Enhancing ecological connectivity: providing climate change resilience to the Rural Municipality of Ritchot

By

Natalie Lagassé

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Department of City Planning

University of Manitoba

Winnipeg

Abstract

Over the last century land conversion has led to natural land loss and fragmentation in the Rural Municipality of Ritchot. This loss has changed the composition and configuration of biological elements in the landscape altering biodiversity and contributing to a degradation of ecosystem services. Climate change is expected to increase the potential for flooding, drought, heat stress, fire, and pest problems, and alter terrestrial and aquatic ecosystem. This threatens to further alter biodiversity and ecosystem services by reconfiguring ecosystems and their associated functions as they respond to anticipated effects. Building resilience into the landscape requires a balance between land use pressure. The ecological network planning approach balances these priorities by connecting fragmented ecosystems to support biodiversity and ecological function within a human land use context. Using the Sustainable Land Planning Framework and GIS spatial analysis, the research quantified landscape ecosystem composition and configuration of a sample site in the Rural Municipality of Ritchot. The research determined that natural lands consisted of forest, grassland, wetland, and riparian ecosystems, were fragmented, and occupied substantially less area than their historical range. These natural lands are found within an agriculture dominant landscape with clustered settlement. The ecological network was developed to reflect natural land clusters, and ecosystem patches were prioritized for protection and restoration according to size and proximity criteria. Prioritized sites have greater potential to support biodiversity and ecosystem services and their conservation and restoration may help build landscape resilience into the municipality. Further application requires greater understanding of species and genetic level biodiversity and abiotic biophysical characteristic that shape the landscape to confirm and quantify ecosystem services. Also, application would require a greater focus on agricultural lands to identify how productive lands can contribute positively to the ecological network and support biodiversity and ecosystem services.

Keywords: Biodiversity, Ecological Network Planning, Climate Change, Policy, Natural Land Loss, Fragmentation, Landscape Composition, Landscape Configuration

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Chapter 1: Introduction

The IPCC report in 2018 declared human activities have already caused a 1.0C of warming above pre-industrial levels and that current rates of warming will very likely cause an increase of 1.5C between 2030 and 2052 (Intergovernmental Panel on Climate Change, 2018, p. 6). In the Winnipeg Metropolitan Region, climate change is predicted to have effects on temperature and precipitation, where the municipality will experience more very hot days (i.e. >30C) and tropical nights (i.e. >20C), a shorter frost free season and more freeze thaw cycles, and more heavy precipitation days with increased intensity (Prairie Climate Centre, 2018a; Prairie Climate Centre, 2018b; Sauchyn & Kulshreshtha, 2008, p. 285). This will increase the potential for flooding, drought, heat stress, fire, and pest problems, and alter terrestrial and aquatic ecosystems that support biological resources and provide benefits to human wellbeing and underpin livelihoods (IISD, 2007; International Bank for Reconstruction and Development, 2008, p.1). This is anticipated to impact the region by affecting agriculture, Lake Winnipeg, and settlement areas, major contributors to Manitoba's economy (IISD, 2007). Then, a way is needed to add landscape resilience to anticipated climate change effects and reduce impacts to Manitoba's economy and well-being.

Conservation and restoration of natural lands has been suggested as a way to add resilience to the landscape as it reduces biodiversity loss and helps maintain the biological materials that support the continued delivery of ecosystem services that can mitigate potential effects of climate change. As a result, there is an urgent need to reduce the impacts of climate change on biodiversity (Secretariat of the Convention on Biological

Diversity, 2009, p. 1). However, this is made difficult by past and present human activities like agriculture and urbanization that have modified and manipulated the landscape as many of these changes have contributed positively to social and economic development. As a consequence, land modification has led to biodiversity loss and degradation of associated ecosystem services as a result of natural ecosystem fragmentation, loss and modification (International Bank for Reconstruction and Development, 2008, p.1; Secretariat of the Convention on Biological Diversity, 2009).

