). However, scientific analysis of their connectivity and fragmentation or biodiversity has not occurred (Cary Hamel, NCC, personal communication, October 18, 2009).

These potential corridors have been the focus of conservation efforts between DMPPF and RMNP by Nature Conservancy of Canada (NCC) and Parkland Habitat Partnership (PHP), thus appearing to have the most visible remaining habitat that are clustered together on the map (Figure 3 and Figure 4). The PHP, made up of multiple private enterprises and government agencies, work together to preserve habitat and biodiversity. This partnership is interested in connectivity in this region (PHP, 2009). The PHP is actively conserving and restoring land between these two mountains but needs a study to verify strategic habitat choices. This study will assist the PHP effort by identifying corridors where land strategically selected to increase connectivity between RM and DM. Undisturbed and forest habitat remain between them but whether this provides a continuous corridor connecting these two areas is uncertain.

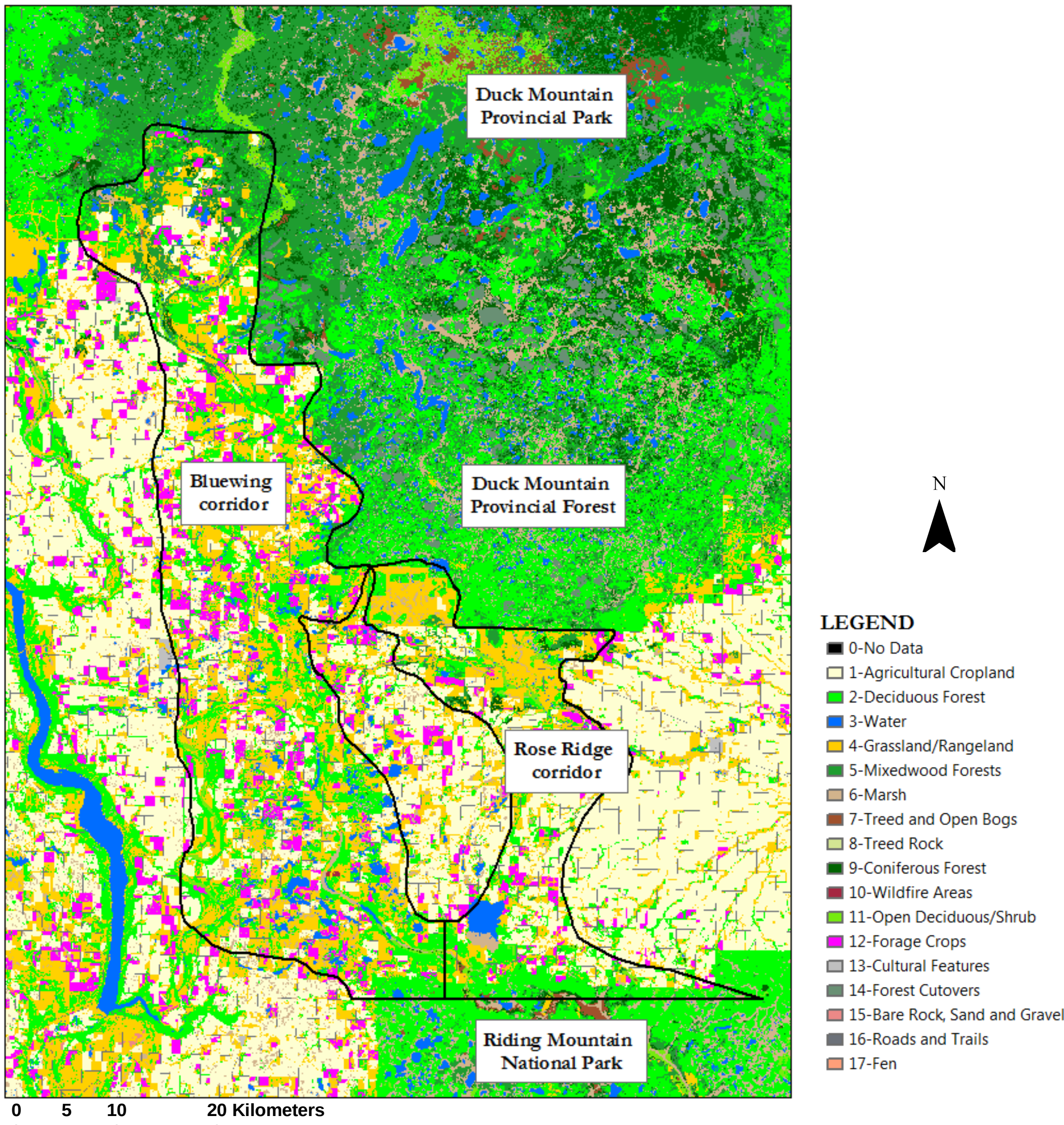

Figure 3: Map showing the Unofficial Bluewing (left) and Rose Ridge (right) Corridors (NCC, 2009; Manitoba Remote Sensing Centre, 2004).

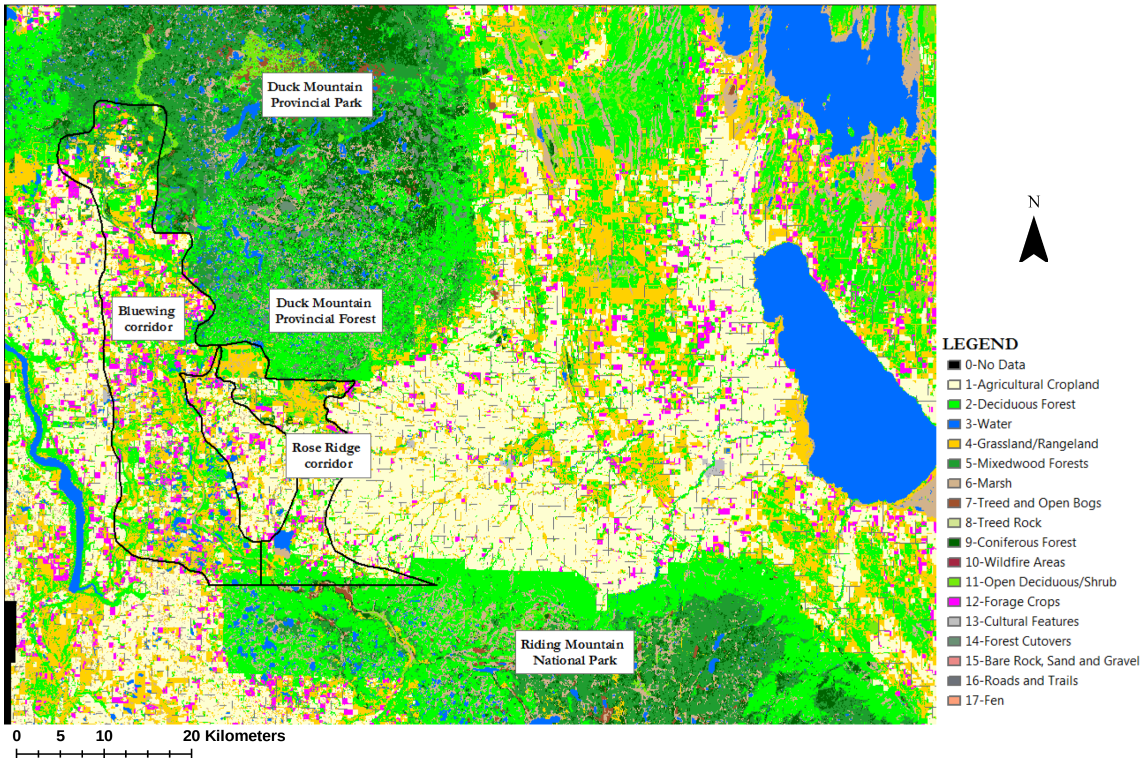

Figure 4: The Study Area to explore Connectivity between Riding Mountain National Park and Duck Mountain Provincial Forest and Park.

1.3.2 Aspen Parkland

Aspen parkland refers to a very large area of transitional biome between prairie and boreal forest. Aspen poplar trees and spruce trees are interspersed with prairie grasslands (Hogg & Hurdle, 1995; World Wildlife Fund, 2001). The majority of aspen parkland in North America is in Canada spreading over the provinces of British Columbia, Alberta, Saskatchewan and Manitoba, including a small portion in the United States (Olson, 2000). This area referred to as the "boreal forest prairie transitional zone" is the largest in the world and contains important habitat for waterfowl breeding (Ricketts et al., 1999). In the aspen parkland eco-region, less than 10% of the original habitat remains intact (World Wildlife Fund, 2001).

In Manitoba, the Riding Mountain aspen parkland is one of the few areas with ecological function and integrity (NCC, 2008) in a world that is quickly developing. The land surrounding the park has been transformed into agriculture cropland and grazing land over the years. Besides agricultural development, other changes to this area include invasive species, natural water flow, woody vegetation encroachment, fire management and climate change (NCC, 2008).

1.3.3 Riding Mountain National Park

Wapusk National Park and RMNP are the only two Manitoba national parks under the control of the federal government. Unlike Wapusk National Park, RMNP is located on the Manitoba Escarpment. The land that surrounds RMNP is mainly agriculture or prairie farmland and was once forests or grasslands (Caners & Kenkel, 2003; UNESCO, 2007). In 1986, RMNP was designated a biosphere reserve by UNESCO (UNESCO, 2007). RMNP has grassland that once occurred throughout southern Manitoba. Since the European settlement in the late 19th century, transformation has happened to this land. Today, the region supports a rural agricultural economy. The economy also benefits from tourists attracted by the national park (UNESCO, 2007).

The park is made of boreal forest with meadows and lakes in Manitoba's prairie landscape covering 3,000 km^2. RMNP is on the Manitoba Escarpment with gorges, hills and valleys. The park is home to a range of vegetation communities along with birds, mammals, fish and butterflies species adapted to the mixed wood forests containing aspen, spruce and popular (CEAA, 2004; Parks Canada, 2007). The vegetation communities include grasslands dominated by rough fescue (UNESCO, 2007). Wolves, moose, elk, black bears, hundreds of bird species and a captive bison herd are present in this park. The genetic isolation of wolves is a concern for this park (Fritts & Carbyn, 1995). Research on wolves (Stronen, 2009) and elk (Brook, 2008) in RMNP and its outskirts found that these species migrate out of the park. Wildlife often roam outside of park boundaries into nearby agricultural areas, which may put them at risk (Forbes & Theberge, 1996).

1.3.4 Duck Mountain Provincial Park and Forest

Duck Mountain Provincial Park (DMPP) is another conservation area located on the Manitoba Escarpment. In early 1900s, DMPP became an important source of timber with both portable and fixed lumber mills operating within the park area. The landscape consists of rolling hills, forest, wetlands and upland meadows (Manitoba Conservation, 2007).

Like RMNP, DMPP provides a refuge for various wildlife mainly large animals. Examples are moose, black bear, white-tailed deer, lynx, coyote and grey wolf (Manitoba Conservation, 2007). Outside of the park boundaries, the conversion of native prairie and forest to agriculture, along with livestock grazing, has caused not only a reduction in land cover, but also forest fragmentation and reduction in habitat size (Merriam, 1988). Duck Mountain Provincial Forest (DMPF) has an area of 3370 km^2 and DMPP has an area of 1424.3 km^2 (Parkland Agricultural Resource Co-op, n.d.), amounting to almost 5000 km^2. Inside the DMPF on-going logging operations occur with some logging also allowed inside DMPP, although described as "minimal" (Parkland Agricultural Resource Co-op, n.d.). Within DMPF, there is a variety of hardwood and softwood trees including trembling aspen, balsam popular, white spruce, balsam fir, jack pine, black spruce, tamarack bogs, white elm, green ash, birch, Manitoba maple and bur oak (Parkland Agricultural Resource Co-op, n.d.; White et al., 2005). North of DMPP is Porcupine Provincial Forest rich in boreal forest with a range of wildlife habitats (Swan River Chamber of Commerce Tourist Bureau, n.d.).

CHAPTER 2: LITERATURE REVIEW

As part of this literature review regarding the potential for a corridor between RM and DM, the key terms and topics of the objectives were reviewed and defined, namely corridors, connectivity, fragmentation and geographical information system (GIS) methods. In addition, the terms biodiversity, habitat, development and conservation were defined and examined in relation to connectivity, fragmentation and corridors. An intensive review and analysis of GIS methods applied to corridors and connectivity was also undertaken.

2.1 Biodiversity

Biodiversity is the variation among as well as within plant and animal species in an environment (Fischer & Lindenmayer, 2007). Biodiversity is inversely related to habitat fragmentation and positively related to connectivity (Fischer & Lindenmayer, 2007).Therefore, the loss of native vegetation generally reduces native species diversity (Fischer & Lindenmayer, 2007).

Patch size is the key predictor of species diversity within a patch (Forman & Godron, 1981). Smaller patches of vegetation cannot support as many species as larger patches resulting in less biodiversity. Even though large patches have many benefits, smaller patches can complement larger patches of vegetation by providing certain habitat conditions not available in larger patches of vegetation (Fischer & Lindenmayer, 2007).

Larger patches or habitat corridors provide more and greater variety of resources for the survival of different species (Kindall & Manen, 2007). Dale and Gignac (2007) examined the size and shape of patches of upland boreal mixed-wood forest in Alberta. They found plant species diversity and abundance increased at a patch size of 11 hectares or more. Herkert (1993) recommended that patches should be at least 50 ha (125 ac), and preferably 100 ha (250 ac) for grassland and forest bird species most sensitive to habitat fragmentation. Since fragmentation can decrease the average patch size, smaller patches may be much more risky to species when less resources are available (Rutledge, 2003).

Biodiversity is an issue in the RMAP area. The threats to biodiversity and species habitat outlined by NCC in the Riding Mountain Aspen Parkland Conservation Plan include land conversion, invasive species, grazing practices, problematic native species and climate change (NCC, 2007). In particular, agriculture expansion has caused forest fragmentation and wetland drainage to convert to agricultural uses (NCC, 2007). Walker (2002) noted a gradual increase in forest fragmentation over time from the 1950s to the 1990s by viewing aerial images, mainly in the central region. Furthermore, native grassland exists only in a few remaining areas such as inside RMNP (NCC, 2007).

Conservation efforts are made to maintain the diversity in the ecosystems (Lindenmayer et al., 2006). Conservation can effectively promote both management of natural resources and preserve biodiversity ecologically and sustainably (Fischer & Lindenmayer, 2007). Forest biodiversity conservation includes maintaining connectivity of habitats and communities, while sustaining ecological processes. Habitat represents the different environments at multiple spatial scales suitable for species to occupy (Fischer & Lindenmayer, 2007). Habitat patches contain living and non-living elements with both ecosystems and resources. A variety of habitats are crucial to the survival of more than one species in forests, wetlands and other types of ecosystems (Rutledge, 2003).

Development typically has the opposite impact on biodiversity as conservation. It can remove natural habitat as well as can decrease the total suitable habitat area for wildlife thus changing the habitat composition (Tomimatsu & Ohara, 2006). However, development can also result in fragmentation and loss of habitat thereby reducing biodiversity (Fischer & Lindenmayer, 2007; Tomimatsu & Ohara, 2006). The landscape matrix is an area of unsuitable habitat between two patches. These gaps are usually the result of habitat fragmentation (Joly et al., 2003). Although the landscape matrix is not a preferred habitat for the survival of species, yet this matrix may still be adequate for survival if adjoining areas are suitable. In certain areas, native vegetation may be structurally similar within patches that can provide some connectivity, which may benefit species (Fischer & Lindenmayer, 2007).

2.2 Habitat Fragmentation

Habitat fragmentation and habitat loss present significant threats to wildlife survival and biodiversity (Fischer & Lindenmayer, 2007). Fragmentation can: l) reduce habitat into individual fragments or patches that are smaller than the original habitat, 2) alter the quality of habitats and create spatial isolation between species populations potentially resulting in extinction (Tomimatsu & Ohara, 2006), 3) undermine all taxonomic or classified groups of plants and animals at different trophic levels, 4) reduce the quality of the landscape leading to many different responses from species, and 5) diminish the ability of species to move between suitable habitats in the landscape (Fischer & Lindenmayer, 2007; van Nouhyus, 2005).

Fragmenting suitable habitat creates patches with newly formed edges or boundaries that can affect biodiversity. Edge effects have the following characteristics, having: l) boundaries with potential exposure to landscape matrix and environmental changes in both biotic as well as abiotic conditions, 2) shared adjacent patches of vegetation (Fischer & Lindenmayer, 2007), 3) unique habitat conditions often different from the core of the habitat patch (Aurambout et al., 2005), and 4) exposed areas for prey in a species population to a large number of predators (Aurambout et al., 2005).

A few GIS studies (Aidnell, 2006; Charney, 2006) found the area between RM and DM to be fragmented for wolves and ungulates. However, in this study area, fragmentation reduces the size of habitat patches, isolating populations of different species within them, potentially resulting in extinction (Tomimatsu & Ohara, 2006). Aidnell (2006) and Charney (2006) found the RMNP area to be fragmented for wolves and ungulates respectively. Aidnell (2006), Charney (2006), Brook (2008) and NCC (2008) explained that wolves, moose and elk had been found to travel and breed in the area between RM and DM as well as would benefit from a corridor. Fragmentation reduces the size of habitat patches and increases the isolation of the populations within them, potentially resulting in extinction due to stochastic processes.

Habitat fragmentation, being a complex topic, is an important area of study and can be done in more than one way. There are two common ways to study habitat fragmentation (Fischer & Lindenmayer, 2007). The first way is to research the individual species and their interactions with both their habitats and ecosystems. The different migratory birds, native prairie birds and mammals residing in RMNP and DMPPF that require a large home as well as migratory range are impacted by connectivity (NCC, 2008). Each species could be tracked for their movement to determine appropriate corridors. However, studying all the individual species is impractical for determining impacts of fragmentation with available technologies (Fischer & Lindenmayer, 2007). Another way to study fragmentation is to focus on the interpretation of landscape patterns correlated with species diversity and richness, founded on the principles of island biogeography (Fischer & Lindenmayer, 2007). Landscape pattern models, such as the patch-matrix-corridor model and variegation model, actually involve land cover (Fischer & Lindenmayer, 2007). By definition, these models objectively compare species data to find potential and ecological damage as well as to simplify complex ecological processes (Fischer & Lindenmayer, 2007).

2.3 Connectivity

Connectivity exists at multiple scales. Fischer and Lindenmayer (2007) described the complexity of connectivity identifying three scales: 1) Habitat connectivity is the linkage between habitat patches suitable for a particular species studied at the patch or landscape scale, 2) Landscape connectivity involves subjectively interpreting the linkage of native vegetation in the landscape, and 3) Ecological connectivity focuses on the linkage between ecological processes at different scales. However, habitat or patch isolation is the opposite of connectivity. The conversion of natural land to agriculture and other uses is a dominant trend. Resource managers have been trying to use landscape connectivity to protect and conserve wildlife (Kindall & Manen, 2007). Isolation refers to the spatial distance that one habitat patch is separated from the other, which negatively impacts animal movement (Bender et al., 2003). Creating a corridor to conserve species is a long-term process since connectivity can only decrease with constant land development.

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2.4 Corridors

Corridors can be used as a management strategy to increase biodiversity and connectivity. Corridors may be designed for habitat or travel. However, corridors are commonly divided into two types: 1) travel corridors providing only sufficient and temporary habitat for animal movement, and 2) habitat corridors consisting of a chain of habitat patches to provide enough resources for species survival and to promote movement between patches (Kindall & Manen, 2007). A corridor for wildlife movement is defined as a route that protects preferred habitat used for animal movement (Parks Canada, 2012). Permeability is a term often used in association with landscape wildlife movement and emphasizes the capacity for animal movement in the landscape (Harris & Hazen, 2006).

A corridor has many purposes. This multipurpose aspect is clear in its different descriptions. A corridor is a strip of land that can: l) connect two or more similar habitat patches with different land compositions from the surrounding matrix (Kindall & Manen, 2007), 2) restore connectivity between isolated natural habitat areas and facilitates wildlife movement (Fleury & Brown, 1997; Vogt et al., 2009) along with seed and pollen dispersal for plants (Drielsma et al., 2007), 3) minimize habitat fragmentation, 4) place less strain on isolated habitats, 5) decrease the risk of extinction, 6) increase the size of wildlife habitats, and 7) maintain biodiversity (Hess & Fischer, 2001).

Corridors are important for connectivity but also can create risks for negative outcomes. Corridors may result in the following negative outcomes: 1) increase mortality from vulnerable species attracted to the edge of habitats, 2) supersede other conservation options with lower costs that may be more beneficial like increasing core protected area management or size, 3) spread processes such as disease or wildfire and harmful species among protected areas, and 4) favor highly adaptable and mobile species over at-risk or sedentary species (Spencer, 2005). Other factors that influence corridor success include: 1) overall corridor integrity, 2) species sensitivity, 3) habitats, 4) corridor width, 5) corridor length, and 6) the ability for animals to move in the landscape (Parks Canada, 2012; Vogt et al., 2009).

By protecting a network of corridors, the requirements of most species can also be met. That could be done over a wider area rather than just connecting a corridor for a specific species and habitat (Parks Canada, 2012). Enlarging habitat patch size is also beneficial to isolated habitat patches in certain situations (Falcy & Estades, 2007). Falcy and Estades (2007) compared the effectiveness of corridors to enlarging habitat patches. They found that, in some cases, enlarging habitat patch size is more effective than corridors. As a rule, larger habitat patches are especially beneficial once a patch surpasses the minimum size of a habitat (Dale & Gignac, 2007; Herkert, 1993).