When combined with the stresses of climate change, natural lands have a reduced capacity to respond to changes further threatening remaining biodiversity and the continued delivery of ecosystem services. As a result, reducing non-climatic stresses like natural land loss and fragmentation and adopting strategies that strengthen network connectivity have been suggested as ways to increase the adaptive capacity of natural lands (Secretariat of the Convention on Biological Diversity, 2009). The degree of connectivity in a landscape has a direct, proximate effect on ecosystems as it can either impede or facilitate the flow of energy, species and processes, thereby impacting the ability of ecosystems to respond to a changing climate (McRae, Hall, Beier, & Theobald, 2012; Watson, et al., 2017). Therefore, adding landscape resilience to climate change requires a focus on landscape connectivity that will facilitate functionally over large and diverse areas, as this will support ecosystem services that contribute directly and indirectly to human well-being (Watson et al., 2017, p. 202; Albert et al., 2016, p. 101).

The Winnipeg Metropolitan Region (WMR) wishes to add climate resiliency to the landscape and has prioritized increased connectivity with objectives and recommendations established in its *Regional Growth Strategy: Securing our Future*. Adopted in 2016, the strategy made it a priority to improve environmental stewardship of the region by recommending policy be adopted to define and legislate the protection of the green space network to ensure resiliency is built into the region (Partnership of the Manitoba Capital Region, 2016). However, the WMR is also experiencing a period of growth. In 2016, the region had a total population of 821,975 – 64% of the total provincial population – and had increased by 6.6% from 2011 totals (Statistics Canada, 2017a; Statistics Canada, 2017b). This growth rate is expected to continue for several years with some communities anticipated to grow by as much as 42% (MMM Group, 2014). As the WMR population continues to increase, human land uses will demand more space and risk the loss of ecosystems, often permanently, further fragmenting the landscape, reducing habitat, and threatening biodiversity.

Yet, as human land use demand increases, the importance of conserving and restoring natural lands for the continued provision of ecosystems services and to add resilience to climate change. Balancing these land use pressures are not new to planners in peri-urban areas like the WMR as they are often in locations of high land use competition (Caldwell, Hilts, & Wilton, 2017). In the WMR, agricultural land uses have historically been prioritized in municipal planning. This has led to substantial land modification as a result of related activities like wetland drainage, soil modification, and forest clearing, which has resulted in substantial ecosystem change and loss of historic wetland, grassland, and forest ecosystems. Now, increasing growth in WMR municipalities is adding pressure to the remaining natural lands by also competing for space and land. Therefore, to support land use planning practices in the WMR that sustain and enhance biodiversity, an approach is needed that can offer a way to connect the fragmented network of ecosystems within a human dominated land-use context.

Ecological network planning may offer this approach. First used as a conservation tool, ecological network planning has been integrated into land use planning and used as a way to connect fragmented networks of natural lands to increase biodiversity and ecological function to support the continued delivery of ecosystem services (Battisti, 2013; Gonzalez, Thompson, & Loreau, 2017, p. 187). Because it is based on landscape ecology principles, it offers land use planners a way to consider core ecological concepts in defining a physical network of natural lands and provides direction on how to configure landscapes in ways that maintains and restore biodiversity and ecological function. Then, understanding what natural ecosystems are present in a landscape and where they are located can help identify their composition and configuration and define their physical network, in doing so identifying opportunities to reduce natural ecosystem loss and fragmentation thereby enhancing landscape climate change resilience.

1.1 Problem Statement

While the goals of the WMR Regional Growth Strategy address the region's ambitions for enhanced environmental stewardship and added resilience, planning authority in Manitoba has been delegated to municipalities. All 18-member municipalities of the WMR have committed to implementing regional objectives in development plans and adopt land use policies to meet regional objectives. Though ultimately, land use development plans are implemented by municipalities and reflect local needs. As municipalities and planning districts administer and are responsible for land use planning and governance, regional growth objectives must be applied within the municipal/planning district policy framework. In that way, municipal/planning district policy can promote the protection of the regional ecological network by using land use development plans to define the network and by-laws to regulate its protection. The objectives set by the WMR to support ecological network protection have highlighted a need in practice with respect to understanding how landscape scale ecological connectivity is defined and integrated into municipal development plans. To ensure the ecological network is appropriately defined, the concept of ecological connectivity and how it is measured needs to be clarified. Determining how to integrate ecological connectivity within a municipal land use framework is the focus of this research practicum. It investigates how landscape ecology principles can be applied to municipal land use planning practice to support reduced biodiversity loss and enhanced connectivity and meet regional environmental stewardship priorities. Further, the research considers how planning practice can apply these concepts in peri-urban areas experiencing growth and development and develop a visual tool that will help communicate ecological network protection to municipal planners. The intent is to develop a visual tool that inherently reflects the regional context and can be applied to any municipality within the Winnipeg Metropolitan Region. The research will focus on the Rural Municipality (RM) of Ritchot located in the southern portion of the Winnipeg Metropolitan Region because it is experiencing growth and has policies that support ecological network planning.

The RM of Ritchot borders the City of Winnipeg and has experienced substantial growth of 22% since 2011 (Statistics Canada, 2017c). Growth is expected to continue, with the population estimated to increase by 42% by 2030 (MMM Group, 2014). An objective of the MacDonald-Ritchot Development Plan is to protect agricultural and natural resources aiming to conserve and preserve these areas. Reflecting this, urban settlements in the municipality have been limited by areas reserved for environmental and agricultural protection. Further, the Macdonald-Ritchot environmental policies aim to maintain and improve the integrity of natural lands by identifying opportunities to enhance the linkages between natural ecological areas:

> <u>Section 3.1.8, 2d:</u> *"Maintain and improve the health and integrity of the Green/Agricultural Policy Area's natural ecosystems and biodiversity by ensuring land uses: provide opportunities to establish linkages between natural ecological areas such as riverbanks and green spaces such as parks"* (Lombard North Group, 2011, p. 21).

This policy statement demonstrates the support of the municipal policy framework in the protection of the ecological network and the need to investigate planning practices that advance its definition and legislation. The municipality's current and anticipated growth presents an opportunity to discuss new perspectives in land use development and identify implementation measures that accommodate growth while also enhancing the ecological network. The aim of this practicum's research is to develop a visual tool that could be adapted and used by municipal planners to provide municipal decision-makers with a framework to define the ecological network and facilitate its protection.

1.2 Research Objectives and Research Questions

The objectives of this research practicum are:

- To demonstrate how landscape ecology principles can be used to quantify existing land cover types, define the ecological network, and identify opportunities for connectivity in the RM of Ritchot to inform how to address municipal and regional policy objectives and build resilience into the landscape.
- To develop a visual tool for municipal and regional planners and decision-makers to better understand, define, and communicate ecological network planning as it relates to biodiversity in the RM of Ritchot.

The key questions guiding this research are presented below for the two research objectives:

A: For understanding and defining the ecological network

1. How can landscape ecology principles be used to define land cover type ecological networks and better understand how connectivity can support biodiversity and the continued provision of ecosystem services?
2. In what ways can enhanced understanding of ecological network connectivity help to organize and define land use in the Municipality of Ritchot and the Winnipeg Metropolitan Region to add climate change resilience?
3. What lessons can be identified from other municipalities and regions attempting ecological network planning that could be applied to municipalities within the RM of Ritchot and the Winnipeg Metropolitan Region?