2.5 Studies of Landscape Connectivity and Fragmentation or Corridor with GIS

The literature on habitat connectivity and fragmentation was carefully reviewed to identify the different methods and indices. Table 1 includes 14 studies that have connectivity or fragmentation findings. For these 14 studies each study has a list of species studied, description of methods applied for connectivity and corridors with key findings in Table 1.

Habitat connectivity and fragmentation was an aspect in each of 14 studies in Table 1. However these studies represent a diverse sample of existing literature regarding habitat connectivity and fragmentation. Some studies analyzed the biodiversity of plant species (Beier & Noss, 2008; Brudvig et al., 2009; Galpern et al., 2010; O'Brien et al., 2006). Corridors were found to benefit biodiversity in areas surrounding corridors for plant species by connecting patches in the landscape and by promoting species richness (Adriaensen et al., 2003; Beier & Noss, 2008; Brudvig et al., 2009; Damschen et al., 2006; Galpern et al., 2010; Goetz et al., 2009; Hannon & Schmiegelow, 2002; O'Brien et al., 2006; Pinto & Keitt, 2009).

Spatial graphs (SG) were the most popular method applied for the connectivity and fragmentation studies reviewed. James et al. (2007) applied SGs to show landscape connectivity, support forest management and plan reserve networks. (Damschen et al., 2006; Goetz et al., 2009; James et al., 2007). Fall et al. (2007) assessed habitat connectivity using SGs, for its utility in conservation.

Some studies show how management decisions are completed at both the patch and landscape scales. Rayfield et al. (2008) used a GIS program called MARXAN program to simulate and examine the effects of static and dynamic protected areas. Goodwin and Fahrig (2002) used a simulated and experimental landscape to study connectivity and the structure of habitat patches. SGs methods were applied to determine inter-patch distance, landscape characteristics and potential species movement (Adriaensen et al., 2003; Galpern et al., 2010; Goetz et al., 2009; James et al., 2007; Pinto & Keitt, 2009; Urban & Keitt, 2001). Both least-cost paths (LCP) and SGs were used to simulate functional connectivity in particular the movement of a theoretical animal, and actual movement of species between patches in an agricultural landscape (Adriaensen et al., 2003; O'Brien et al., 2006; Pinto & Keitt, 2009). Urban and Keitt (2001) also defined terminology and application of graph theory for landscape ecology and explains the basis of SG modeling. Please see Table 1 for more information.

Table 1: Literature Review of Landscape Connectivity and Fragmentation or Corridor Applying Geographical Information System

No.	Study	Study area	Focal Species	Method	Connectivity/Fragmentation Application? (Yes/No)	Corridor Application? (Yes/No)	Findings
1	Adriaensen et al. (2003)	Hoge en Lage Rielen, Belgium	None - an agri-cultural land-scape	LCP path modeling	Yes – used LCPs to simulate functional connectivity on movement of a theoretical organism between patches in an agricultural landscape.	Yes – applied LCPs in a virtual landscape to determine connectivity.	LCPs were found to be useful to model inter-patch distance, testing scenarios between landscape characteristics and potential species movement.
2	Beier and Noss (2008)	N/A	N/A	Literature review	Yes – proposed questions and assumptions that should be included in designing corridors.	Yes – identified issues in designing corridors and possible questions/ assumptions.	Designed models for corridors between 2 or more patches using 16 key questions/assumptions. Suggested 1) designing corridors to have connectivity that benefits more than one focal species, and 2) creating separate corridor models for species that take different times to move through corridors.

3	Brudvig et al. (2009)	South Carolina, United States	Pine forest	Field study	Yes – designed corridors to focus on the connectivity of plant species and to measure species richness for both animal-dispersed and wind-dispersed.	Yes – tested corridor and edge effects using man-made corridors inside a forest.	Corridors increased species richness in favorable patches. This also increased the biodiversity of plant species in non-favorable patches surrounding favorable patches.
4	Damschen et al. (2006)	South Carolina, United States	Longleaf pine forests	Field study	Yes – examined corridors considering connectivity and fragmentation.	Yes – tested corridors effect on plant species richness using man-made corridors inside a forest.	Corridors increases plant species richness than having isolated forest patches. Findings Supports corridors as a management tool that increases plant species richness and preserve biodiversity.
5	Fall et al. (2007)	Manitoba	Wood-land caribou	SG modeling	Yes – assessed habitat connectivity using SGs.	No	Applied SGs to assess habitat connectivity.
6	Galpern et al. (2010)	N/A	N/A	Literature review	Yes – reviewed studies that used SGs to model connectivity of habitat patches.	Yes – SGs can determine corridor quality by adding/removing of patches or paths to identify important patches and paths	SGs have been used to find areas in the landscape that are connected and highly connected to compare connectivity between SGs to find important patches for connectivity as well as to find

							important paths among patches.
7	Goetz et al. (2009)	Northeastern U.S.	N/A	SG modeling	Yes – examined connectivity of core habitat with emphasis on parks and protected areas using SGs. Used SGs and connectivity metrics to analyze landscape connectivity of core habitat for management and potential easements	Yes – generated LCPs that show potential corridors between core habitats.	This study showed the need for core habitat nearby to parks and protected areas. Undeveloped habitat were found to be important for connecting parks and protected areas which otherwise are isolated from other areas with increasing pressure from urbanization.
8	Goodwin and Fahrig (2002)	N/A	T. borealis beetle	Field study	Yes – studied structural connectivity of patches and the area between patches by using actual species movement to review patch are distribution and importance in the landscape.	No	The spacing of patches in the landscape was found to be more important than what is between habitat patches. Landscape connectivity and landscape structure were found to be interrelated. Thus, a landscape with a large distance between patches and habitat loss reduces connectivity.

9	Hannon and Schmiegelow (2002)	Central Alberta	Various boreal forest birds	Field study	Yes – carried out man-made logging to examine isolated or connected corridors forest reserves. Found that connecting small forest reserves in corridors may not be enough to offset existing fragmentation for boreal birds	Yes – found that corridors may not benefit the species richness of most boreal birds after logging	Birds may not be the best to use as primary species in designing a corridor. Instead a broader view of plant and animal communities should be examined.
10	James et al. (2007)	Quebec	Boreal forest	SG model-ing	Yes – used SGs to show landscape connectivity. In particular, support forest management and plan reserve network at the landscape scale.	No	Found SGs effective to show forest patch and landscape connectivity of forest habitat.
11	O'Brien et al. (2006)	Southeastern Manitoba	Wood-land Caribou	SG model-ing	Yes – used global positioning system (GPS) telemetry location points and SGs to determine connectivity.	Yes – shows the importance of the spatial configuration of patches in the landscape. It also favors the use of SGs to examine habitat connectivity and can be used to find potential corridors and keys areas where	Found areas with a number of clusters of highly connected habitat in SGs actually contained Woodland caribou from telemetry points that made up of their home range. Demonstrated the difficult task of modeling functional connectivity using a

						connectivity is important for woodland caribou.	simple yet informative method.
12	Pinto and Keitt (2009)	Brazil	Brazilian Atlantic forest	LCP and SG modeling	Yes – evaluated connectivity by generating potential wildlife movement paths using multiple LCPs and SGs in simulated and actual landscapes using the different methods.	Yes – corridors were found. Corridor width and the number of paths generated were evaluated using multiple LCPs and SGs.	Found that in a simulated landscape, the distribution of suitable habitat can affect where potential wildlife dispersal routes are under different costs and lengths of LCPs. When comparing different methods, multiple routes (e.g. SGs) are better than one optimum route (e.g. LCP) because alternate paths with similar costs may be available. Furthermore, clusters of favorable habitat can form many dispersal routes that can be reduced to only a few routes in a larger scale.
13	Rayfield et al. (2008)	Quebec	Ameri-can marten	MARXA N (Another GIS modeling	Yes – used the MARXAN program to simulate as well as examine the effects of static and dynamic	No	The quality of the matrix between habitat patches should be managed for future planning of protected areas. Also,

				tool for conserv-ation planning of protected areas and reserves) (The University of Queensland, 2012)	protected areas. Dynamic had higher connectivity than static protected areas in SGs because of higher connectivity among home ranges.		dynamic compared to static protected areas were better because it includes higher quality home ranges. While static protected areas were constantly effected by forest fragmentation outside of protected areas
14	Urban and Keitt (2001)	4 states in Southwestern USA	Mexican Spotted owl	SG modeling	Yes – explained how SGs can be generally used to assess individual patches and landscape connectivity as a whole.	No	Defined terminology and application of graph theory for landscape ecology to explain the basis of SG modeling.

2.6 Geographical Information System Metrics Applicable to Connectivity

GIS metrics offer considerable information for decision-making, regarding landscape analysis of connectivity. However, landscape metrics produce a single value that may not represent a complex landscape and structural connectivity accurately. This single value can lead to misleading results (Gustafson, 1998; Tischendorf, 2001). Using metrics to model connectivity creates different results and insights than those collected out in the field (Goodwin, 2003). Modeling is good at showing complex relationships between different connectivity metrics that are not present in field data. Therefore, modeling and field studies are often used independently. The use of different connectivity metrics may not be that easily comparable by statistical analysis (Goodwin, 2003), although multiple metrics should be compared to consider multiple aspects of connectivity.

Landscape metrics and patch statistics provide insight into habitat connectivity and fragmentation (Li et al., 2005; Magle et al., 2009; Riitters et al., 1995). Landscape metrics also help to determine patch connectivity, mainly when there is no field data to measure movement, connectivity or fragmentation (Magle et al., 2009), when comparing with the data in this thesis. Landscape metrics can describe the landscape in different ways and themes (Rutledge, 2003). Landscape metrics include: 1) composition (e.g. abundance, diversity, evenness and richness), and 2) configuration (e.g. patch area, edge, shape complexity and core area). There are two broad types of landscape metrics: 1) non-spatial metrics that focus on landscape patterns such as total number of patches and proportion of total area for each land cover class, and 2) spatial metrics that emphasize patch characteristics, connectivity or distance between patches and fragmentation by measuring patch composition, shape and configuration (Rutledge, 2003). Many metrics are interrelated (e.g. patch's edge effects, connectivity and patch sizes). Multiple metrics of connectivity exist without any single one being the best metric (Calabrese & Fagan, 2004). Factors, such as disagreement over definition, measurement, complexity of results and data requirements, make it difficult to choose a perfect measure. However, the study acknowledges that graph theory methods provided the most significant data to enable decision-making (Calabrese & Fagan, 2004).

In order to generate metrics easily, a few common programs can be used to generate a variety of statistics about the landscape (Turner, 2005). FRAGSTATS is a standalone computer program. Both Patch Analyst and Patch GRID are different ArcGIS versions of FRAGSTATS. The statistics about the landscape generated include: total number of patches, mean patch size, total edge density and aggregation index. These are indicators of biodiversity which can measure connectivity at the class and landscape levels (Li et al., 2005). Another simple method of measurement is the use of Euclidean Distance (ED) or so-called "nearest neighbor measurement". However, ED cannot measure connectivity. Rather, it is the shortest direct distance between two points. Even though the "nearest neighbor distance" is often used to evaluate patch isolation, clearly the single nearest patch may not fully represent the ecological neighborhood of the focal patch (Bender et al., 2003; Moilanen & Nieminen, 2002). However, measuring connectivity between patches using ED ignores the behavior of migrating species, due to focusing on structural connectivity rather than functional connectivity (Taylor et al., 2006). Functional connectivity can instead be measured through the use of least-cost distances (Adriaensen et al., 2003; Bunn et al., 2000; Drielsma et al., 2007; Nikolakaki, 2004). Various studies have shown least-cost distances to be a better measure of connectivity than ED (Chardon et al., 2003; Coulon et al., 2004).

The LCP is one method to determine connectivity. The LCP can be interpreted as: 1) the best possible route between two points influenced by the criteria or non-monetary cost (LaRue & Nielsen, 2008), and 2) the measure of isolation based on the distance between two points (Broquet et al., 2006). In a LCP model, the landscape matrix is the area between the patches that is broken down into cells in a grid with each having a specific resistance value or cost. Certain land cover types are less traversable to some species than others. Therefore, cells containing these cover types are assigned a higher cost (Brooker et al., 1999).

Although LCPs are the theoretical best routes for a species to travel, these paths may not be used in real-life. The path of a species through a landscape involves multiple decisions at each point in the route (Brooker et al., 1999). Thus, trying to accurately to predict the path by using a simple model with only a few variables is quite difficult. However, least-cost distances are considered more likely to provide highly accurate distance between patches than ED (Chardon et al., 2003; Coulon et al., 2004). Both are considered to represent a viable first step towards measuring functional connectivity. However, this LCP approach is more acceptable for screening and comparative purposes (Lin, 2008).

LCPs can be applied to a species. An umbrella species is used in order to reflect the connectivity requirements of different species guilds (i.e. aquatic, terrestrial, avian). This method is most robust but can potentially add a considerable amount of time to the analysis. It also requires information on dispersal characteristics for multiple species (Lin, 2007). There are numerous LCP studies of wildlife on studying the landscape and for conservation, genetic flow and potential corridors. Examples of wildlife studies are the Siberian flying squirrel (Hurme et al., 2007), blotched tiger salamander (Spear et al., 2005), the Florida panther (Kautz et al., 2006) and ungulate species between RMNP and DMPF (Charney, 2006).

Charney (2006) assessed ungulate habitat from DMPF all the way to Spruce Woods Provincial Park. The study evaluated habitat suitability and landscape permeability in the region by providing LCPs for potential movement routes and priority areas for conservation. The results in Charney (2006) showed that the region surrounding RMNP had a highly fragmented landscape, but carried a few patches of suitable habitats available for long distance movement by wildlife. Based on ungulate movement suitability for areas surrounding RMNP, the area between RMNP and DMPF was the least fragmented, while the most fragmented happened to be southwestern RMNP. Charney (2006) carried out a LCP analysis between RM and DM for ungulates and found the RR corridor as a potential corridor.

Typically, although the LCP is used for one species analysis, yet it can also be used for conservation and land use pattern data. LCP models have also been used to examine functional connectivity in the landscape and to explain how landscape structure can affect wildlife movement (Adriaensen et al., 2003). The LCP model generally includes three criteria: l) the cost surface, 2) the total cost from one point to another, and 3) the path direction (Parunak et al., 2006). When wildlife is involved, the cost in LCP models considers certain factors. These can influence habitats quite suitable and sensitive for species movement. For example, the type of vegetation present in an area can affect LCP (Kautz et al., 2006). Water and land use data are also perfect examples of major factors for inclusion in the cost surface for movement. Finally, barriers to animal movement includes logging, land use, water, roads, agricultural land and power lines (Broquet et al., 2006; Manitoba Remote Sensing Centre, 2004). However, LCP is not always used as a created cost surface for an animal to move on. Aurambout et al. (2005) used a fictional animal species instead of actual collected animal movement data. Since all species do not react to habitat fragmentation the same way, Aurambout et al. (2005) used a test species to get the general view of habitat requirements for species sensitive to habitat fragmentation. Criteria for the fictitious species include: 1) avoidance of any land where there is human disturbance, 2) inability to cross a river, and 3) ability to move through unsuitable habitat. Therefore, the LCP model is a straightforward and well-known approach for landscape conservation. LCPs, on the other hand, only shows one path and ignores alternative paths that can be more costly (Urban et al., 2009).

SGs are based on the graph theory. This theory has been used in other disciplines, such as computer and mathematics, for a long time to connect different nodes by lines or links. In landscape ecology, SG use the principles of the graph theory to offer a simple yet robust way of examining habitat connectivity and patches in the landscape (Urban et al., 2009). The SG model consists of nodes that represent habitat patches or local population of species. The lines or links represent LCPs to connect habitat patches and local species population. All of these together form highly connected clusters, which represent functional connectivity to show potential flow, and frequency of movement between patches at the regional scale (Urban et al., 2009).

In SGs, some of the ways the relationship between patches could be examined are: 1) the interaction between populations (metapopulation) for instance the movement from a productive patch or nearby patches to less productive ones to prevent extinction (the source-sink model, and the long-distance rescue or spreading-of-risk model) (Moilanen, 2011; Urban et al., 2009), and 2) patches that facilitate movement in the landscape between destinations (the stepping-stone model) (Pereira et al., 2011). SGs can be used to simulate animal behavior in different habitat compositions and configurations (Fall et al., 2007). This can be useful for multispecies conservation to plan parks and protected areas. Planning is done by overlaying or intersecting multiple graphs to find shared patches and LCPs preferred by multiple species (Urban et al., 2009). Although SG has many advantages, it simplifies a complex landscape. In order to compensate for generalization researchers often use SGs as an initial step along with other modelling methods (Bunn et al., 2000). SGs have been used with animals such as the woodland caribou around a national park in central Manitoba (Fall et al., 2007), spotted owl (Urban & Keitt, 2001) and marine species (Treml et al., 2008). SGs also have been: 1) used to find habitat connectivity in fragmented landscapes (Minor & Urban, 2008) including fragmented agricultural landscapes (Bodin & Norberg, 2007), 2) altered to find important habitat patches and corridors for conservation (Pascual-Hortal & Saura, 2006), and 3) used to find important areas surrounding protected areas for conservation that is essential for connectivity between protected areas in the United States (Goetz et al., 2009).

Although SGs simplify the actual landscape and its features, SG analysis is a good compromise that reflects both structural and functional connectivity (Fall et al., 2007). In addition, SGs also turn complex configurations of landscape features into something more understandable to find patterns of movement between patches, thus showing connectivity in the landscape (Cantwell & Forman, 1993; Urban et al., 2009). Conveniently, SG does this with little data without requiring any long-term species population data that can be applicable at any scale (Bunn et al., 2000). For example, in analyzing the landscape that focuses on patch, corridor and matrix, the following SG results can be observed: 1) common and uncommon patterns, 2) least and most connected elements including the relationship between different elements, and 3) any association between SGs when compared with other modeling methods (Cantwell & Forman, 1993).

2.7 Conclusion

This literature review explained the needs of patch connectivity and corridors for biodiversity. Landscape conservation literature showed the importance of maintaining ecosystem integrity and the need for corridors to prevent fragmentation. A review of different GIS studies on habitat fragmentation and connectivity provided an analysis of the different methods available.

Both RMNP and DMPPF are surrounded by agricultural activity with limited habitat for many species (CEAA, 2004; Manitoba Conservation, 2007; NCC, 2008; Parks Canada, 2007). As mentioned in the introduction, corridors can work at three levels to provide: l) habitat connectivity for particular species, 2) connectivity of ecological processes at multiple scales, and 3) functional connectivity (Fischer & Lindenmayer, 2007).

A corridor, if well preserved, could truly restore connectivity between isolated natural habitat areas to potentially: 1) facilitate wildlife movement (Fleury & Brown, 1997; Vogt et al., 2009), 2) create a path for seed and pollen dispersal for plants (Drielsma et al., 2007), 3) minimize habitat fragmentation, 4) place less strain on isolated habitats, 5) decrease the risk of extinction, 6) increase the size of wildlife habitats, and 7) maintain biodiversity (Hess & Fischer, 2001). This corridor would also enable a larger region for wildlife movement for: 1) breeding, 2) enlarging home ranges, 3) finding food and water during the different seasons, 4) ensure genetic variability, and 5) maintaining wildlife populations over a wide area

(Parks Canada, 2012). Movement is required to take advantage of the species home range's available resources (Parks Canada, 2012). Therefore, by establishing and maintaining corridors of connected forested land, one could ensure landscape connectivity to provide both physical linkages and protection of the entire landscape ecological system (Rodriguez Gonzalez et al., 2008).

Chapter 3: Methods to Explore Landscape Conditions, Connectivity and Corridors

3.1 Introduction

This chapter details the many methods that were used to explore connectivity between forest patches and undeveloped land. The methods included GIS analysis by: 1) Patch GRID (PG), 2) ED, 3) LCC, 4) LCP, and 5) SG. These different GIS analysis methods were applied to answer the following questions: 1) What is the current landscape condition between RMNP and DMPPF? 2) How does connectivity compare between western, central and eastern areas between RMNP and DMPPF for forested and undisturbed land? 3) Should the BW or RR corridors be the focus of habitat conservation and wildlife corridor development?, and 4) What GIS methods were useful in determining habitat connectivity and fragmentation between RMNP and DMPPF?

These methods were applied to test the following null hypotheses: 1) Forest fragmentation and disturbance is not evident between RM and DM, 2) Potential corridors in the western area between RM and DM are not more undisturbed and forested than central or eastern areas in RM and DM, and 3) BW and RR corridors are no different in terms of forest fragmentation and disturbance than other areas.

3.2 Overview of Method

This method focused on a landscape pattern approach that considered preferred habitat to be forest or undisturbed land cover. Several methods were used to show forest and undisturbed land connectivity. Methods included analyzing metadata of the land use and land cover data (called LU/LC hereafter) in ArcGIS to find land cover by percentage (%) and then generating statistics using PG. To make the data useful, the LU/LC data was modified and processed by the following steps: 1) Reclassifying LU/LC into forested and undisturbed land, 2) Dividing the area between the two mountains into three regions – west, central and east, 3) Determining basic landscape statistics using histogram tool and PG in ArcGIS, and 4) Carrying out PG, ED, LCC, LCP and SG using optimal settings as determined by sensitivity analysis. More advanced methods including LCC and LCP were used to find the percentage of forest and undisturbed lands on each corridor identified. In addition, SGs were applied to explore the connectivity in the landscape and judge fragmentation visually and statistically. Both LCP and SGs identified potential corridors. Other programs requiring animal movement data were not considered for various reasons. Refer to Table 2 below how the objectives match with the methods in this study.