B. For developing a visual tool.

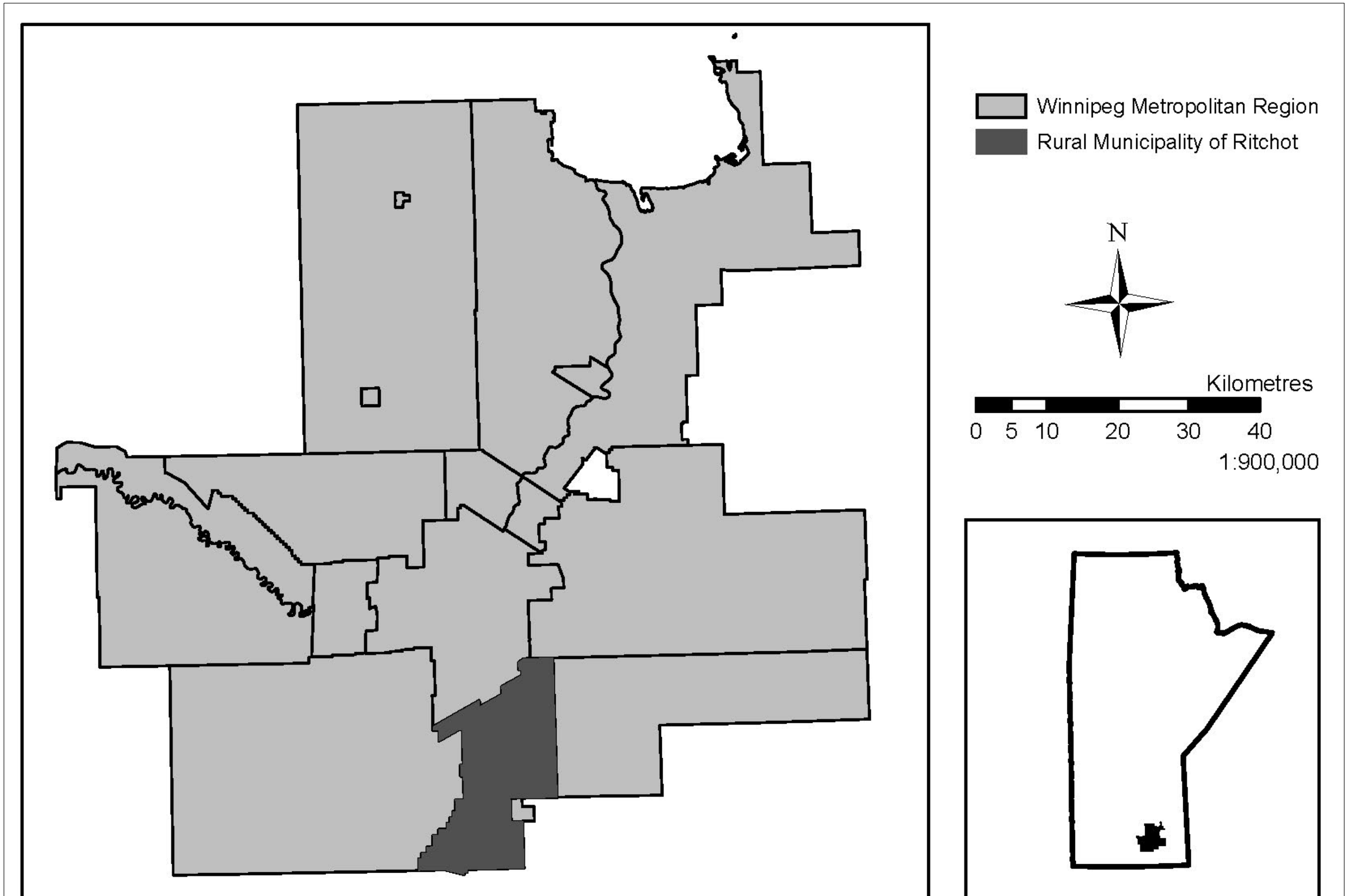
4. How can land cover types be classified and quantified? What landscape metrics related to biodiversity should be used?
5. What is the current condition of ecological connectivity in the Municipality of Ritchot?
    a) Where are the gaps in the ecological network? Where is the landscape fragmented?
    b) How are urban and agricultural land uses organized? What are the spatial landscape conflicts and opportunities to enhance connectivity?
6. How can the visual tool inform land use planners on how to define a land cover type ecological network? How can this tool assist in guiding growth and shaping land use patterns while also achieving municipal and regional environmental objectives?

1.3 Regional and Local Context: Rural Municipality of Ritchot

Centered around the City of Winnipeg, the Winnipeg Metropolitan Region comprises a geographical area in southern Manitoba of approximately 7,795 km^2 (Stantec, 2016). It forms the northern axis of the Red River Corridor (Lombard North Group, 2011) and includes the confluence of the Red River and Assiniboine River (Figure 1.1). The RM of Ritchot is one of the 18 municipalities that constitute the WMR. Located south of Winnipeg, the municipality encompasses a total area of 334 km^2 (Statistics Canada, 2017b) and borders the Red River (Figure 1.1).