Table 2: Matching Objectives to Methods in this Study

Objectives	Method					
	Field data	**PG**	**ED**	**LCC**	**LCP**	**SG**
▪ To find the current landscape conditions between RMNP and DMPPF.	✓	✓	✓	✓	✓	✓
▪ To find potential connectivity of forested and undisturbed land in the western, central and eastern regions between RMNP and DMPPF.	✓	X	X	✓	✓	✓
▪ To compare two unofficial corridors between RMNP and DMPPF, BW and RR, in terms of their forest cover and undisturbed land.	✓	X	X	X	✓	✓
▪ To determine the utility of different GIS methods in determining corridors and fragmentation, without animal data.	X	✓	✓	✓	✓	✓

3.3 Detailed Methods

All of the landscape pattern analysis in this study was performed on the LU/LC digital land inventory provided by Manitoba Conservation. The LU/LC of southern Manitoba raster data (Manitoba Remote Sensing Centre, 2004) were chosen after assessing alternative databases (Table 3), including: Forest Resource Inventory (FRI) satellite images, Forest Management Unit polygon layer, aerial and field photos as well as other data. LU/LC was chosen, as it was the most up-to-date, accurate and suitable to use for analysis. The LU/LC of southern Manitoba was created by the Manitoba Centre for Remote Sensing (Manitoba Remote Sensing Centre, 2004) using LandSat imagery collected between 1999-2003 (Iain Edye, Parks Canada, personal communication, June 29, 2009). The LU/LC has a resolution of 30 m pixel resolution, and contains 17 LU/LC classes using supervised or controlled classification.

LU/LC data was compared by collecting field data that consisted of photos, 142 GPS points (Figure 5) and plot information using Garmin 60CSX GPS, Samsung Digimax S600 camera, Canon EOS Rebel XSI camera, handheld-mirrored compass. For each of the points: 1) field data sheets were used to gather basic information about the landscape including notable features, moisture, drainage, topography, topographic shape, soil (USCS), and 2) photos of notable features along with each direction (north, west, south, east) were also taken on site.

Field data was applied to determine the level of development and the quality of forest cover. This field data was applied for the following classes of unique land features: 1) Forests including open deciduous/shrubs, rocky areas with trees so-called "treed rock", 2) wildfire areas and forest cutovers contained up to 50% tree cover, whether scattered or not, 3) wildfire areas burned more than five years ago, 4) forest cutovers logged more than 10 years ago had regenerated since the disturbances to provide forest cover, 5) grassland/rangeland was found to have little or no trees or shrubs and have on-going man-made disturbance, 6) road, rock, sand and gravel (usually excavated pits), 7) agricultural crop, forage or rangeland were verified to be disturbances that can be considered unnatural for habitat and limit wildlife activity, and 8) water, marsh, treed and open bogs. To determine the appropriate classes for different areas of the LU/LC, field work was carried out to determine the situation. The meaning of each class in terms of level of development and forest was determined by looking at specific classes identified through GPS points placed on the LU/LC layer. Table 3 provides the GIS model data source. The LU/LC raster data was the base data applied. However, this data was updated by more recent data including data from NCC (2009), field data (2009) as well as other data.

Please refer to Appendix I for more detailed description of each of the 17 classes that were derived from the metadata of the LU/LC. Geospatial metadata describe the characteristics of geographic features such as the type of land cover or land use of a specific feature with location or coordinates when viewed in a GIS program (Ahonen-Rainio, 2005). During data processing, the LU/LC was found to be too large as it includes all of southern Manitoba. Therefore, the frame for this study was on the following three scales from largest to smallest: 1) the whole area between RM and DM (Figure 5 and Figure 6), 2) the western, central and eastern areas between RM and DM (Figure 6), and 3) the BW and RR corridors (Figure 3 and Figure 4).

In the analysis with the LU/LC data, the specific steps were:

1) The landscape layer was cropped to include only the areas outside of RM and DM to get a more accurate forest and undisturbed statistics for main results. Ultimately, these common base layers of the landscape and specific regions between RM and DM were processed into *.shp, GRID or *.asc format that formed the basis for PG, LCP and SG to test different forest and undisturbed scenarios.

2) Reclassified the existing 17 classes of the LU/LC layer (Manitoba Remote Sensing Centre, 2004) considering field data findings into the following two scenarios both with different binary options of: 1) forest or non-forest and 2) on-going disturbance versus undisturbed or undeveloped land. Please see Table 4 and Table 5 for reclassification categories for forest and for disturbance respectively. The forest areas include eight classifications. The undisturbed areas include eleven classification areas. The areas considered in undisturbed areas that are not considered in forest areas include water, marsh and fen.

3) Determined methodology settings by conducting a sensitivity analysis to investigate the following: 1) optimal cell size, 2) optimal cost value using a specified range and split into four equal intervals, 3) different scenarios – modified forested and undisturbed classification, and 4) program settings. This analysis was completed to find which GIS data and program settings to use for the analysis of the thesis:

a. Cell size applied was 30 after comparing cell sizes of: 30 and 200 in ED, LCC, LCP and SG for sensitivity analysis of forest and non-forest (FNF) and disturbed and undisturbed (DND) scenarios.

b. Cost values were experimented with by considering three different values: (including from low to high): 1) forested/undisturbed (1.00), 2) non-forested/undisturbed (75 or 11.25), and 3) roads and/or agriculture (100 or 15.00) in LCP and SG, as well as different cost values for high and low of 25, 50, 75 and 100 in LCP, and of cost values: 3.75, 7.50, 11.25 and 15.00 in SG.

c. Cost value of 1 was assigned for preferred land (forest or undisturbed) and 100 for least preferred land (unforested or undisturbed) in LCP. In SG, a cost value of 1 was assigned for preferred land and a cost value of 15 for least preferred land.

d. Directionality was considered by comparing the starting point of the LCP from RMNP to that of DMPPF to see if it resulted in significantly different paths.

e. Line production by exploring the different ways LCP can produce a line – "For each cell", "for each zone" and "best single" and determined that the ideal was the "best single" because the intention of LCP was to find a single optimal path between RM and DM. Thus, best single optimal path was applied to the LCP analysis.

4) Determined basic landscape statistics using the histogram tool and PG in ArcGIS of LU/LC layer using LU/LC divisions to get landscape composition.

5) Compared all methods ED, LCC, LCP and SG with structural connectivity at different scales (landscape, regional and corridor) along with strengths and weaknesses to determine connectivity and fragmentation.

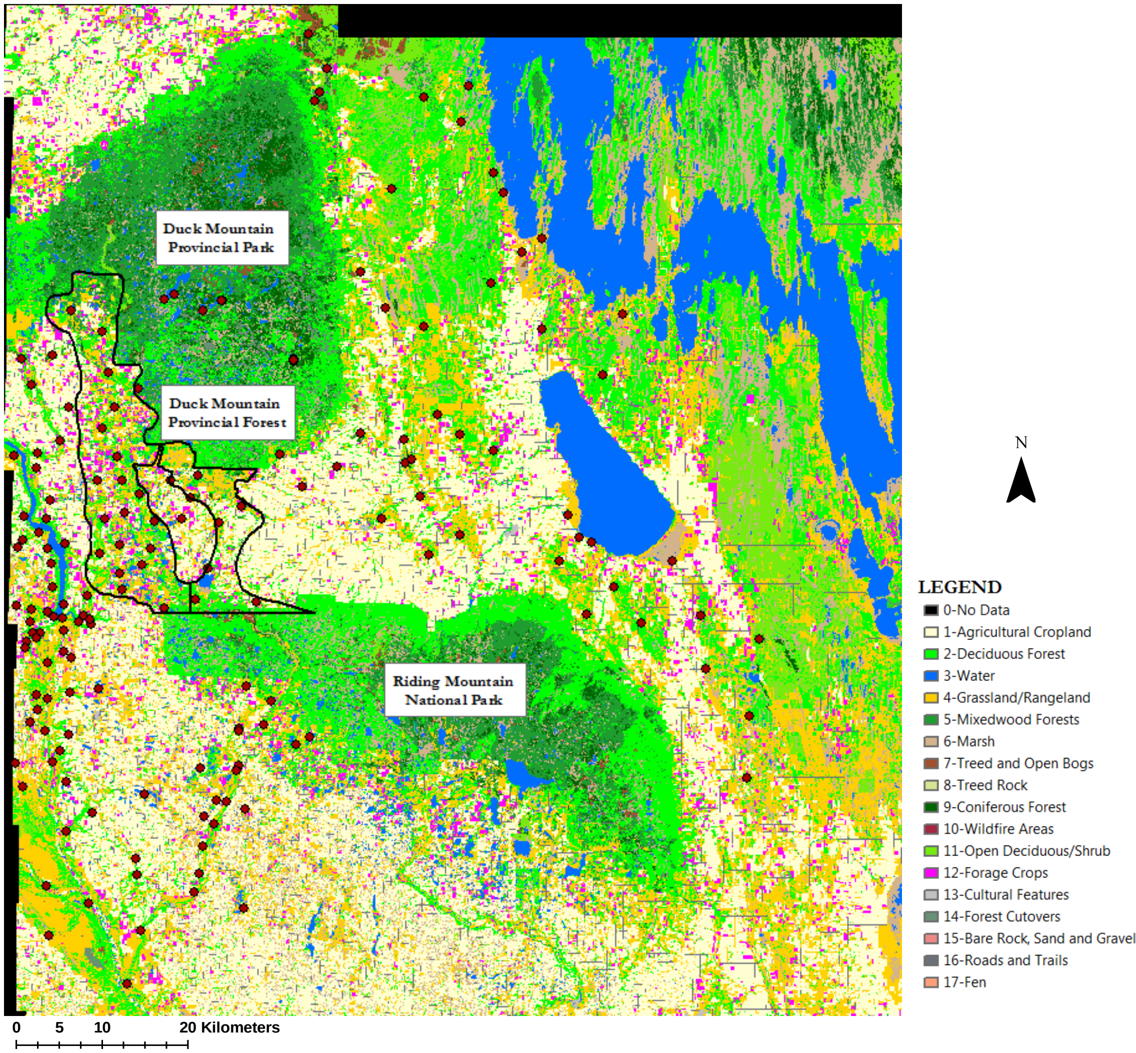

Figure 5: Map of 142 Global Positioning System Points Visited to Collect Photos, Field Data and to Confirm Features.

Table 3: GIS Model Data Sources

Type of Data	**Data Source**	**Original Data Name**	**Age of Data**
LU/LC raster data of Southern Manitoba 30 meter pixel resolution with 17 different LU/LC classes	Manitoba Remote Sensing Centre	Lm04_mbcl17	2003
BW and RR corridors shape files	Nature Conservancy of Canada	RMAP_Boundary_Smoothed.shp	2009
Field data - photos, GPS points and plot information	Kerry He Hao and Godwin Chan	Various – photos in *.jpg and points in *.shp	2009
SELES – configuration files to create SGs	Parks Canada	Various in *.txt format using DNRGarmin	2010
Digital orthophotos in 5km tiles relevant for study area in TIFF or MrSID format	Forest Resource Inventory (FRI) (MLI, n.d.)	-------nwg.tif	About 1986
Forest types in shape files	Forest Management Unit (FMU) (MLI, n.d.)	t----wpun.shp	About 1986
Information of interest that is specific to the study area	Ecological area, Ecological zone, Ecological region, Rural Municipalities, Crown land, Provincial Parks, Wildlife Management Areas, Wildlife Refuges and Protected Areas (MLI, n.d.)	Various	Varies

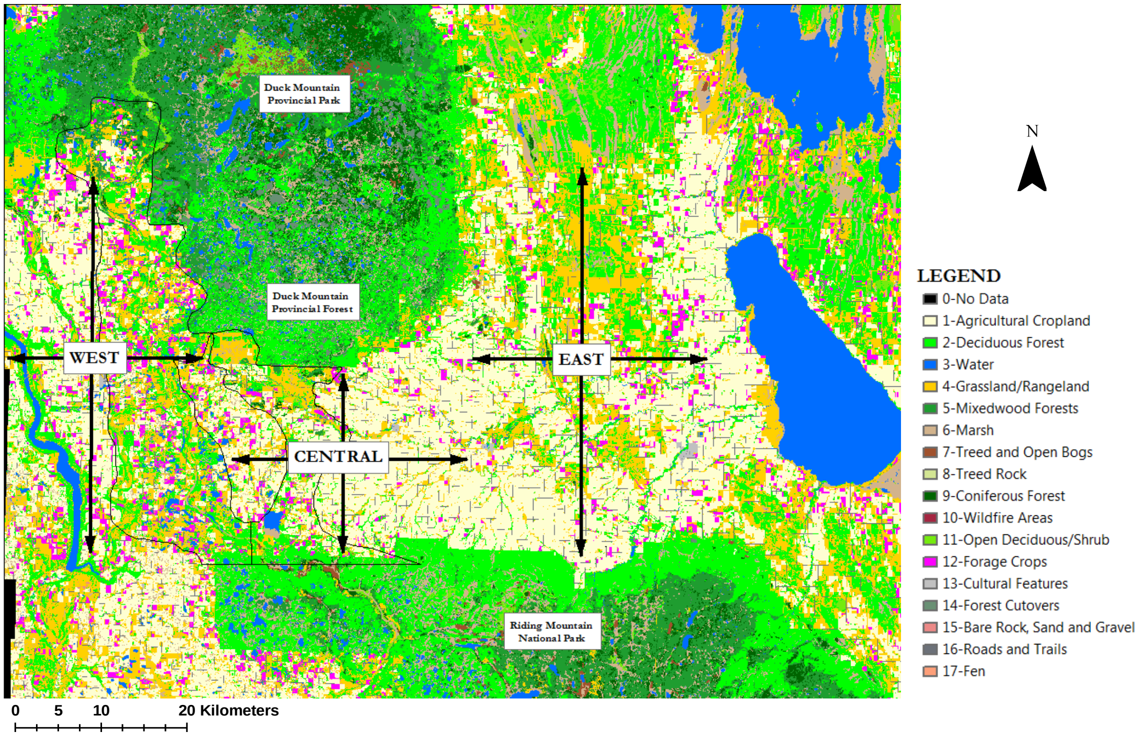

Figure 6: Map showing the Landscape between Riding Mountain National Park and Duck Mountain Provincial Forest and Park with the Three Areas used for Analysis.

Table 4: Forest and Non-forest Reclassification of the LU/LC Layer

Classification	
Forest	**Non-forest**
Deciduous Forest	Agricultural Cropland
Mixedwood Forests	Water
Treed and Open Bogs	Grassland/Rangeland
Treed Rock	Marsh
Coniferous Forest	Forage Crops
Wildfire Areas	Cultural Features
Open Deciduous/Shrubs	Bare Rock, Sand and Gravel
Forest Cutovers	Roads and Trails
	Fen

Table 5: Undisturbed and Disturbed Reclassification of the LU/LC Layer

Classification	
Undisturbed	**Disturbed**
Deciduous Forest	Agricultural Cropland
Water	Grassland/Rangeland
Mixedwood Forests	Forage Crops
Marsh	Cultural Features
Treed and Open Bogs	Bare Rock, Sand and Gravel
Treed Rock	Roads and Trails
Coniferous Forest	
Wildfire Areas	
Open Deciduous/Shrubs	
Forest Cutovers	
Fen	

Chapter 4: Research Findings and Analysis

4.1 Introduction

The findings of this analysis provided the current landscape conditions between RM and DM in section 4.2. Also in section 4.2.5, the connectivity of forested and undisturbed land in the western, central and eastern regions between RM and DM was explored. In addition, two potential corridors, namely BW and RR, were also explored regarding their connectivity for both forested and undisturbed land. Finally, the utility of a few selected GIS methods was determined for connectivity and fragmentation of forested and undisturbed land without animal data in section 4.3.

4.2 What is the Current Landscape Condition between Riding Mountain National Park and Duck Mountain Provincial Forest?

4.2.1 Land Composition of Land Use and Land Cover data for all Three Scales of Analysis

The findings of land composition for the LU/LC data vary at different scales of analysis. For all three scales, there was more quantity of undisturbed land than forested, as undisturbed areas includes forested land as well. At the landscape scale, forest makes up over one-fifth of the landscape (21.43%) (Figure 7, Figure 8 and Table 4), with much existing forest in this study area. In addition to forest, undisturbed land includes water and marsh (Table 7), covering one-quarter (26.33%) of the landscape (Figure 9 and Table 6). On the regional scale in Table 6, western RM and DM contain the most forest (23.39%) and undisturbed (30.92%) land. Central RM and DM contain the least forest (16.85%) and most disturbed (78.04%)

land out of all the areas between RM and DM. As shown in Table 7 the overall landscape is made up of a number of undeveloped land or types of forest including deciduous (17.80%), mixedwood forests (1.72%), open deciduous/shrubs (1.45%) and coniferous (0.34%) as well as treed and open bogs (0.05%), forest cutovers (0.07%), water (2.08%) and marsh (2.82%). The landscape of developed land is mainly agricultural cropland (43.11%) and grassland/rangeland (22.36%) with forage crops (5.35%) and minor land types. Furthermore, other landscape and patch statistics revealed the following more detailed results from LCP and SG. Table 17 in appendix III shows diversity metrics for landscape and different regions. When analyzing the three regions, the western region scores the best with the highest measure of relative patch diversity (using Shannon's diversity index, Simpson's diversity index and modified Simpson's diversity index) and patch distribution or abundance (using Shannon's evenness index, Simpson's evenness index and modified Simpson's evenness index) in comparison with the central and eastern regions. Table 18 in appendix III shows area, patch density, size and edge metrics for different classes in overall landscape. The area patches makeup in the landscape comprise predominantly of agricultural land (31.09%), followed by deciduous forest (24.03%) and grassland/rangeland (16.25%). Table 19 in Appendix III shows diversity and interspatial metrics of different classes in overall landscape. The mean nearest neighbor distance, deciduous forest and mixedwood forest are closest to other similar classed patches in the landscape on the average. Table 20 in Appendix III shows core area metrics for different classes in overall landscape. The forest and undisturbed land show that wildfire areas (10.40 ha) and forest cutovers (24.41 ha) have the highest mean core area that can potentially be restored for valuable forest habitat. In addition, deciduous forest, mixed wood forests and coniferous forest have the highest total core area and favorable core characteristics in the landscape. Table 21 shows the statistics of patches, LCPs and clusters that make up the SG. The undisturbed scenario reveals the shortest mean distance to nearest patch, shortest mean length of LCP between patches and the largest cluster size for BW, RR along with the western, central and eastern areas.

Patch diversity is important because wildlife do not just visit identical patches, but roam around to find resources such as food and water to survive (Drielsma et al., 2007; Fleury & Brown, 1997; Parks Canada, 2012; Vogt et al., 2009). In addition, patch diversity can affect a species' own diversity (Fischer & Lindenmayer, 2007). This is important for corridors because it can have all the advantages of increasing biodiversity and connectivity that would otherwise be absent (Drielsma et al., 2007; Fleury & Brown, 1997; Hess & Fischer, 2001; Kindall & Manen, 2007; Vogt et al., 2009). The following are historical factors showing reasons for forest reduction and how land use has changed. Walker (2002) showed extensive forest loss surrounding RMNP during a 40 year period from the 1950's to early 1990s. The Parkland region is utilized commercially for livestock and grain production and other agriculture (Brierley & Todd, 1990). Since the European settlement in the late 19th century, the land has been transformed into agricultural land.

Today, the region supports a rural agricultural economy. Therefore, with more farms or agriculture in the area, there is less forest and undeveloped land. Land use has changed due to land conversion by logging/deforestation or burning of land to clear for use in agriculture. In addition, land set aside for crops and cattle grazing often have fences as boundaries. When looking at the undisturbed and forested land scenarios, deciduous forest had the most patches and edge density. Nonetheless, deciduous contained the shortest so-called "mean nearest neighbor distance" and highest amount of core area habitat. Therefore, overall the results show that the western region is an important area for forest cover. The most important cover type is deciduous forest since it makes up most of the landscape for natural cover. However, deciduous forest faces fragmentation with the largest number of patches. Thus, both non-forest and disturbance can affect habitat connectivity and fragmentation. In terms of field data confirmation the LU/LC was found to be accurate at large scales but some generalization occurred at smaller scales. The omission of small streams and non-paved roads were not present in the LU/LC data. In the data, gaps in forest were not labeled but were confirmed by fieldwork and photo identification to be power line corridors with some grass and shrub vegetation (Figure 32 in Appendix IV). The photos and fieldwork clarified landscape features were not distinguishable on the LU/LC layer. Field photos clearly show openings in the landscape that do not have forest cover and can be as small as a gravel road to as large as an agricultural field of grassland, cropland or hayfield. Development occurs at all scales and data collected from satellite imagery were found in this study to be missing some features at smaller scales. Thus interpreting spatial patterns using different scales can sometimes be more complex (Kent et al., 2006). A short research visit to the field study area was necessary to confirm a detailed categorization of the landscape features afterwards. For example, without field data the logged and wildfire areas of forests would have been considered disturbed, but they were considered both forested and undisturbed. The photos in Appendix IV show different aspects of the landscape from the field data collection and identify its status as developed or forested land.