The WMR is also the name of the regional not-for-profit organization created as a response to planning issues requiring a broader regional context. The Government of Manitoba established the Capital Region Committee of elected officials in 1998 to investigate how to better integrate and coordinate regional planning. In 2006 the *Capital Region Partnership Act* was passed to facilitate the creation of a regional partnership organization. As a response, the Partnership of the Manitoba Capital Region (PMCR) -- now known as the WMR -- was established to address various regional concerns including land use planning and environmental protection. The Act directs Mayors and Reeves from each member municipality to meet and develop recommendations for the organization and governance of the region; the RM of Ritchot is included as a member. The organization is governed by a Board of Directors composed of a representative Mayor or Reeve of each member municipality. The Board is responsible for the overall governance of the organization, has ultimate authority over resources and activities, and is responsible for making major strategic decisions for the region. Regional strategies are incorporated into municipal planning frameworks once each member municipality in the region passes a resolution adopting the strategy (Province of Manitoba, 2017a). Through the development and adoption of regional strategies, municipalities in the WMR ensure their local development plans align with regional priorities. The RM of Ritchot is part of the Mcdonald-Ritchot Planning District, which includes regional strategies within its long-range comprehensive Development Plan. The Municipal Council and the Planning District Board base their decisions

Figure 1.1 **Winnipeg Metropolitan Region: Rural Municipality of Ritchot**



Source: Province of Manitoba, 2004

on the objectives of the plan and aim to implement their policies (Lombard North Group, 2011).

1.4 Significance of Research

This research highlights the ways in which ecological networks can be better defined and effectively protected by municipalities to reduce biodiversity loss and build climate change resilience into the landscape. Through investigation of ecological network protection, this research aims to identify how to advance planning practice to preserve and conserve ecosystems that support biodiversity as well as the opportunities and barriers that could support or inhibit these initiatives. The main focus of this practicum is to develop a deeper understanding of the ecological network planning in the Winnipeg Metropolitan Region. Because this practicum aims to develop a visual tool to assist municipal and regional planners and decision-makers understand, define and communicate ecological network protection, there is a need to understand what defines the key components of the ecological network and why. The research undertaken has presented a way to evaluate a landscape as it relates to land cover types and the biological elements of the landscape and define an associated ecological network. It builds on the work others who identified a need to understand landscape biophysical characteristics that shape ecosystems in the WMR to determine where to conserve and restore natural lands. By exploring the land cover type biophysical characteristic, this research has clarified how to measure and evaluate the biological elements at the landscape scale to define the biotic elements of the ecological network and restore connectivity.

This practicum will help inform planning practice intended to support ecological network protection in the Winnipeg Metropolitan Region and add to scholarly planning knowledge. With climate change increasingly recognized in municipal planning policy, there is a growing awareness of the potential land use planning offers in adding landscape resilience to climate change mitigation and adaptation. This potential has been recognized by governing bodies who have developed plans with objectives that will rely to some degree on land use planning practices to achieve. Achieving objectives listed in plans will require a different perspective on land use development and an increased willingness to implement innovative planning approaches. The research completed as part of this practicum presents an opportunity to apply different land use planning practices that would help achieve municipal policy objectives and regional priorities and assist in delivering broader climate change and sustainable development goals.

1.5 Research Approach

The research approach followed for this MDP research began with a literature review, followed by a precedent analysis, and finally, included the development of a visual tool.

Literature Review

The literature review provides a broad understanding of ecological connectivity through an investigation of the literature. It included three related themes: 1) Climate change and biodiversity, 2) Land use and biodiversity; and 3) Land use and ecological network planning. The first theme established the relationship between climate change and biodiversity and discussed the strategic climate change and biodiversity planning framework present in the municipality. The second theme investigated the landscape ecology principles that underpin ecological network connectivity to understand how land use connectivity relates to biodiversity and climate change resilience efforts, and how ecological network planning can encourage spatial patterns that support reduced biodiversity loss and enhanced connectivity. The third theme attempted to clarify how ecological network planning supports and complements physical land use planning, provided some context as to how to define ecological networks, and discussed how natural lands can be identified for protection and enhanced connectivity.