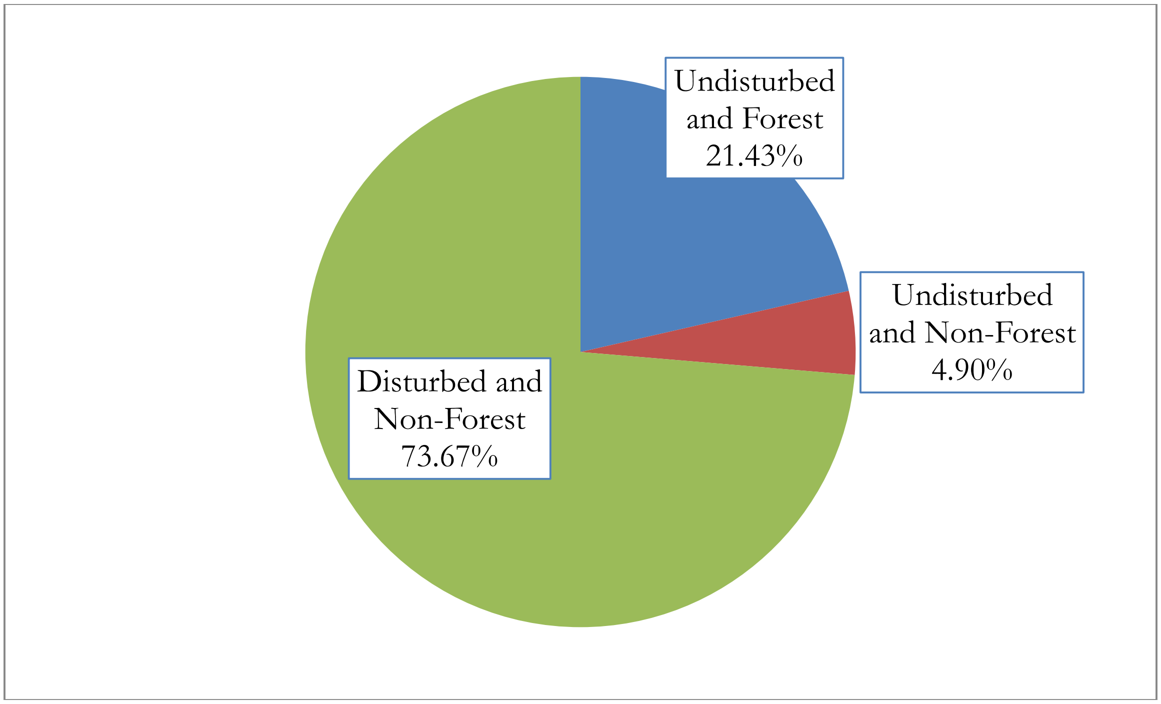

Figure 7: Difference in Composition between Forested and Undisturbed Land in the Landscape.

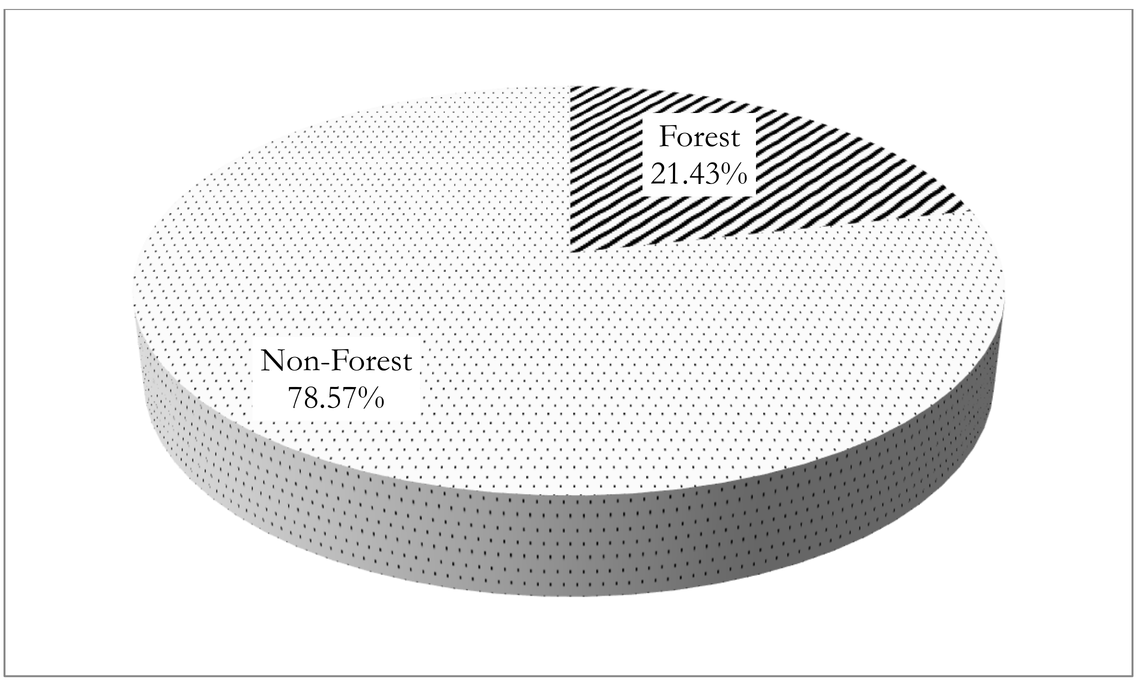

Figure 8: Percentage of Forest and Non-Forest Land at the Landscape Scale between Riding Mountain National Park and Duck Mountain Provincial Forest and Park.

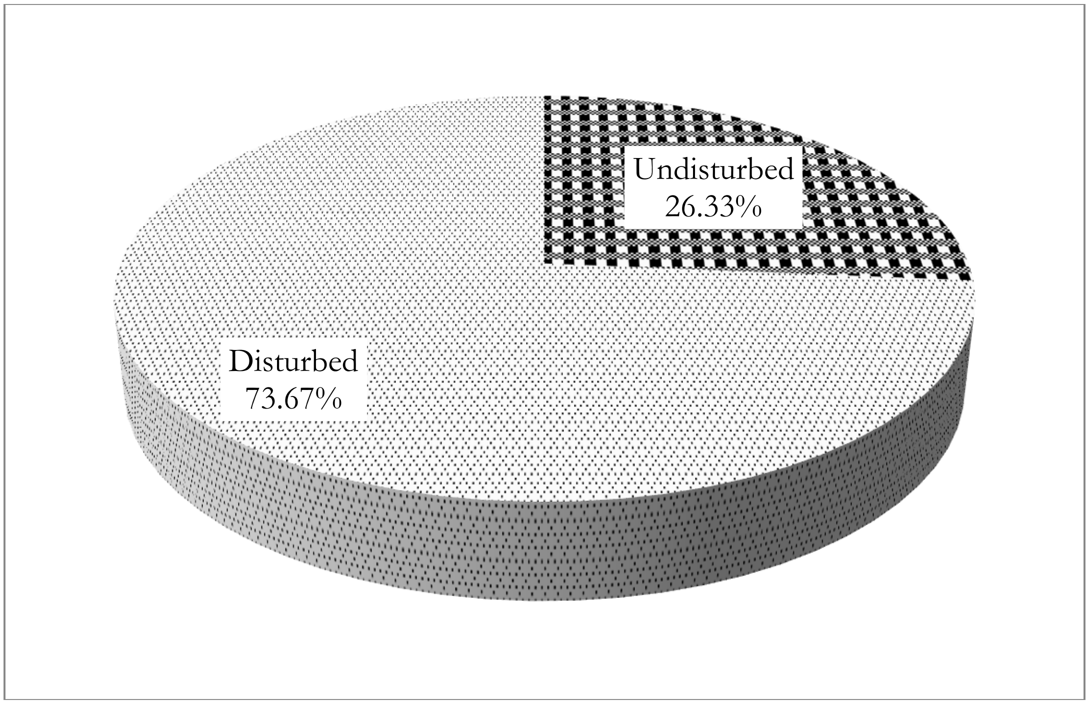

Figure 9: Percentage of Undisturbed and Disturbed Land at the Landscape Scale between Riding Mountain National Park and Duck Mountain Provincial Park and Forest.

Table 6: Percentage of Forested and Undisturbed at all scales of Analysis for Areas between RM and DM

	Scenario			
Scale of Analysis	**Forest**	**Non-Forest**	**Undisturbed**	**Disturbed**
Overall Landscape	21.43	78.57	26.33	73.67
West	23.39	76.62	30.92	69.09
Central	16.85	83.16	21.97	78.04
East	22.57	79.28	25.64	76.21
BW	32.21	67.78	39.99	60.00
RR	31.04	68.96	38.19	61.81

Table 7: Land Use/Land Cover Composition in the Areas between RM and DM (in Percentage)

Land Use/Land Cover	Scale of Analysis					
	Overall	Region			Corridor	
	Landscape	West	Central	East	BW	RR
Deciduous Forest	17.80	19.17	13.79	17.58	23.62	23.39
Mixedwood Forests	1.72	3.07	1.55	0.75	6.41	3.38
Treed and Open Bogs	0.05	0.02	0.05	0.08	0.02	0.28
Treed Rock	0.00	0.00	0.00	0.00	0.00	0.00
Coniferous Forest	0.34	0.45	0.46	2.02	0.94	1.50
Wildfire Areas	0.00	0.01	0.00	0.00	0.03	0.00
Open Deciduous/Shrubs	1.45	0.66	1.00	2.02	1.16	2.49
Forest Cutovers	0.07	0.01	0.00	0.12	0.03	0.00
Water	2.08	4.26	2.18	0.51	4.19	2.74
Marsh	2.82	3.27	2.94	2.56	3.59	4.41
Fen	0.00	0.00	0.00	0.00	0.00	0.00
Agricultural Cropland	43.11	34.20	49.94	48.02	19.09	28.41
Grassland/Rangeland	22.36	24.41	20.67	21.45	29.49	26.43
Forage Crops	5.35	8.04	4.66	3.59	9.37	4.71
Cultural Features	0.23	0.12	0.12	0.34	0.02	0.00
Bare Rock, Sand and Gravel	0.04	0.05	0.04	0.04	0.02	0.11
Roads and Trails	2.58	2.27	2.61	2.77	2.01	2.15

4.2.2 Least-cost corridor and Least-cost path

Least-cost corridor (LCC) as a tool showed a map with the potential corridors through forested and undisturbed areas (Figure 10 and Figure 11). The LCCs were in the same locations as the BW and RR corridors. The most costly area was in the eastern RM and DM. This LCC tool is an improvement over the ED tool. By assigning the cost of land cover and land use in landscape to calculate LCC the cost can be determined without developing statistics that can be analyzed and compared.

LCC provides a first step to identify the key regions for corridors that contain the preferred landscapes through mapping. Specifically, LCC can use a color spectrum to differentiate high to low cost values without dealing too much with data. However, LCC does not provide any metrics to compare different corridors. The broad areas identified did not provide information regarding connectivity or fragmentation, but only the areas least costly to pass through. As a result, LCC may be more useful than LCP to find an approximate area for a potential corridor rather than one possible path.

LCP produced the potential path of least-cost and measured distance when travelling amongst forested or undisturbed lands from RM to DM. LCP found the percentage of forested and undisturbed lands between the two areas. LCPs produce an optimal path between two points that is more detailed than LCC, because LCC identifies a general region rather than a path. There is no continuous forested and undisturbed connection between RM and DM according to LCP. The LCPs were generated for forested and undisturbed scenarios. The LCP map generated reinforces the unofficial recognized corridor called BW in the west region and RR in the central region between RM and DM. Future conservation work to create a connecting path in these areas can be assisted by the LCP maps. With the LCP analysis showing 34.04% non-forest and about 26.09% disturbed in the western region landscape, travelling entirely under forest cover is not possible.

This forest fragmentation requires analyzing paths for connectivity. Deciduous forest was found to be a dominant forest type in the whole landscape and was the most dominant forest type intersected by the LCPs. Furthermore, in DND analysis, grassland/rangeland and deciduous forest makeup about the same percentage intersected by the LCPs. This can show the importance of grassland/rangeland that supplements forest patches. In general, deciduous forest and grassland/rangeland dominate the LCP intersection between RM and DM. Although the LCP is the best possible route between two points influenced by non-monetary cost (LaRue & Nielsen, 2008) this may not be the best routes in real-life (Brooker et al., 1999). The shortest and least costly path from RM and DM through both forested lands and undisturbed land lies in the BW corridor and not the RR Corridor according to

Figure 12 and Figure 13. The forested LCP produced a non-linear path compared to LCP on undisturbed lands. This was obviously due to dispersed forest patches and additional undisturbed land in the landscape. The BW corridor is much longer (41.75 km) and wider (10.74 km to 20.19 km) than the RR corridor (32.20 km in length and 5.66 km to 17.39 km in width) (Table 10). In LCP analysis, the length of the LCP for forested land (44.53 km) was slightly longer than for undisturbed land (41.65 km) appearing in the BW corridor (Table 11). The greater width of the BW corridor may help wildlife that travel long distances in suitable habitat.

As shown in Table 8, the area between RM and DM, the FNF LCP intersected mainly with grassland/rangeland (17.69%) and deciduous forest (62.89%) land. This differed from the DND LCP, which intersected with mainly deciduous forest (49.81%) followed by grassland/rangeland (14.39%). Thus, the LCP intersected with 65.96% forested land and 73.91% undisturbed land (Table 8).

Figure 14 shows a number of crown lands established mainly for wildlife and water management adjacent to the boundary of northern RMNP and western DMPPF inside the BW and RR corridors. However, a potential corridor can take advantage of these existing designations. This can be in place to preserve the land to incorporate this into building a corridor that is mainly concentrated in western DMPPF and northwestern RMNP. In terms of biological relevancy, smaller patches of vegetation cannot support as many species as larger patches resulting in less biodiversity to complement larger patches of vegetation by providing certain habitat conditions not available in larger patches of vegetation (Fischer & Lindenmayer, 2007). In addition, forest biodiversity conservation includes maintaining connectivity for habitats, communities and ecological processes (Fischer & Lindenmayer, 2007). However, without connected forest, development results in fragmentation and loss of habitat, thus reducing biodiversity (Fischer & Lindenmayer, 2007; Tomimatsu & Ohara, 2006). Furthermore, the landscape matrix is not a preferred habitat for the survival of species, but may still be adequate for survival if adjoining areas are suitable (Fischer & Lindenmayer, 2007). A corridor favored by forest species would also enable a larger region for wildlife movement between RM and DM for: 1) breeding, 2) enlarging home ranges, 3) finding food and water during the different seasons, 4) ensuring genetic variability and 5) maintaining wildlife populations over a wide area (Parks Canada, 2012). As an overall assessment of LCP method, this study found the following limitations namely: 1) only one path between two points is created, ignoring the connectivity between all other patches in the landscape, 2) a corridor is probably not wide enough at 30 m resolution, but increasing the cell size or applying a buffer to this may be options, and 3) no metrics or statistics are generated automatically since LCPs just produce a line,. However, statistics could be generated by intersecting the LU/LC layer with the LCP to find that deciduous forest and agricultural cropland predominated as shown later in Table 8 below.

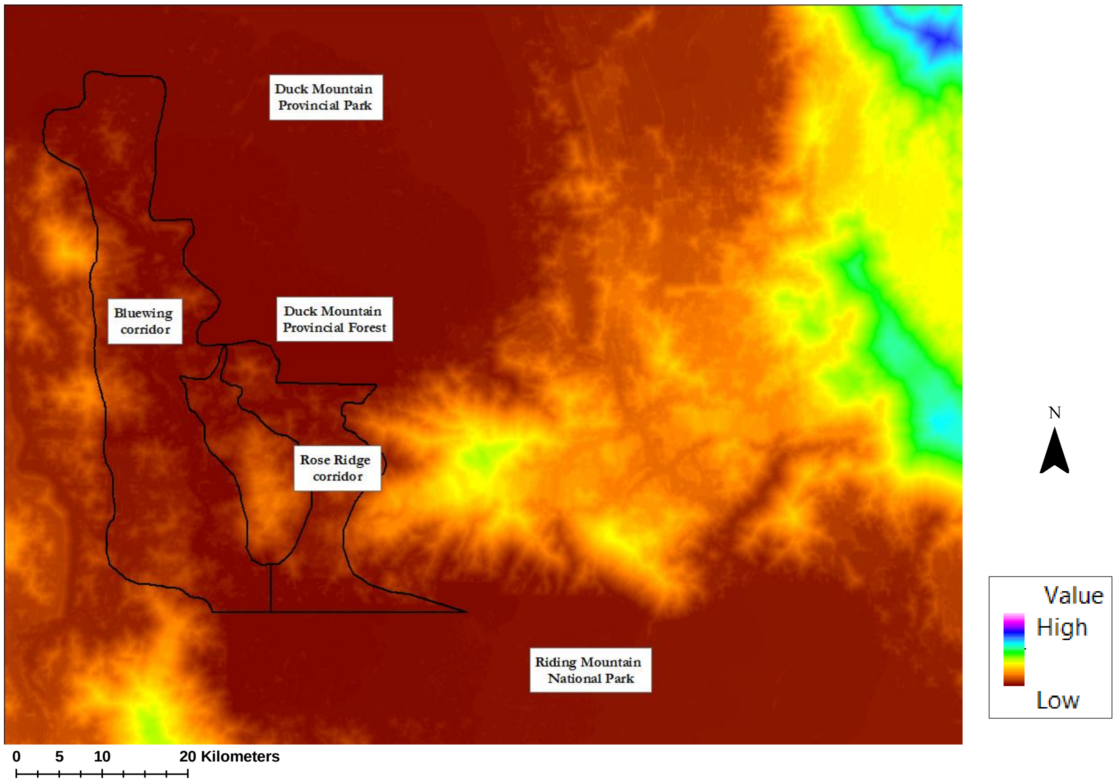

Figure 10: Least-cost corridor for Forested Land.

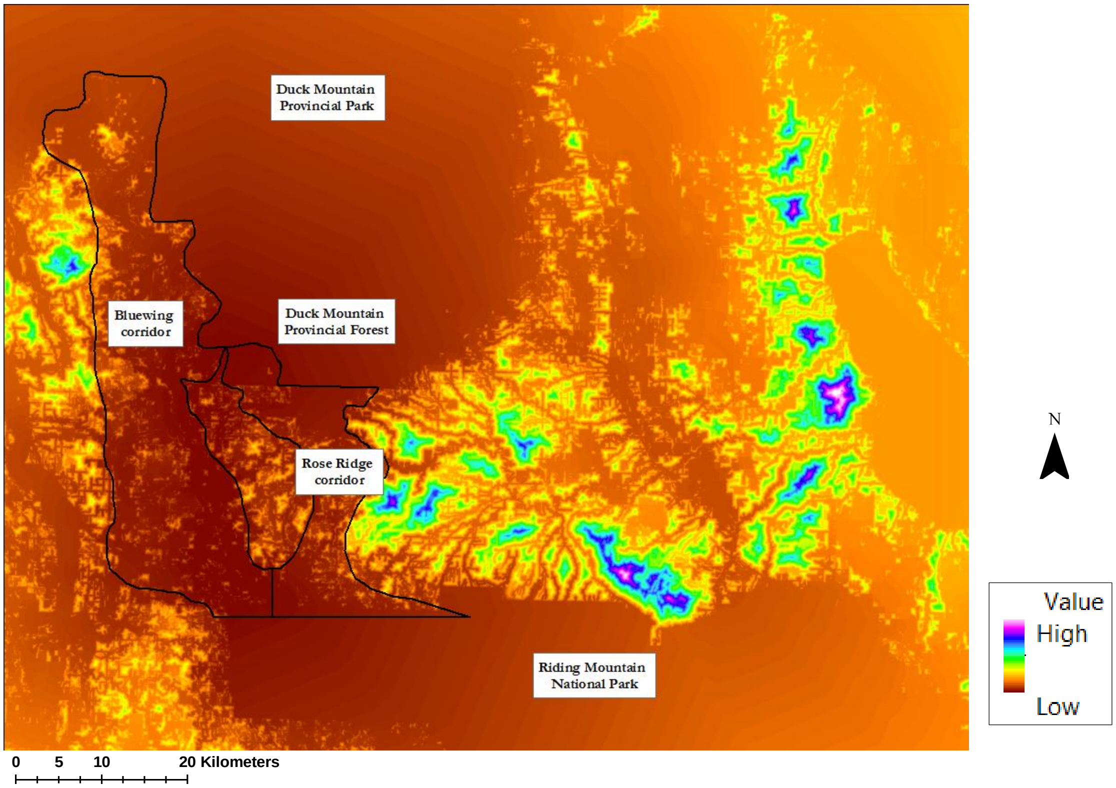

Figure 11: Least-cost corridor for Undisturbed Land.