Precedent Review

The research investigated precedents in the City of Edmonton, Halifax Regional Municipality, and the City of Ottawa to examine how they implemented strategies to protect/enhance/repair the ecological network. These are summarized in Appendix D. The precedent review assisted in understanding how land use practitioners can support the implementation of ecological connectivity in municipal development and better inform planning practice in the WMR and the R.M. of Ritchot. It examined how ecological networks were defined, which ecological and human elements were considered, and how protection strategies considered ecological network measurement and evaluation.

Visual Tool

Finally, the research produced a visual tool that identified the existing ecological network in the St Adolphe sample site in the Rural Municipality of Ritchot. The visual tool identified areas suitable for ecological network protection and restoration, the relationships between ecological network and the land designation policy framework, and the potential opportunities and barriers to connectivity. It was developed following a series of steps outlined in the Sustainable Land Planning Framework and visualized using the spatial analysis tool ArcGIS (see Chapter 3 Research Methods). Planning Phases included:

A. Focus Planning Phase

   This step compiled findings from the literature review and the precedent review to define the focus of the proposed ecological network. This step also developed a better understanding of the historical landscape land cover type context by collecting and examining historical maps. Finally, this step developed a classification system for the existing ecological network by compiling and refining available land cover type datasets and built a base map using ArcGIS.

B. Analysis Planning Phase

This step centred on characterizing landscape composition of the sample site by undertaking an analysis of the landscape. Using landscape metrics provided in the Sustainable Land Planning Framework, this planning phase quantified landscape composition.

C. Diagnosis Planning Phase

This step centred on characterizing landscape configuration of the sample site by undertaking an analysis of the landscape. Using landscape metrics provided in the Sustainable Land Planning Framework, this planning phase quantified landscape configuration.

D. Prognosis Planning Phase

This step combined information gathered from previous steps to generate a visual tool that identified the existing ecological network, land use and human dimension factors, areas suitable for protection and restoration, the relationship between the ecological network and the land designation policy framework, and potential areas of conflict or opportunity.

1.6 Chapter Outline

This MDP document is organized into six chapters. Chapter 1 introduces the research subject including the research problem, objectives, questions, approach, and significance.

Chapter 2 presents the result of the investigation of literature to establish an understanding of biodiversity and ecological network planning. It began with a discussion of the relationship between climate change and biodiversity, followed by an investigation of the relationship between land use and biodiversity, then discussed how ecological network planning can be integrated within the land use planning process. Chapter 3 introduces the methodology used in the research approach. This chapter investigates precedents that applied ecological network planning. Three plans were studied including: The City of Edmonton's Breath Plan, Halifax Regional Municipality's Ecological Network Connectivity Plan, and the City of Ottawa's Green Space Master Plan. This chapter also applied the Sustainable Land Planning Framework logic model, and described methods used in each associated planning phase as well as the steps taken with the ArcGIS program to develop the associated visual tool. Chapter 4 presents the findings from the sample site and is focused on delivering an analysis of results. Chapter 5 focuses on synthesizing analytical research findings presented and reflected on how they related to stated research objectives and questions. Chapter 6 first answers research questions, then introduces recommendations for future research, and finally, offers a conclusion to the practicum.

Chapter 2: Literature Review Ecological Network Connectivity

This chapter presents a summary of the literature on ecological network planning as it relates to protecting biodiversity and reducing fragmentation in effort to build climate change resilience into landscape. The chapter begins by introducing natural land modification by presenting the RM of Ritchot context and discussing natural land loss and fragmentation, with the use of landscape ecology principles. Next, a discussion is presented on the relationship between land modification and climate change resilience, and the structure of the land use planning policy framework as it relates to climate change and biodiversity and how physical land use planning could support reducing natural land loss and fragmentation. The chapter concludes by discussing of ecological network planning principles, identifying steps that need to be taken to develop an ecological network, and the key factors to consider when identifying and defining an ecological network to reduce natural land loss and fragmentation.

2.1 Natural Land Modification: Loss and Fragmentation

This section discusses land modification in the RM of Ritchot and investigates how natural land loss and fragmentation affect landscape biodiversity and ecosystem services.