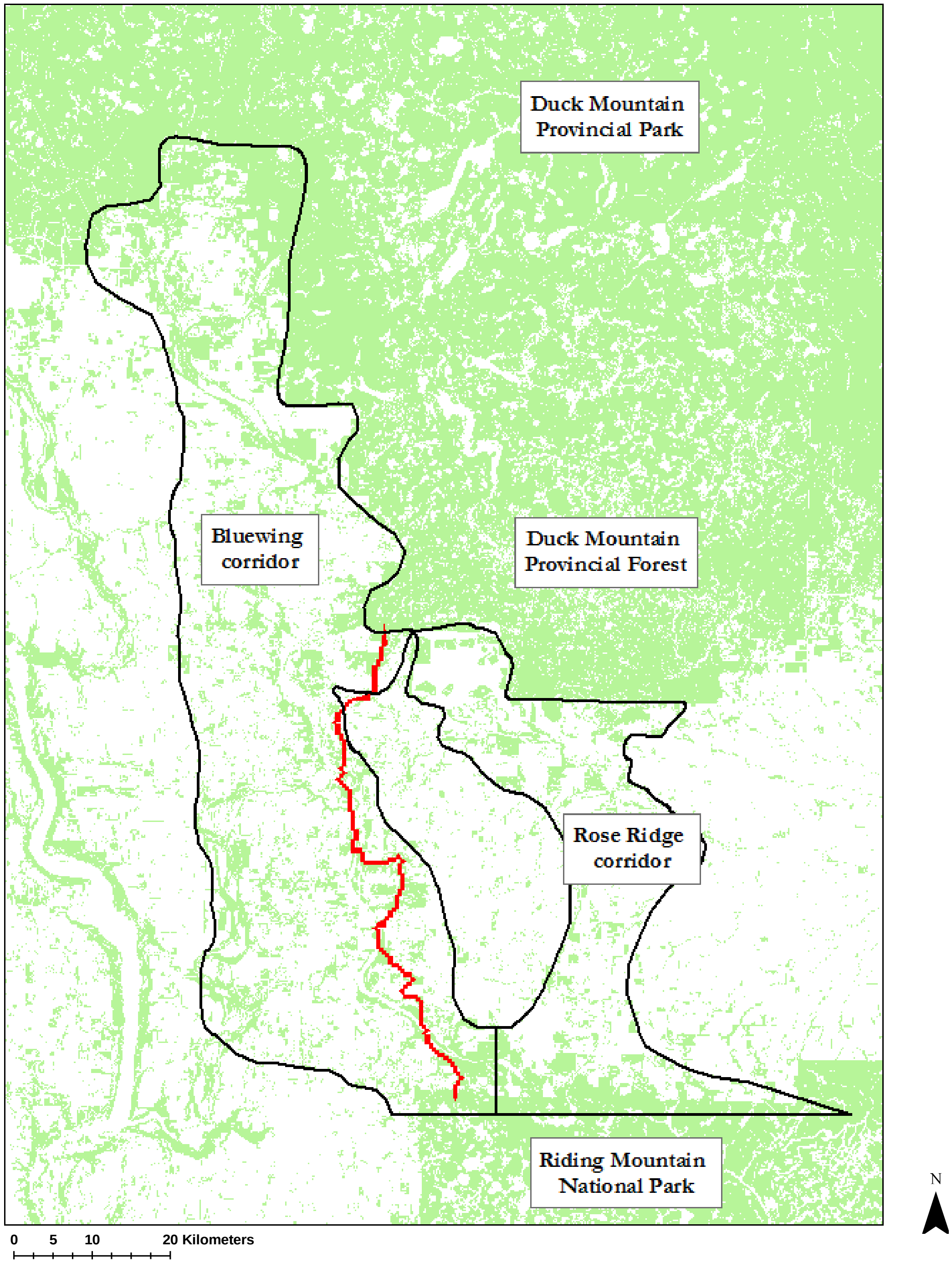

Figure 12: The shortest and Least-cost path between Riding Mountain National Park and Duck Mountain Provincial Park and Forest lies in the Bluewing corridor.

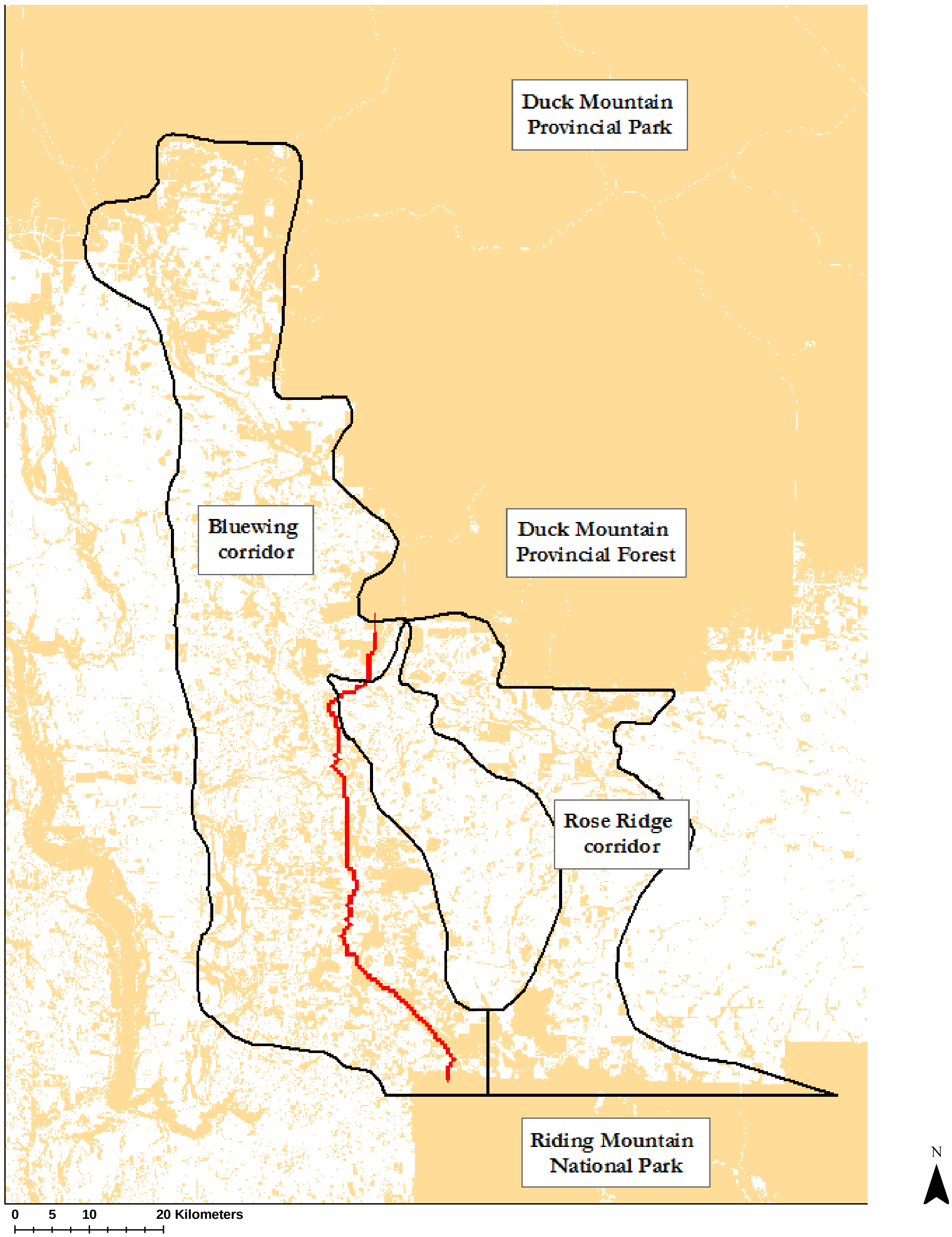

Figure 13: Least-cost path between Riding Mountain National Park and Duck Mountain Provincial Park and Forest through Undisturbed Land lies in the Bluewing Corridor.

Table 8: Types of Land Cover and Land Use the LCPs passed through Forested and Undisturbed Land between RM and DM (in Percentage)

Land Cover	Forest and non-forest (%)	Undisturbed and disturbed (%)
Deciduous Forest	62.89	49.81
Mixedwood Forests	1.45	1.83
Treed and Open Bogs	0	0
Treed Rock	0	0
Coniferous Forest	0.24	0.45
Wildfire Areas	0	0
Open Deciduous/Shrubs	1.38	2.48
Forest Cutovers	0	0
Water	3.53	9.84
Marsh	4.42	12.61
Fen	0	0
Agricultural Cropland	4.55	5.45
Grassland/Rangeland	17.69	14.39
Forage Crops	2.08	1.2
Cultural Features	0	0
Bare Rock, Sand and Gravel	0	0
Roads and Trails	1.76	1.94

Table 9: The Proportion of Forested and Undisturbed lands crossed by the LCP (in Percentage)

Scenario	Forest (%)	Non-Forest (%)	Undisturbed (%)	Disturbed (%)
Least-cost path	65.96	34.04	73.91	26.09

Table 10: The Length and Width of the Two Potential Corridors

Location	Length of Corridor (Approximately in km)	Width of Corridor (Approximately in km)
BW (only portion that is between RMNP and southwestern DMPPF	41.75	10.74 to 20.19
RR	32.20	5.66 to 17.39

Table 11: The Length of the LCP for each Scenario

Scenario	Length of LCP (Approximately in km)
Forested and Non-forest	44.53
Undisturbed and Disturbed	41.65

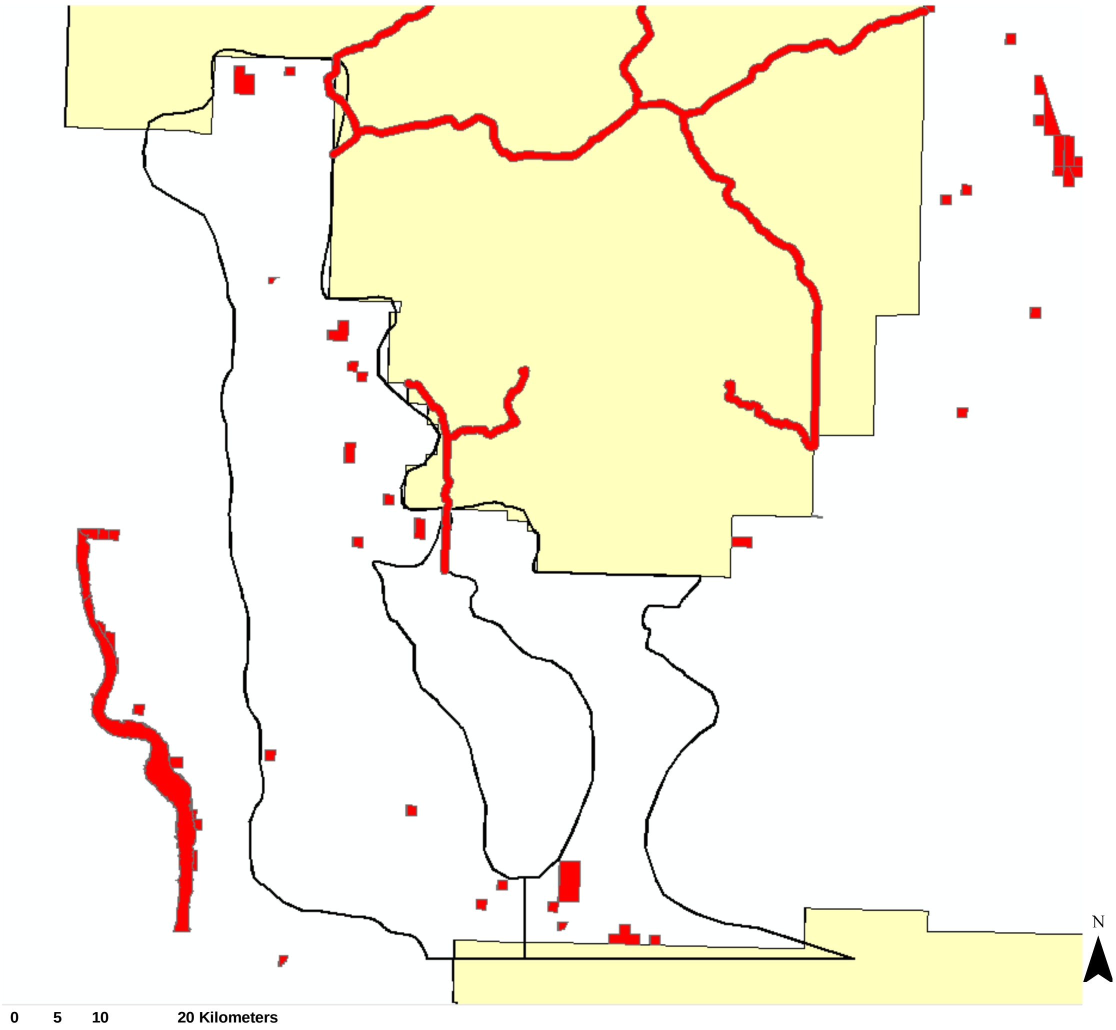

Figure 14: Map showing Wildlife Refuges (Thick Lines) and Crown Land (Square or Rectangular Shaped) Designated as Wildlife Land, Wildlife Management Area, Water Management, Marsh/Bog, Fen and Ecological Reserve.

4.2.3 Spatial Graphs

Urban et al. (2009) found graph theory principles provide a robust but simple way to examine habitat connectivity and patches in the landscape. The SG findings of this study showed the degree of connectivity between forested and undisturbed patches through statistics. The SGs, created in SELES, showed landscape connectivity and fragmentation. Connectivity was analyzed by weighing the amount of habitat (cluster size) against the scale at which potential movement between patches occurs (cost distance threshold).

Clusters are a group of forested or undisturbed patches that could be habitat for certain wildlife. Cost distance threshold decides connectivity by seeing if the ED between boundaries of patches is less than the specified distance threshold (Galpern et al., 2010). Cluster size nonetheless, was set against cost distance to see which area had a larger cluster size or highest amount of forested and undisturbed habitat (Figure 15 to Figure 18). Cluster size in the Western area including the BW corridor was found greater than in the Central and Eastern areas and RR corridor. Bigger cluster size means more habitat, whereas higher cost distance thresholds means more cost to travel at longer distance to other landscape patches (Galpern et al, 2010). As a result, this showed that large areas such as the western, eastern and BW corridor do create large cluster sizes over higher cost thresholds (Figure 15 to Figure 18). However, maps in Walker (2002) showed that in 1991 there were more forest in the western area than the central area between RM and DM. This research data agree with these findings. O'Brien et al. (2006) in their research on spatial configuration revealed the importance, distribution, and connectivity of Woodland caribou winter habitat.

Research by Minor and Urban (2008) showed SG could explore connectivity in fragmented landscapes. Goetz et al. (2009) also used SG to find important areas surrounding protected areas for conservation most essential for connectivity between protected areas in the United States. This research shared certain aspects of their findings in order to justify SGs use for fragmented landscapes and areas surrounding protected areas essential for connectivity. Since the western, central and eastern areas together with the BW and RR corridors were different in size and area, the cluster size was normalized to make the three areas equal in weight for connectivity analysis (Figure 19 to Figure 27). When land size was normalized, the western area and the BW corridor had the highest connectivity for forested and undisturbed land. The normalized data was generated for small and large cost thresholds to distinguish any patterns. This showed undisturbed land has higher connectivity than forested land based on higher cluster size at similar cost distance thresholds to the other areas (Figure 19). However, the western area has higher connectivity through forested and undisturbed land than the central and eastern areas. This finding of higher connectivity was based on higher cluster size at similar cost distance thresholds than the other areas (Figure 20, Figure 21, Figure 22 and Figure 23). The BW corridor also had higher connectivity than the RR corridor through forested and undisturbed land based on higher cluster size at similar cost distance thresholds than the RR Corridor (Figure 24, Figure 25, Figure 26 and Figure 27).

In both theory and practice, SGs can generate connections between patches. This SG method provides more than one path out of a patch rather than one single path like LCP. In contrast, LCP can only connect a limited number of patches. The input criteria for SG are similar to making a LCP. However, the output focuses less on paths and more on connectivity between all patches in a study area. SGs also provide more comprehensive metrics and statistics that are useful in connectivity analysis. Even though a single path is not created by SGs, yet potential corridors can be determined by choosing areas with higher connectivity and much denser, connected cluster of patches with shorter distances between patches (Moilanen, 2011; Pereira et al., 2011; Urban et al., 2009). Therefore, SG data can enhance the results of LCPs along with other methods to evaluate and find potential corridors or paths.

Table 21 in Appendix IV reveals that the DND scenario provides more numerous shorter paths in close proximity than FNF. This research showed that a larger amount of habitat available between patches increases connectivity. For FNF, the western areas including the BW corridor was the best choice because the largest nearest distance to other patches was only 2 km. In comparison, the largest LCP to other patches was 5 km, whereas the largest cluster of patches made up 36 thousand ha. However, the worst area, in terms of connectivity, was the central region because: 1) the largest nearest distance to other patches was 4.13 km, 2) the largest LCP to other patches was 6 km, and 3) the largest cluster of patches was only 19 thousand ha. This research found that the remaining forest patches in the central area were surrounded mostly by agricultural cropland, forage cropland and rangeland. Further removal of forest patches in this area could result in low connectivity and increased distance between forest patches. Therefore, the SGs statistics showed that the western side had the least distance between patches with the biggest cluster size at higher cost distance thresholds (please see Table 21 in Appendix IV for specific cost distance thresholds values).

The other methods (ED, LCC and LCP) also provided potential corridors. These corridors showed two potential routes between RM and DM: 1) the BW (based on LCC and least-cost distance – LCP), and 2) RR corridors (based on LCC and shortest direct distance - ED). The SG maps, however, showed specific areas where forest fragmentation happened. More fragmentation occurred in the central areas out of the three regions along with the southern areas of the BW corridor and mostly in the RR corridor. The pivotal areas for potential movement were evident nodes linking several other patches. Denser links or lines suggested multiple routes to another group of patches, while shorter links showed less distance to make it easier for wildlife to roam between patches. Those areas with small amounts of forest and multiple links between patches showed patches mostly important for connectivity. In general, one or a few long links indicated a distinct area of isolated or fragmented patches. Therefore, conservation was considered important to maintain forest connectivity, especially for isolated and fragmented forest patches.

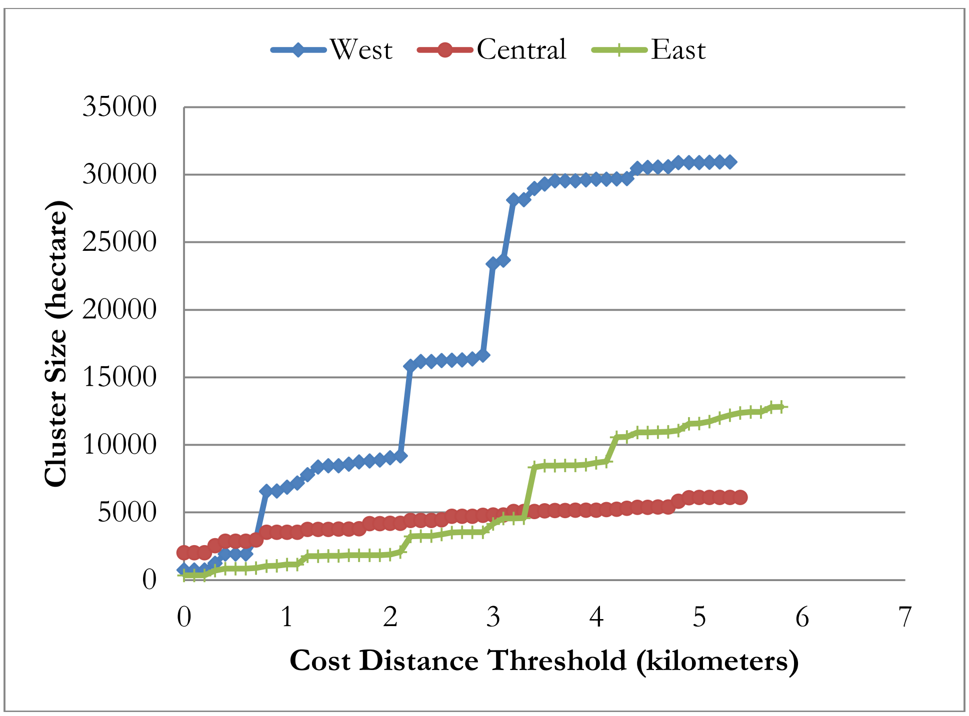

Figure 15: Forested Land Connectivity between the Western, Central and Eastern areas.

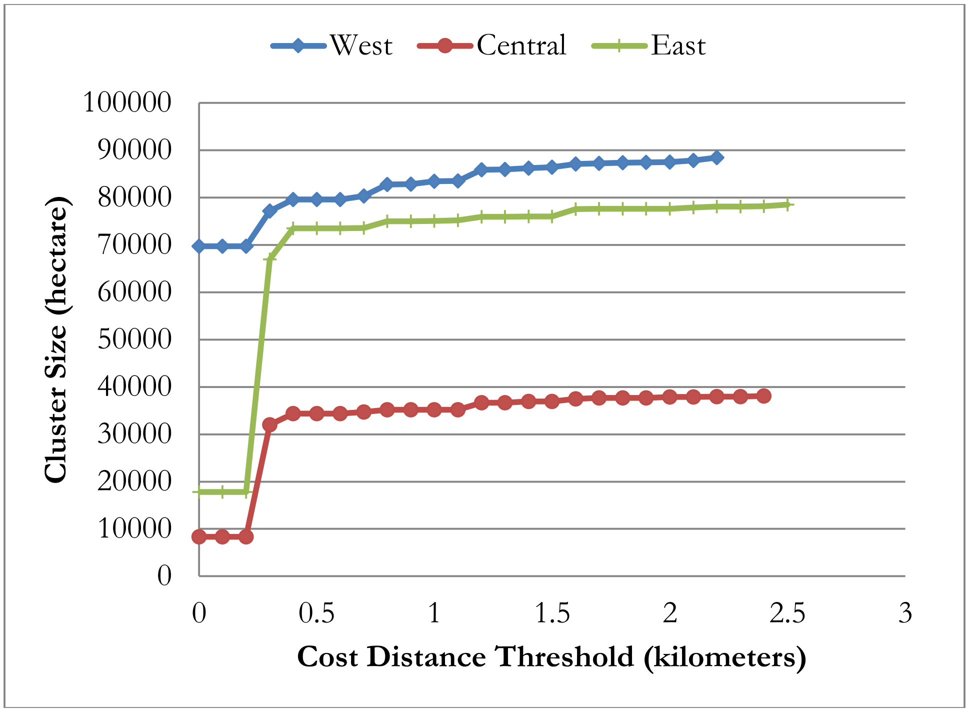

Figure 16: Undisturbed Land Connectivity between the Western, Central and Eastern areas

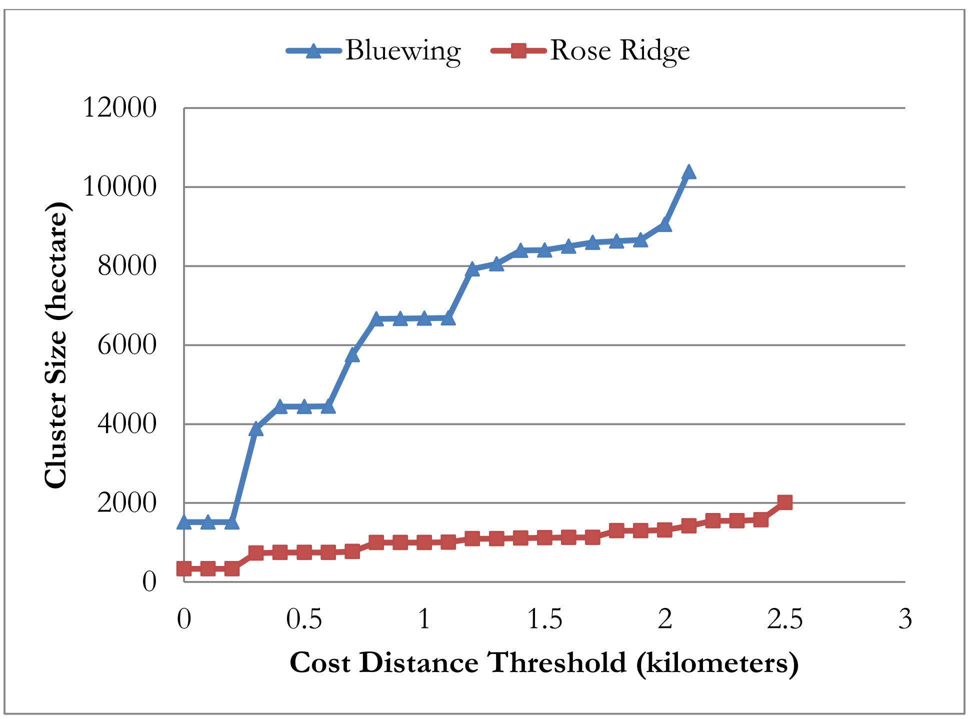

Figure 17: Forested Land Connectivity between Bluewing and Rose Ridge corridors.

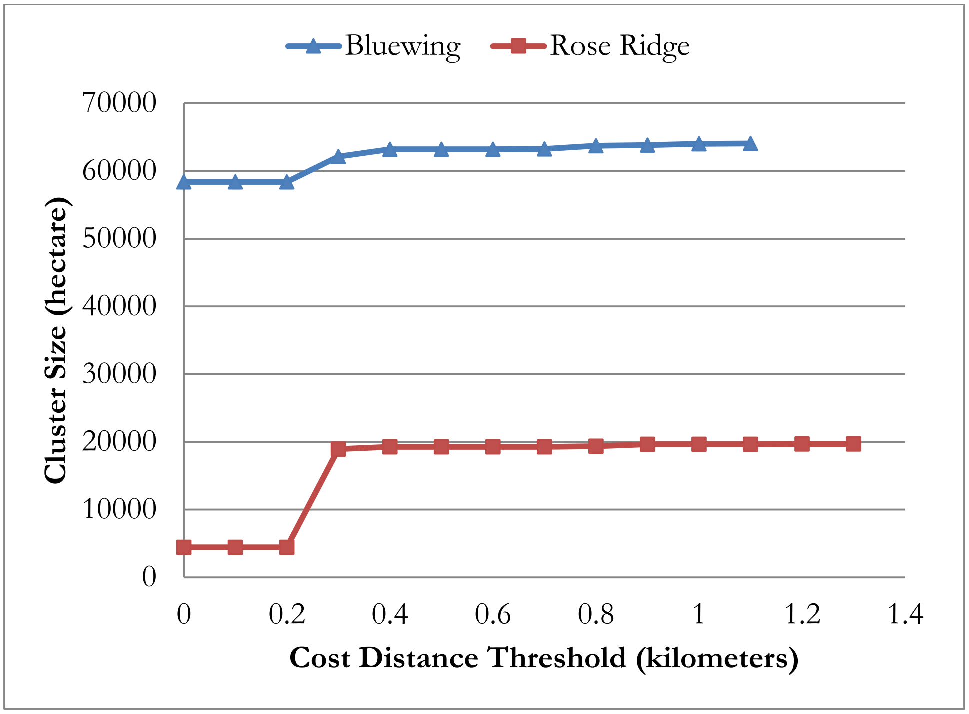

Figure 18: Undisturbed Land Connectivity between Bluewing and Rose Ridge corridors.

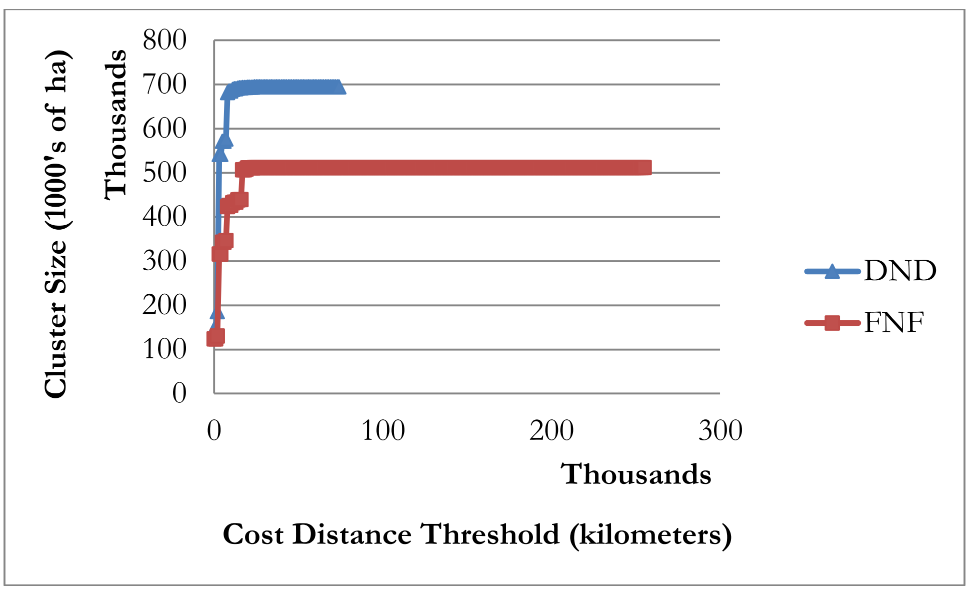

Figure 19: The Difference in Connectivity between Forested and Undisturbed Land at the Landscape Scale.

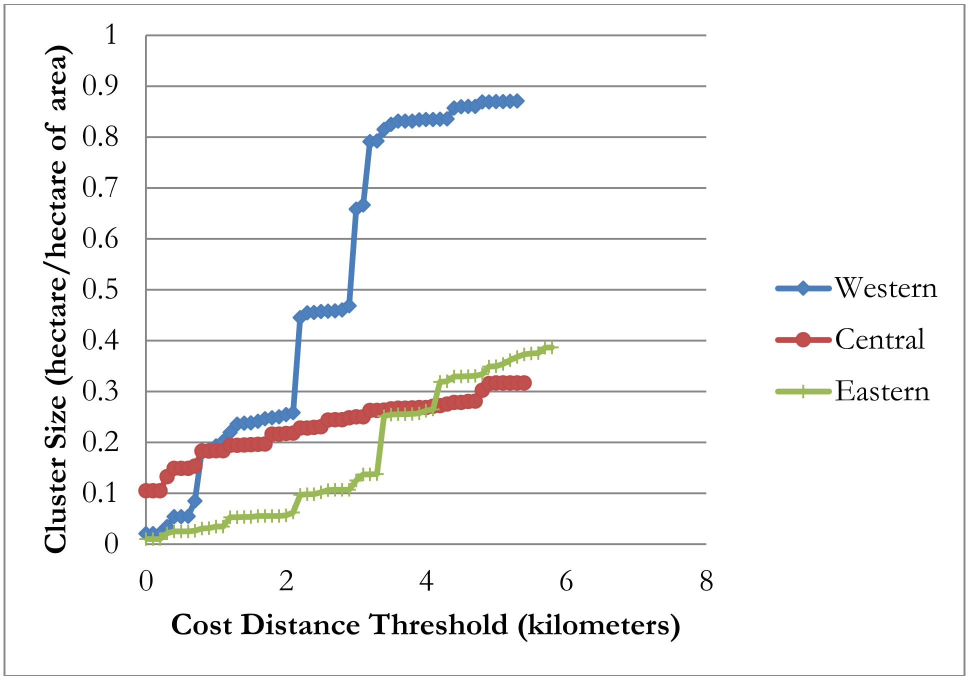

Figure 20: The Difference in Forested Land Connectivity between the Western, Central and Eastern areas (Small Cost Distance Threshold).

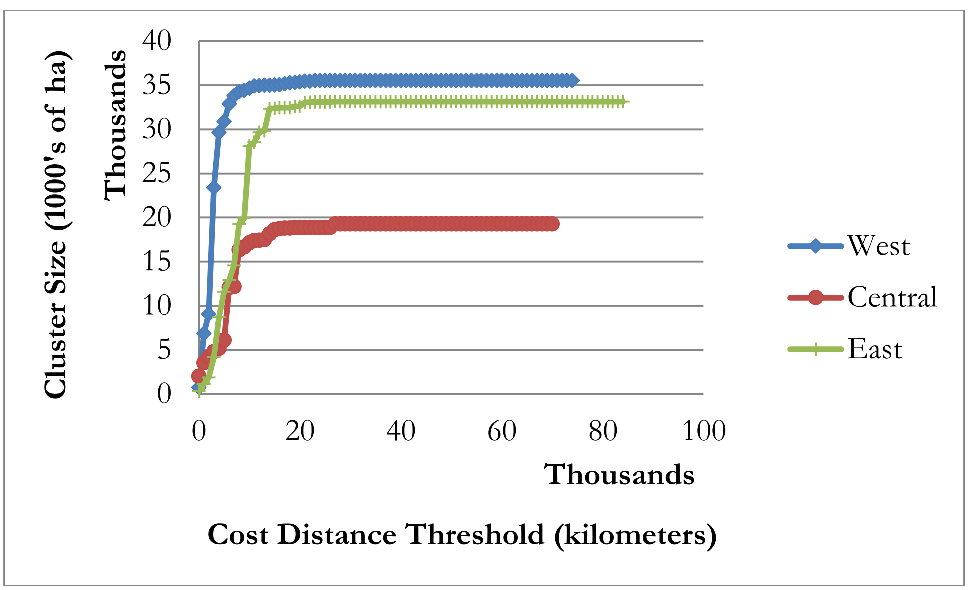

Figure 21: The Difference in Forested Land Connectivity between the Western, Central and Eastern areas (Large Cost Distance Threshold).

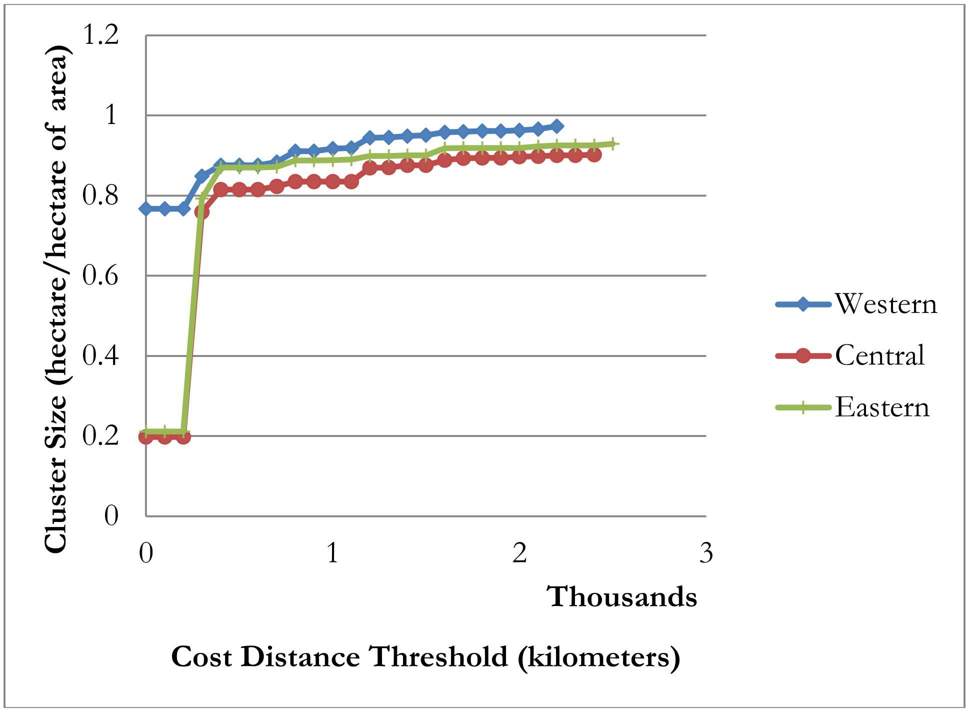

Figure 22: The Difference in Undisturbed Land Connectivity between the Western, Central and Eastern areas (Small Cost Distance Threshold).

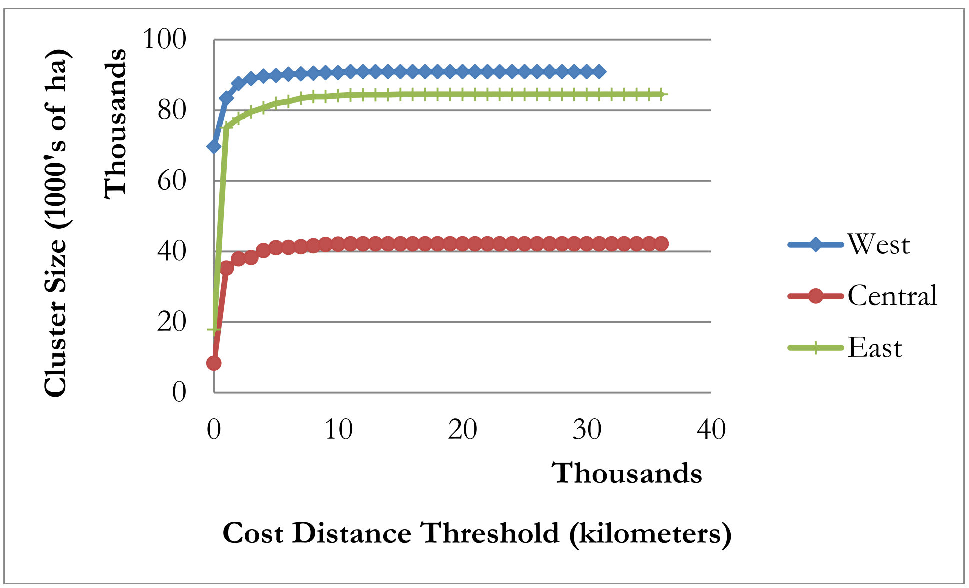

Figure 23: The Difference in Undisturbed Land Connectivity between the Western, Central and Eastern areas (Large Cost Distance Threshold).

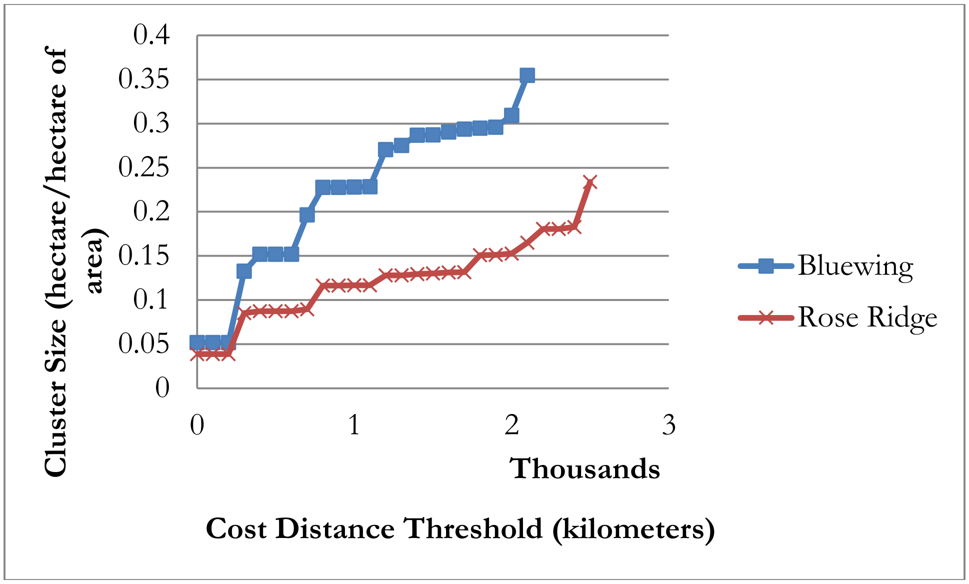

Figure 24: The Difference in Forested Land Connectivity between Bluewing and Rose Ridge corridors (Small Cost Distance Threshold).

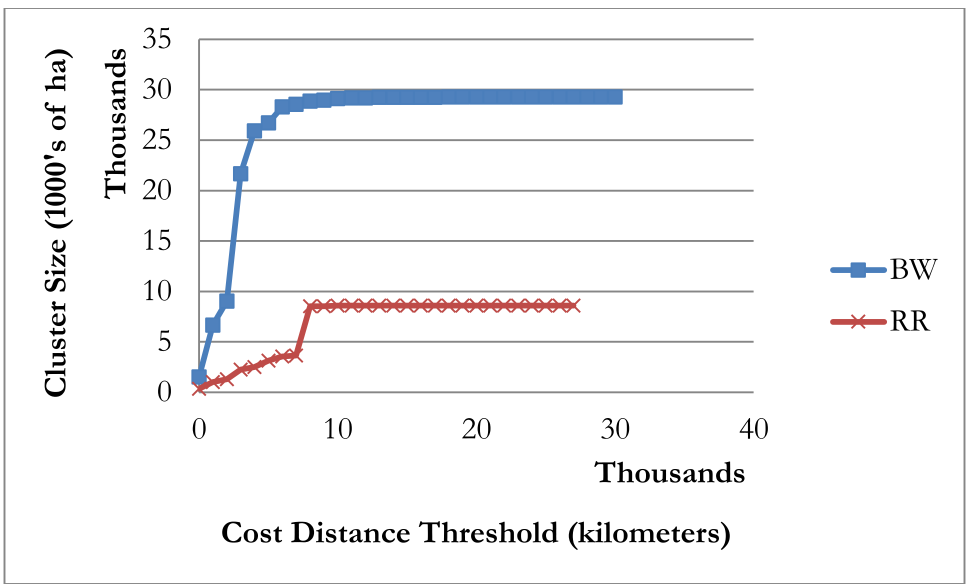

Figure 25: The Difference in Forested Land Connectivity between Bluewing and Rose Ridge corridors (Large Cost Distance Threshold).

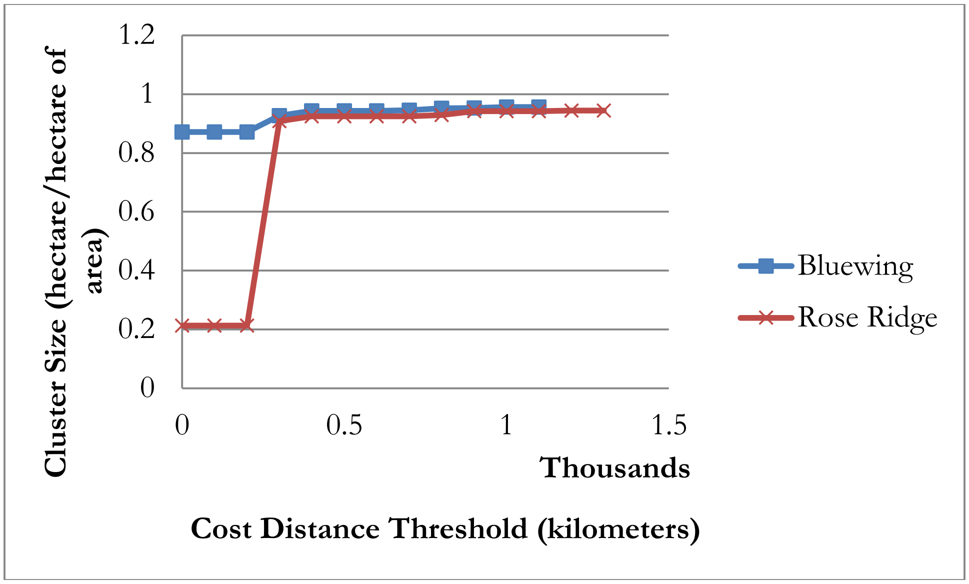

Figure 26: The Difference in Undisturbed Land Connectivity between Bluewing and Rose Ridge corridors (Small Cost Distance Threshold).