2.1.1 Introduction: Land Modification

Over time, terrestrial and aquatic systems have been transformed by the modification of the landscape through events like the advent of agriculture, establishment of settlements, and historic deforestation, to more modern phenomenon like the development of urban centres and transportation routes (Dale, Efroymson, & Kline, 2011, p. 756). In peri-urban areas landscape transformation is driven by dynamic forces like: urban migration, agricultural intensification, industrialization and the location of things like distribution centres, waste and wastewater treatment infrastructure (Wandl & Magoni, 2017, p. 2). The proximity of these areas to major urban centres makes them an attractive choice for development, often resulting in population growth and increased urbanization. As a result, peri-urban areas often see rural land uses like agriculture compete with the pressures of urban growth and change, as often the lands best suited for agriculture are also the ones best suited for urban expansion of non-agricultural uses (Caldwell et al., 2017, p. 153). In many Canadian peri-urban areas, the proximity to major urban centers has made the land so attractive to development that much of it has been purchased on speculation of future development (Caldwell et al., 2017, p. 154). By doing so, land values are often seen to rise as there is an expectation of urban development (Caldwell et al., 2017, p. 154). As a response to the increase in land value and subsequent reduced land availability, peri-urban areas can see a rationalization of farmland which causes an increase in agricultural land fragmentation (Caldwell et al., 2017, p. 154). These dynamics shape landscape patterns spatially and temporally, as the size, shape and extent of development will occur as a response to socio-economic forces that play out over time.

When land is converted to more rural and urban uses natural land is lost and remnant patches of natural ecosystems are increasingly fragmented. When natural ecosystems are lost as a result of human induced landscape conversion and fragmentation, dependent species within the ecosystem redistribute or are lost, resulting in a decline in species population and variability (Millennium Ecosystem Assessment, 2005, p. 35; Mantyka-Pringle, Martin, & Rhodes, 2012, p. 1239). When natural ecosystems are fragmented remnant patches are rendered more isolated and less connected. This is important to consider because the degree of spatial connectedness between patches will facilitate or impede the flow and movement of energy, materials, and organisms across the landscape (Theobald, Crooks, & Norman, 2011, p. 2445; Park, 2015, p.

425; McRae, et al., 2012; Leitao et al., 2006, p. 12). Then, converting natural lands to rural and urban uses not only results in the loss of biological genetic material and species but changes the structure and characteristics of entire ecosystems, thereby also changing the ecological processes and functions present (Mooney, et al., 2009, p. 48; Millennium Ecosystem Assessment, 2005, p. 33). Globally, landscape transformation has modified ecosystems to such an extent that has caused great biodiversity loss and major changes in ecosystem services, where one global analysis determined that over sixty percent of services provided by biological ecosystem elements had diminished in the past fifty years (Millennium Ecosystem Assessment, 2005; Mooney, et al., 2009, p. 46). As a result, all global ecosystems have now been significantly altered by human actions (Millennium Ecosystem Assessment, 2005, p. 26).

Over the last century and half, the Canadian prairies have seen vast modification of the landscape and a transformation of natural lands to other uses. Historically, much of the prairie ecozone in Manitoba, including the RM of Ritchot, was covered by tall-grass and mixed-grass prairie. Although grasslands dominated the landscape in the RM of Ritchot, the distribution of grasses was dependent on natural drainage conditions where in wetter areas along watercourses river bottom forest established (Agriculture and Agri-Food Canada, 1998, p. 261; Province of Manitoba, 2003a, p. 10). Like grasslands, forest species distribution was a response to drainage conditions, where species like bur oak and trembling aspen were found in better drained sites and basswood, cottonwoods, Manitoba maple, and green ash were found in wetter sites (Agriculture and Agri-Food Canada, 1998, p. 261). However, like other areas in the Canadian prairies in the late nineteenth century, the RM of Ritchot saw the development of new settlements and agriculture transform the landscape.