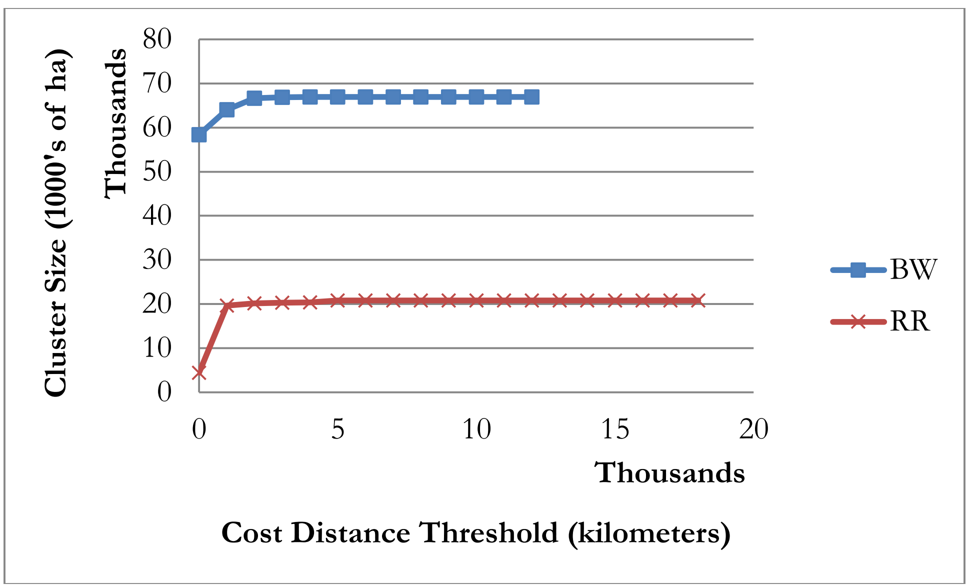

Figure 27: The Difference in Undisturbed Land Connectivity between Bluewing and Rose Ridge corridors (Large Cost Distance Threshold).

4.3 What GIS Methods were useful in determining Connectivity and Fragmentation between RMNP and DMPPF?

In sensitivity analysis, instead of using a binary landscape, three or four categories of costs values were tested. Thus, the range of costs for each land use were expanded for different classes, such as for agriculture, roads, water and wetlands. For example, when grassland/rangeland, one of the dominant land types, was assigned a low cost the results changed for LCP and SG. This change for grassland/rangeland made it appear that there was greater connectivity with more favorable habitat between patches as well as between RM and DM. However, grassland/rangeland was assigned a high cost because of the field work showing that the land had no natural cover for wildlife: these lands were highly managed and disturbed in most areas. After collecting field data, most agricultural areas, including agricultural cropland, grassland/rangeland and forage crops were observed to have no natural cover for wildlife and barriers to wildlife, such as fences. Hence, the decision was made to assign agricultural areas the value of disturbed land. Even with a multiple settings to provide a more nuanced development status to show subtle differences in degree of development, the result was similar to the binary landscape for both FNF and DND.

To determine a corridor much data was required to evaluate the suitability of the landscape. In order for a good corridor design a number of factors must be known: 1) what areas to connect, 2) structural connectivity requirements, 3) functional connectivity requirements, and 4) species at risk of extinction from limited habitat or connectivity (Beier et al., 2007). Each method provided its own contribution to the analysis of connectivity. Maps were provided by ED, LCC, LCP and SG. Statistics were calculated by PG, LCP and SG. The LCC method indicated corridor boundary and size. Lastly, distance statistics were calculated by PG, ED, LCP and SG. However, there were some manual calculation as indicated in Table 12 below with an asterisk (*). Table 13 showed both advantages and disadvantages of each of the methods based on findings along with literature about some methods providing more information for decision-making. For distinct advantages PG could show basic statistics of landscape, ED could produce a map, LCC can identify potential corridor, LCP can optimal path and SG can provide cluster statistics. However, disadvantages could include the following: both PG and ED did not produce a map, LCC could not generate useful statistics for patch connectivity and fragmentation, LCP could not show overall patch connectivity and lastly, SG could not show definitive corridor (more detail references were available in Table 13 below).

The summary of indicator findings for corridor development and decision-making were shown in Table 14. These indicators were as follows shortest direct distance or ED, LCP for forested and undisturbed land, mainly most fragmented area for forested and undisturbed land, mainly most connected area for forest and undisturbed land and lastly, the need for connectivity between RM and DM. This research findings was based on previous research by Walker (2002), Charney (2006), Brook (2008), (Aidnell, 2006) and (NCC, 2008). As a result, the following areas were identified with pros and cons: central area, BW corridor, RR corridor and western area (for more detail please refer to Table 14 below).

For the final decision-making on selecting the best corridor, this research focused on the western, central and eastern areas. Finally, Table 15 reviewed the finding organized by areas to support corridor development in each area (ranked out of the three areas). The eastern area was not found by any method to have the best corridor or connectivity. The central area was found to have the shortest distance between RM and DM. The western area was found to have the best corridor and connectivity (for detail please refer to Table 15 below). However, the different GIS methods provided sufficient information to select a corridor based on connectivity. Although the shortest possible path between RM and DM was through the central region, as indicated by the ED tool, a corridor must consider both the quality and connectivity of habitat. If we consider the preferred habitat as forest or undeveloped land, then the LCC could show corridors within the BW and next to the RR region. Similarly, the LCP, which is the best route between two points, could be influenced by the short distance in the western-central area that is inside the BW corridor. Finally, the SG showed the western region including the BW corridor had the highest connectivity. The BW corridor was the least fragmented area, as compared to the RR corridor along with central and eastern regions of RM and DM. The forested landscape had a higher cost than that of the undisturbed land. Undisturbed land considered all natural land cover and not just forested land as preferred land, including three additional land use classes in addition to forested land. Thus, the forest path produced complex paths more costly to travel than the undisturbed data with relatively straight paths. Although the paths for the FNF and DND scenarios were not exactly the same, they were in the same general area – the western region. However, the analysis by SG, in particular, found the undeveloped land in BW to have even better patch connectivity and reduced fragmentation than forested land.

Table 12: Capabilities of each GIS Method

Method	Produce a Map	Calculate any Statistics	Corridor Boundary and Size	Calculate Distance Statistics
PG	X	✓	X	✓
ED	✓	X	X	✓*
LCC	✓	X	✓*	X
LCP	✓	✓*	X	✓*
SG	✓	✓	X	✓

✓ = Yes
X = No
***** = manual calculation required

Table 13: Advantages and Disadvantages of each of the Methods based on Findings and Literature

Method	Advantages	Disadvantages	References
PG	▪ Shows basic statistics of the landscape	▪ Does not produce a map that shows a path or connectivity and fragmentation along with associated statistics	▪ Li et al. (2005) and Turner (2005)
ED	▪ Produces a map with colors and shades to visually show the distance between RM and DM	▪ Does not include factors that promote or restrict movement nor show potential links between RM and DM. ▪ Does not produce a map that shows a path or connectivity and fragmentation along with associated statistics	▪ Bender et al. (2003) and Moilanen and Nieminen (2002)
LCC	▪ Maps and identifies potential corridors	▪ Does not produce useful statistics for patch	▪ ESRI (2006)

	between two points by using cost criteria	connectivity and fragmentation	
LCP	▪ Determines an optimal path between two points using cost criteria ▪Statistics can be calculated manually	▪ Does not show the overall patch connectivity in the landscape - only one path that links a limited number of patches	▪ Brooker et al. (1999) and LaRue and Nielsen (2008)
SG	▪ Documents the overall connectivity of the landscape including all potential linkages between patches at the patch level ▪ Provides cluster statistics	▪ Does not show a definitive corridor that can be used for conservation ▪ Map is hard to interpret – visually busy	▪ Cantwell and Forman (1993), Goetz et al. (2009), Pascual-Hortal and Saura (2006) and Urban et al. (2009).

Table 14: Summary of Indicator Findings for Corridors Decision-Making

Indicator	Research finding from this study (with method used)	Previous Research
▪ Shortest direct distance (ED)	▪ Central – see Table 12, and Table 16 (ED).	▪ A 1991 map in Walker (2002) shows a narrow strip of forest that can be considered the shortest direct distance between RM and DM.
▪ LCP for forested and undisturbed land	▪ BW corridor inside the western area between RM and DM (LCP).	▪ Charney (2006) shows a potential path exists in the RR Corridor in central RM and DM for ungulates.
▪ Most fragmented area for forested and undisturbed land ▪ Most non-forest and disturbed area	▪ Out of the three areas: central region - see LU/LC composition and SG (Figure 21 and Figure 23). ▪ Out of the two corridors: RR corridor - see LU/LC composition and SG (Figure 24, Figure 25, Figure 26 and Figure 27).	▪ Walker (2002) shows north of RMNP as most fragmented particularly the RR corridor. Widespread forest loss from agriculture developed over many years especially in the RR corridor.
▪ Most connected area for forest and undisturbed land ▪ Most forest and undisturbed area	▪ Out of the three areas: western region - see LU/LC composition and SG (Figure 20, Figure 21, Figure 22 and Figure 23).	▪ A 1991 map in Walker (2002) shows the BW corridor (western area) having more forest than the RR Corridor (central area).

▪ Largest cluster size or area a group of patches make up ▪ Nearest distance to patch ▪ Shortest LCP between patches	▪ Out of the two corridors: BW corridor see LU/LC composition and SG (Figure 24, Figure 25, Figure 26, and Figure 27).	
▪ The need for connectivity between RM and DM	▪ Agriculture-related activities surround forest and undisturbed patches. ▪ Central area came out as the worst area in terms of amount of connectivity and fragmentation among forest and undisturbed patches. See SG (Figure 21, Figure 23 and Table 21).	▪ Brook (2008) – elk exist in areas adjacent to RMNP. ▪ Required for survival of wolves population (Aidnell, 2006). ▪ Walker (2002) - shows north of RMNP as most fragmented from agriculture over the years. ▪ In the Riding Mountain Aspen Parkland Conservation Plan (NCC, 2008)

Table 15: Summary of Best Corridor and Connectivity by each Method for Different Areas

Area	Best Corridor and Connectivity by each method for the study area (according to area)
Eastern	▪ Not found by any method to have the best corridor or connectivity
Central	▪ Shortest distance (ED).
Western	▪ LCP for forested and undisturbed land. ▪ Most forest and undisturbed area according to statistics. ▪ Most connected area for forest and undisturbed land according to statistics. ▪ Largest cluster size or area a group of patches make up. ▪ Nearest distance to patch. ▪ Shortest LCP between patches.

Chapter 5: Discussion, Conclusions and Recommendations

Without any established corridors between RM and DM, corridor development requires research as to the need for connectivity and the best location for a corridor. Stronen (2009) and Brook (2008) have found wildlife to roam and migrate to agricultural lands outside RMNP boundaries, which may put wildlife at risk (Forbes & Theberge, 1996). Both RMNP and DMPPF are surrounded by agricultural activity, which provides limited habitat for many species (CEAA, 2004; Manitoba Conservation, 2007; NCC, 2008; Parks Canada, 2007). Without any existing continuous corridor of undisturbed land between RM and DM, nor much forested area outside of RM, according to LCP, conservation work for an official corridor seems necessary.

Literature showed the importance of maintaining ecosystem integrity and the need for corridors to prevent fragmentation. Establishing a BW corridor would restore connectivity between the isolated natural habitat areas between RM and DM to potentially: 1) facilitate wildlife movement (Fleury & Brown, 1997; Vogt et al., 2009), 2) create a path for seed and pollen dispersal for plants (Drielsma et al., 2007), 3) minimize habitat fragmentation, 4) place less strain on isolated habitats, 5) decrease the risk of extinction, 6) increase the size of wildlife habitats, and 7) maintain biodiversity (Hess & Fischer, 2001). This corridor would also enable a larger region for wildlife movement between RM and DM for: 1) breeding, 2) enlarging home ranges, 3) finding food and water during the different seasons, 4) ensuring genetic variability, and 5) maintaining wildlife populations over a wide area (Parks Canada, 2012). By establishing and maintaining corridors of connected undisturbed land, landscape connectivity provides physical linkages between the parks and protection of the entire landscape ecological system(Rodriguez Gonzalez et al., 2008). Creating a corridor will become more important with the constant and rapid pace of land development.

Many metrics and maps showed that the BW corridor was the most intact for undisturbed land and forested land. The LCC analysis visually portrays a large strip of existing forest in the BW corridor that does not occur in the RR Corridor. The LCP also shows the strip of forest in BW as a potential route between RM and DM for forested and undisturbed land. Charney (2006) also carried out a LCP analysis between the two areas for ungulates and found the RR corridor as a potential corridor. However, these research findings conflict with Charney's recommendations of a corridor due to her use of different criteria and less advanced methods.

Hence, the recommendation is for designing the BW corridor. For SG, the BW showed higher connectivity than the RR corridor due to its higher cluster size and lower cost distance threshold for forested and undisturbed land. The SG model consists of nodes that represent habitat patches. Cluster size in the BW corridor, however, is greater than in the Central and Eastern areas, which means higher amounts of habitat providing less cost of travelling to other nearby patches. This BW corridor contains a higher percent of undisturbed land with a mix of forest, water and wetlands than the RR corridor, thus would provide a strip of land to: l) connect the parks with similar habitat patches from the surrounding matrix (Kindall & Manen, 2007), 2) restore connectivity between the isolated natural habitat areas of the park to facilitate wildlife movement (Fleury & Brown, 1997; Vogt et al., 2009) along with seed and pollen dispersal for plants (Drielsma et al., 2007), 3) minimize habitat fragmentation by agriculture and other developments in the parkland, 4) place less strain on isolated habitats of parks, 5) decrease the risk of extinction, 6) increase the size of wildlife habitats of parks, and 7) maintain biodiversity (Hess & Fischer, 2001). The path in the BW corridor identified by different GIS metrics/models is compatible with the desire to remove wildlife from agrarian areas. Nonetheless, some animals may not be considered desirable near agrarian areas. Brook (2008) reported possible spread of tuberculosis from elk to farmer's cattle and could cause conflict between elk and farmer surrounding RMNP. With a wildlife corridor in RM and DM, there could be lesser negative impacts to wildlife. Anyhow, wildlife is still using these agrarian areas noted by Aidnell (2006) with telemetry data showing wolves move through the BW and RR corridors. In addition, Charney (2006) found ungulates to use the central RR corridor passing through many agriculture. In this study, LCP and SG identified a path in the west side. Based on its more natural state and level of development, the BW corridor should be the focus for corridor development because it is easier to preserve land than remediate it. However, the research data indicated the BW corridor is much longer at 41.75 km, which is more costly to conserve compared to the 32.2 km of the RR corridor.

In determining the undisturbed corridor and forested corridor (without animal data), the various methods used in this research could provide different useful information. The shortest distance between RM and DM was in the central region according to ED without consideration of land use over this distance. LCP identified potential corridors through forest and undisturbed habitat. SG provided a network of patches that could be traced between RM and DM. Many other authors , Brudvig et al. (2009), Galpern et al. (2010), Goetz et al. (2009), O'Brien et al. (2006) and Pinto and Keitt (2009), used LCP and SG for fragmentation, connectivity and corridors. Also, Adriaensen et al. (2003) applied solely LCP to determine corridors. Beier and Noss (2008) analyzed connectivity and found them useful, as did this thesis. The LCP was able to identify both an undisturbed corridor and a forested corridor. The LCPs for both these corridors were found to be in the western region. The LCP between RM and DM showed a path from southwestern DMPF and northwestern RM. It runs 41.7 km through undisturbed land and a bit longer at 44.5 km to prioritize forested land in BW Corridor. This BW Corridor is favored by LCP despite it being 10 km longer than the RR corridor ED of 32.2 km (when measured by geographic or straight-line distance). The LCPs did not intersect any wildlife management areas or refuges, protected areas or provincial parks because the DM wildlife refuge, with an area of 1813 ha, is within the DM boundaries.

The LCP in BW is recommended as the approximate basis for a corridor route, considering SG and other findings. The conservation organizations can use the data and maps in this thesis to determine specific land parcels for conservation in order to create a corridor. Future conservation work should create a continuous path or corridor in these areas and can be further assisted by the SG maps. This conservation work can provide not only different options for patches to create a corridor, but also a basis to select properties for conservation, which will allow multiple options for a continuous path between RM and DM. Nonetheless, these maps and data have been provided to NCC, PHP and Dr. Thompson.

Another consideration for the location of the corridor is the property owners, as this land is highly developed already, particularly for agriculture (Brierley & Todd, 1990). Land owners may or may not be willing to conserve properties. Sometimes, it may not be possible to easily change land use. For example, landowners may not want to abandon their developmental plans to turn the land into a corridor. When considering which areas to select for easement, buying or restoring those that have high connectivity according to SG between patches in BW should be given a priority. This thesis and maps have identified the BW corridor for conservation, with information about the status of the land including wildlife refuges (identified in maps with thick lines) and crown land (square or rectangular shaped). Each land parcel designated as wildlife land, wildlife management area, water management, marsh/bog, fen and ecological reserve (Figure 14) has been identified.

Therefore, this study focused on structural connectivity because functional connectivity usually requires species field data (Fall et al., 2007), which was unavailable. Structural connectivity is suited for studying a species-habitat relationship over an extensive period of time. When species data become available, it could be applied to this data. Although past studies in between RM and DM have used LCP along with species movement, none has applied SG. However, SG has studied woodland caribou movement in lowlands natural region in Manitoba (Fall et al., 2007) and southeastern Manitoba (O'Brien et al., 2006) but not RM and DM.

To increase biodiversity between RM and DM, it is recommended that other conservation methods should be undertaken in addition to corridors. In the literature review (Chapter 2) some studies with favorable habitat and areas of high connectivity should not be the only focus of research on conservation work. Adjacent unfavorable and low connectivity areas have direct influence that should further be studied to enhance conservation efforts. For example, corridors should be enhanced by stronger government policy that is not location specific with wildlife habitat protection and certain limits to land conversion or use.

5.1 Further Research

This research does not specifically consider animal species movement. This GIS analysis can be used with animal movement data to improve accuracy of connectivity to make better decisions in the future. Behavioral and habitat requirements of animals like wolves, golden-winged warblers and fishers can be included in calculating the cost assigned to the land cover. In order to find the best corridor, some generalizations on the behavior and habitat requirements of any specific wildlife species will be needed to make it applicable to a number of species. However, other studies (Fall et al., 2007; Treml et al., 2008; Urban & Keitt, 2001) have been using SG with actual wildlife movement.

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APPENDIX I

Land Use/Land Cover Mapping of Manitoba
(Manitoba Remote Sensing Centre, 2004)

1. Agricultural Cropland; All lands dedicated to the production of annual cereal, oil seed and other specialty crops. This class can be further sub-divided into three crop residue classes; 0%-33%, 34%-66%, 67%-100%.

2. Deciduous Forest; 75%-100% of the forest canopy is deciduous. Dominant species include trembling aspen (Populus tremuloides), balsam poplar (Populus balsamifera) and white birch (Betula papyrifera). May include small patches of grassland, marsh or fens less than two hectares in size.

3. Water; Consists of all open water - lakes, rivers, streams, wetland ponds and lagoons.

4. Grassland/Rangeland; Lands of mixed native and/or tame prairie grasses and herbaceous vegetation. May also include scattered stands of associated shrubs such as willow, choke-cherry, saskatoon and pincherry. Areas may also be used for the cutting of hay while others are grazed. Both upland and lowland meadows fall into this class. There is normally less than 10% shrub or tree cover.

5. Mixedwood Forests; Forest lands where 25% to 75% of the canopy is coniferous. May include patches of treed bogs, marsh or fens less than two hectares.

6. Marsh*; Wetland vegetation of a multitude of different herbaceous species. These marshes range from intermittently inundated (temporary, seasonal, semi-permanent) to permanent depending on the current annual precipitation regime. Common vegetation species include; sedge (Carex spp.), whitetop (Scolochloa festucacea), giant reed grass (Phragmites australis), prairie cordgrass (Spartina pectinata), mannagrass (Glyceria spp.), spikerush (Eleocharis spp.), reedgrass (Calamagrotis spp.), wild barley (Hordeum jubatum), bluegrass (Poa spp.), cattail (Typha spp.) and bulrush (Scirpus spp.) depending on the depth of water. This zone can have a water tolerant shrub component (i.e. willow, Salix spp.) where the shrubs do not dominate the area, but there is clear evidence of wetland indicators.

7. Treed and Open Bogs: Bogs are peatlands typically covered by peat mosses (Sphagnum spp.) and ericaceous shrubs (heath family; eg Labrador tea, Ledum spp.) although other mosses and lichens thrive here as well. Tamarack (Larix laricina) and black spruce (Picea mariana) are also found in boggy landscapes in the boreal forest, the transition zone and in agro-Manitoba.

38. Treed Rock: Lands of exposed bedrock with less than 50% tree cover. The dominant species is jack pine and/or black spruce and occasional areas of shrub.

9. Coniferous Forest: Forest lands where 75% to 100% of the canopy is coniferous. Jack pine and spruce are combined under this class. May include patches of treed bogs, marsh or fens less than two hectares in size.

10. Wildfire areas: Forest lands that have been recently burned (wildfires less than 5 years old) with sporadic regeneration and can include pockets of unburned trees.

11. Open Deciduous / Shrub: Lands characterized by shallow soils and/or poor drainage, which supports primarily a cover of shrubs such as willow, alder, saskatoon and/or stunted trees such as trembling aspen, balsam poplar and birch. An area could contain up to 50% scattered tree cover.

12. Forage Crops: Agricultural lands used in the production of forage such as alfalfa and clover or blends of these with tame species of grass. Fall seeded crops such as winter wheat or fall rye may be included here.

13. Cultural Features: Cities, towns, villages and communities with place names. Also includes peat farms, golf courses, cemeteries, shopping centers, large recreation sites, auto wreckyards, airports, cottage areas, race tracks and rural residential.

14. Forest Cutovers: Forest lands where commercial timber has been completely or partially removed by logging operations. Includes areas which have been replanted (plantations less than 10 years old).

15. Bare Rock, Sand and Gravel: Lands of exposed bedrock, gravel and/or sand, sand dunes and beaches with less than 10% vegetation. Also includes gravel quarry/pit operations, mine tailings, borrow pits and rock quarries.

16. Roads and Trails: Highways, secondary roads, trails and cut survey lines or right-of-ways such as railway lines and transmission lines.

17. Fen*: Fens are peatlands with nutrient-rich, minerotrophic water and organic soils composed of the remains of sedges and/or moss, where sedges, grasses, reeds and moss predominate but could include shrubs and sparse tree cover of black spruce and/or tamarack. Much of the vegetative cover composition of fens would be similar to the vegetation zones of marshes.

*Marsh and Fen are often combined into the larger land use class of Wetlands.

APPENDIX II

Sensitivity Analysis

Sensitivity analysis studies how results change when weights of parameters are altered (Store & Kangas, 2001). This analysis can be especially helpful when the importance of different factors is uncertain (Store & Kangas, 2001).

Sensitivity analysis was conducted to investigate the impact of variations in the following: 1) GIS data source, 2) optimal cell size, 3) optimal cost value, 4) different scenarios – modified forested and undisturbed classification 5) direction of path and 6) program settings.

GIS Data Source: Comparing LU/LC Data to FRI and Satellite Imagery

Comparing Land use/land cover LU/LC data to Forest Resource Inventory (FRI) and aerial photos confirmed that LU/LC were the most appropriate data to analyze based on a number of factors. LU/LC had better resolution of patch shapes with colors to differentiate between the different types of land cover and land use. The LU/LC data showed much smaller patches that were missing in the FRI. Even though the LU/LC is raster, the 30 m resolution provided much more detail for patch shape and the classification of LU/LC classes than the FRI. The reason for this is that the FRI was based on the use of stereoscopes and aerial photography (Cary Hamel, Nature Conservancy of Canada, personal communication, March 11, 2011). The FRI also differentiates between water bodies and wetlands, with possible combination the two land covers into one patch. Due to the 1980s to 1990s age of the data (MLI, n.d.) in the FRI, land cover has been developed over time from forest to agriculture when compared to more recent LU/LC

(Manitoba Remote Sensing Centre, 2004). Some FRI forest patches are replaced with another land cover mostly of agriculture in the newer data.

A second comparison was made with the aerial photos dating from 1992-1998 (MLI, n.d.). They were more visually accurate to show the exact stream or river bends. However, it was unusable for analysis. The LU/LC layer when overlaid on top of the aerial photos were less accurate only when zooming at patches for the different landscape covers. Thus, the newer LU/LC layer were slightly inaccurate, thereby simplifying features. However, is was a good compromise to use for further analysis and for making maps. Aerial photos do not have classification, thus they could not be used for ED, LCC, LCP and SG analysis.

Based on examining the LU/LC data, it had the following advantages: 1) being the most recent information, 2) having the highest resolution and 3) showing more land covers than just the forest categories.

Raster Data Cell Size

In ED, LCC, LCP and SG, cell sizes of 30 and larger were tested to see if the results really differed. The smaller the cell size, the greater the detail, especially at smaller scales. Hence, the small size of 30 m resolution was selected.

Costs in Euclidean Distance and Least-Cost Corridor

Costs 25, 50, 75 and 100 were tested in ED and LCC to determine what cost to apply. A 100 cost value was found to be better than lower cost values in showing any possible corridors due to the level of details.

Euclidean Distance Findings

Euclidean Distance showing RM and DM were two areas in close proximity and distance. However, this tool were not useful for showing paths, forest fragmentation and connectivity. This was a simple tool that calculated the direct distance from a source (as in the case of RM and DM). However, it did not take into account any factors that could promote or restrict wildlife movement (Taylor et al., 2006). In addition, it did not show potential linkages between RM and DM. As a result, this tool was considered the least useful tool.

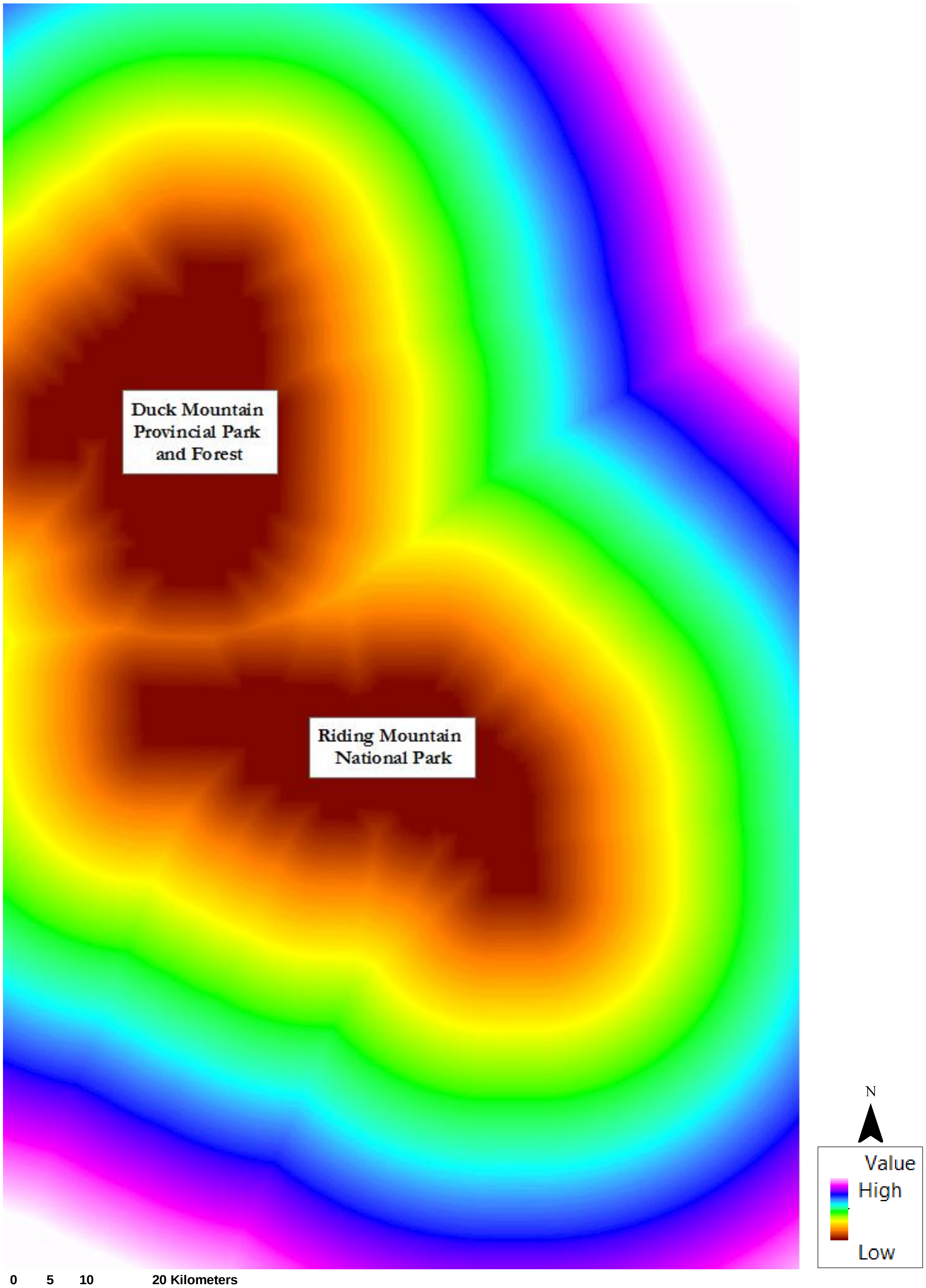

Figure 28: Euclidean Distance only shows the shortest direct distance between Riding Mountain National Park and Duck Mountain Provincial Park and Forest.

Table 16: Euclidean Distance for each Corridor as a Measuring Tool

West	Central	East
24.86 km	17.61 km	27.31 km

The shortest distance was 18 km in the central corridor followed by 25 km in the west and 27 km in the east as shown in Table 16 . The central corridor distance was almost one-third shorter than the east side corridor and about one-quarter shorter than the west corridor. Euclidean Distance showed that the central region was the shortest distance without considering any other factors when travelling between the RM and DM.

Least-Cost Path Factors

Directional Analysis for Running LCP

The findings of LCP were similar when running between RM and DM from North to South and South to North with slight differences. Since these paths were quite similar, analysis was done from South to North (RM to DM). By changing the cell size, it was found smaller cell size of 30 m resolution did provide a more detailed path. Sensitivity analysis showed two possible corridors in western and central regions. FNF analysis produced a landscape that was higher cost than DND, because it included all natural land cover. Thus, the FNF produced more complex and more costly paths to travel than DND. As a result, it produced straight paths from western and central regions. Even though the paths for FNF and DND were different, they were located in the same regions on the landscape.

The generated LCPs using a cell size or resolution of 30 m was preferred because of the finer details at smaller scales. This included the use of smaller patches between larger ones to travel in the landscape. There were several differences in the LCPs produced when a cell size was set to 30 and when no cell size was specified. When cell size was set to 30 m resolution, forest in FNF was clearly more dominant than that of the DND forest. These results were expected to happen because in FNF only forest was used, while in DND other natural land covers, including forest, were used. When no cell size was specified, the computer automatically picked the cell size or resolution as 230 m and 280 m for the intermediate files and LCPs. This resulted in LCPs that were larger in width. The omitted smaller patches may be useful, including larger portions of non-forest or undisturbed land in the path. The larger cell sizes consequently reduced the accuracy of the line and skewed the total land cover percentages, especially for the forest and non-forest scenario. On the other hand, when cell size was set to 30 m to match the original LU/LC data, the LCPs were more accurate. It was done by generating thinner lines that could pass through even the smallest patches when zoomed in at smaller scales. With a cell size of 30 m, it was much easier to identify stepping stone patches or smaller more interesting patches.

The following methods to generate LCP were tested: 1) "for each cell", 2) "for each zone" and 3) "best single". This was done to analyze which right path choice was chosen to show a LCP. As a result, the "best single" was selected because it showed the best single and least costly path. Both "for each zone" and "best single" created a LCP, based on the best path for each zone and one path for all zones respectively. "For each cell" the LCP assessed each cell in each zone (a group of cells, connecting or non-connecting having the same cost value) to make a path (ESRI, 2009; Harvard Design School, n.d.). This method created a more detailed path but took much more time. It was because it included each cell along with the source and also destination polygons. Even though the "for each cell" option was excluded from this case study, yet what was interesting in trials was that this method simply showed additional paths towards north-west, south-west and central DM, as well as more paths to north-west and central RM.

The "for each cell" option was not used because it included the pixels of complete polygons. Thus, it would not be accurate for statistical analysis of only the paths. Values 250, 500, 750 and 1000 were used in trials, but produced the same paths as values 75 and 100 or all values. Therefore, values 25, 50, 75 and 100 are considered to be adequate to conduct analysis.

Spatial Graphs

(1) Determined the sensitivity of costs and found highest cost provided more contrast.
(2) Determined if binary costs were different than using three or four classifications of costs values in the landscape. It including promoting or demoting agriculture, roads, water or wetlands. It was found slightly difference but not significant. Thus binary landscape was chosen.

When grassland/rangeland was considered low cost for DND, the amount of undisturbed habitat was significantly high. When grassland/rangeland was considered high cost, the amount of undisturbed habitat was already high. As a result, this made the SGs having high connectivity, especially when compared to FNF. Therefore, when grassland/rangeland was at low cost for DND, the distance was short and more accessible to travel between all patches. In all cases, the western area was found to have the highest connectivity.

Overall Sensitivity Findings

When analyzing at the regional scale, it was found no matter which scenario, Western RM and DM were most connected and least fragmented. For any one of the scenarios analyzed, the western region had the least amount of fragmentation and highest connectivity between the RM and DM. It was found by having the shortest distance between patches with the highest amount of habitat. In addition, there were not much forested area with highly fragmented forest and undisturbed lands between RM and DM (LU/LC composition, PG and LCP). Likewise, there were no continuous corridor of forest or undisturbed land between RM and DM. Forest analysis produced a landscape that was more costly to travel through than undisturbed lands, because it excluded all the other natural land cover such as water and wetlands.

Landscape connectivity and potential paths for forested and undisturbed lands were slightly different but in the same general area (LCC, LCP and SG). Both BW and RR corridors were supported by the findings from LCC for forest and undisturbed analysis. RR corridor provided the shortest distance between RM and DM. BW corridor was supported by LU/LC composition, LCP and SG findings. The south-eastern portion of BW provided the LCP between RM and DM for forested and undisturbed land. BW had overall higher connectivity than the RR corridor. It was due to larger cluster size over certain cost distance thresholds for forested land, in particular (SG).

APPENDIX III

More Detailed Results from LCP and SG

Table 17: Diversity Metrics for Landscape and Different Regions

Name	Shannon's Diversity Index	Simpson's Diversity Index	Shannon's Evenness Index	Simpson's Evenness Index	Modified Simpson's Diversity Index	Modified Simpson's Evenness Index
Overall Lands-cape	1.92	0.80	0.68	0.86	1.63	0.58
West	1.70	0.77	0.61	0.82	1.47	0.53
Central	1.46	0.65	0.55	0.70	1.05	0.40
East	1.36	0.64	0.50	0.69	1.03	0.38

Table 18: Area, Patch Density, Size and Edge Metrics for Different Classes in Overall Landscape

Class	Class Area (ha)	Percent-age of Lands-cape (%)	No. of Patches	Mean Patch Size (ha)	Patch Size Standard Deviatio n (ha)	Edge Density (m/ha)
Deciduous Forest	213292.71	24.03	26090.00	8.18	249.77	44.43
Mixedwood Forests	77567.67	8.74	23346.00	3.32	114.16	27.02
Treed and Open Bogs	2641.41	0.30	218.00	12.12	31.87	0.49
Treed Rock	0.36	0.00	2.00	0.18	0.00	0.00
Coniferous Forest	26005.86	2.93	7472.00	3.48	28.95	9.52
Wildfire Areas	31.77	0.00	2.00	15.89	4.82	0.01

Open Deciduous/ Shrubs	12605.76	1.42	4070.00	3.10	20.37	3.55
Forest Cutovers	9174.69	1.03	353.00	25.99	35.48	1.15
Water	25773.12	2.90	4480.00	5.75	71.07	6.15
Marsh	46511.64	5.24	21017.00	2.21	16.61	18.66
Agricultural Cropland	275897.34	31.09	2614.00	105.55	570.79	21.79
Grassland/R angeland	144203.49	16.25	16646.00	8.66	109.20	31.28
Forage Crops	34679.97	3.91	1370.00	25.31	27.75	4.46
Cultural Features	1467.72	0.17	58.00	25.31	51.00	0.21
Bare Rock, Sand and Gravel	288.27	0.03	68.00	4.24	4.78	0.09
Roads and Trails	17363.34	1.96	40.00	434.08	2663.16	13.95

Table 19: Diversity and Interspatial Metrics of Different Classes in Overall Landscape

Class	**Mean Nearest Neighbor Distance (m)**	**Mean Proximity Index**	**Interspersion Juxtaposition Index**
Deciduous Forest	69.16	9896.94	65.10
Mixedwood Forests	53.83	3935.97	49.84
Treed and Open Bogs	883.24	53.72	58.47
Treed Rock	22087.91	0.00	44.60
Coniferous Forest	111.32	371.40	44.11
Wildfire Areas	161.55	6.09	33.36
Open Deciduous/Shrubs	182.82	81.22	66.60

Forest Cutovers	376.59	93.25	48.28
Water	257.09	48.94	60.53
Marsh	92.75	135.32	65.88
Agricultural Cropland	72.63	15785.99	52.69
Grassland/Rangeland	72.88	1966.24	58.47
Forage Crops	348.99	159.47	58.64
Cultural Features	2104.19	498.60	49.04
Bare Rock, Sand and Gravel	2534.81	13.41	43.34
Roads and Trails	255.30	56759.36	52.20

Table 20: Core Area Metrics for Different Classes in Overall Landscape

Class	**Total Core Area (ha)**	**Mean Core Area (ha)**	**Core Area Standard Deviation**	**Core Area Density**
Deciduous Forest	137843.01	6.60	229.96	2.35
Mixedwood Forests	37404.00	2.51	102.55	1.68
Treed and Open Bogs	1795.86	9.81	27.09	0.02
Treed Rock	0.00	0.00	0.00	0.00
Coniferous Forest	11496.69	2.00	21.15	0.65
Wildfire Areas	20.79	10.40	3.02	0.00
Open Deciduous/Shrubs	6916.41	4.39	22.25	0.18
Forest Cutovers	7031.07	24.41	31.16	0.03
Water	16689.24	6.07	84.17	0.31
Marsh	19029.87	1.83	16.58	1.17
Agricultural Cropland	227535.39	45.04	361.18	0.57
Grassland/Rangeland	88923.96	6.62	95.61	1.51
Forage Crops	25059.51	14.93	21.48	0.19
Cultural Features	1042.11	11.58	34.02	0.01
Bare Rock, Sand and Gravel	130.14	2.03	3.01	0.01
Roads and Trails	64.08	0.09	2.40	0.08

Table 21: Statistics of Patches, LCPs and Clusters that make up the Spatial Graph

Scale	Scen-ario	Mean Distance to Nearest Patch (km)	Largest Distance to Nearest Patch (km)	Mean Length of LCP between Patches (km)	Largest Length of LCP between Patches (km)	Smallest Cluster Size (1000's of ha)	Largest Cluster Size (1000's of ha)
Land-scape	FNF	0.31	2.77	0.77	17.15	123.53	511.84
	DND	0.29	2.77	0.63	5.08	145.68	694.20
BW	FNF	0.11	1.53	0.37	2.36	1.52	29.27
	DND	0.07	0.48	0.16	1.13	58.37	66.97
RR	FNF	0.12	0.92	0.36	2.58	0.33	8.59
	DND	0.07	0.48	0.16	1.27	4.43	20.84
West	FNF	0.14	2.09	0.49	5.33	0.75	35.54
	DND	0.10	0.78	0.26	2.24	69.75	90.92
Central	FNF	0.21	4.13	0.72	5.60	2.03	19.28
	DND	0.11	0.99	0.32	2.55	8.36	42.18
East	FNF	0.16	2.15	0.54	5.81	0.34	33.14
	DND	0.11	1.34	0.35	2.51	17.83	84.48

APPENDIX IV

Field Data Collection Photos that Show Common Characteristics and Unique Features of the Study Area

Figure 29: Examples of the impacts of Agriculture Activities - Hayland in the Eastern area of Duck Mountain Provincial Park and Forest.

Figure 30: Examples of the impacts of Agriculture Activities - Cropland in Central area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Grandville Area).

Figure 31: Example of how Fences divide Rangeland and Grassland from Treed Areas in Central area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Grandville Area).

Figure 32: Example of Hydro Corridor Creating Gaps in the Forest in Eastern area of Duck Mountain Provincial Park and Forest.

Figure 33: Example of a Grazing Area by Cows in Grassland and Rangeland in Central area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Grandville Area).

Figure 34: Example of Fenced Cropland in Central area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Grandville Area).

Figure 35: Example of Numerous Buildings needed to conduct large-scale Farming Operations in Eastern area of Duck Mountain Provincial Park and Forest.

Figure 36: Example of typical gravel roads that runs along the Border of Quarter-Sections in Central area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Grandville Area).

Figure 37: Example of earth road used locally and runs along quarter-sections in Eastern area of Duck Mountain Provincial Park and Forest.

Figure 38: Example of man-made Rock, Gravel and Sand Pits on Disturbed Land in Eastern area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Turtle River Area).

Figure 39: Example of the large-scale of agriculture activities and how Forest Patches exist in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Lake of the Prairies Area).

Figure 40: Example of the large-scale of agriculture activities and how Forest Patches exist in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Lake of the Prairies Area)

Figure 41: Example of multiple uses of that land at a large scale including Rock, Sand and Gravel Pits and agricultural activities that Fragments Forest in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Lake of the Prairies Region).

Figure 42: Example of development in the Western Region (Assisippi Ski Resort) that is surrounded by Cropland and Fragmented Forest in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Lake of the Prairies Region).

Figure 43: Example of debris left after land clearing of trees and other vegetation in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Lake of the Prairies Region).

Figure 44: Example of horses grazing in Grassland and Rangeland in area South of Riding Mountain National Park (Assiniboine River Area).

Figure 45: Example of a train that goes on indefinitely in the landscape in area South of Riding Mountain National Park (Assiniboine River Area).

Figure 46: Example of Cropland and Forest on sloping hills in area southwest of Riding Mountain National Park (Birdtail Creek Area).

Figure 47: Example of gravel roads within dense forest vegetation in Western area between Riding Mountain National Park and Duck Mountain Provincial Park and Forest (Shell River Area).

Figure 48: Example of the density of Aspen and undergrowth in area southwest of Riding Mountain National Park (Birdtail Creek Area).