Prior to the establishment of the Province of Manitoba in 1870, European settlement of the area was largely associated with the fur trade. In the RM of Ritchot, several settlements including Grande Pointe, Iles des Chênes, St. Adolphe, and St. Agathe were built in the vicinity of the notable Crow Wing Trail, a route that connected the Red River settlement and Fort Garry to St. Paul Minnesota (Province of Manitoba, 2003b, p. 27; Province of Manitoba, 2003c, p. 42). With Manitoba's entry into the Confederation, the landscape pattern in the area began to be influenced by the Land Survey. The first land survey system used in the area was the Parish River-lot Survey System that demarked the landscape by dividing it into narrow two-mile long lots fronting on the Red River (Province of Manitoba, 2003b). In the RM of Ritchot this system was applied the length of the Red River, as well as along the Seine River in the French settlements of Grande Pointe and Iles des Chênes (Province of Manitoba, 2003b, p. 30). The Dominion Survey System was applied to the remainder of the landscape, which demarked the landscape by dividing it into 36-section townships (Province of Manitoba, 2003b). Use of this land survey system allowed for the rapid settlement and development of the area and had a major influence on landscape patterns in the region, impacts that are still visible today (Province of Manitoba, 2003b, p. 30).

Until Manitoba joined the Confederation, settlement in the Canadian prairies had been relatively slow, a trend that continued until the completion of the transcontinental railway in the mid-1880s (Caldwell et al., 2017, p. 14). Natural land was increasingly converted to farmland as more settlers arrived, a pattern that was experienced across the prairie provinces: in 1891 western Canadian settlements totaled eight percent of Canada's farmland and by 1936 the three prairie provinces had over 49,000,000 million hectares of farmland constituting ninety-eight percent of all Canadian farmland (Caldwell, et al., 2017). In the RM of Ritchot this conversion greatly altered the natural vegetation, where much of the original tree belts that lined the Red River valley were felled and virtually all the Tall and Mixed Grass Prairies that covered the area were ploughed for agricultural use (Province of Manitoba, 2003a, p. 10). In addition, substantial change to hydrological patterns were made in effort to drain the landscape and make land suitable for agriculture. To take advantage of the region's rich soils, all the Great Marshes and the vast majority of its smaller wetlands were drained, and many of the blind creeks were connected to nearby rivers or drainage canals (Province of Manitoba, 2003a, p. 14). Because of the substantial drainage activities, a surge of natural land conversion to farmland occurred between the late nineteenth century and the Second World War (Province of Manitoba, 2003d; Caldwell et al., 2017).

Like other Canadian prairie settlements, the early twentieth century brought rapid settlement to the RM of Ritchot as well as expansion of its agricultural sector. Initially, the area was predominantly constituted by small scale mixed-farms (Province of Manitoba, 2003e). The availability of large acreages as well as advances in farm equipment facilitated the sector's rapid mechanization and expansion of farm operations and evolution towards an agricultural system focused on rationalization and based on the production and export of specialized cereal crops (Province of Manitoba, 2003d; Caldwell, et al., 2017). In Manitoba, between 1941 and 1971 there was an increase of farmland and cropland by ten percent and forty-five percent respectively, yet a forty percent decrease in the total number of farms (Caldwell, et al., 2017, p. 21). Finally, with the onset of agribusiness Manitoba saw a shift in agriculture to large farming operations with corporate involvement. Between 1971 and 2011 this shift lead to a reduction of fifty-four percent in the total number of farms, yet there was an increase in cropping intensification and large-scale farming operations (Caldwell, et al., 2017).

Today, landscape patterns visible in the RM of Ritchot continue to be influenced by the land use decisions of the past where both settlement and agriculture have had a substantial impact in the RM of Ritchot and the surrounding region. Rather than following the typical western Canadian prairie settlement pattern, many of the RM of Ritchot's settlement areas reflect the Parish River-lot Survey System (Province of Manitoba, 2003c). The use of both the Parish River Lot Survey System and the Dominion Survey System created an unusual mix of development patterns with road configurations unlike other municipalities not located along the Red, Assiniboine or Seine Rivers (Province of Manitoba, 2003b, p.30). As a result, the municipality has settlement areas with linear development patterns that differentiate from their surrounding farmland that follow only the Dominion Survey System. In addition, new demarcation patterns have resulted from the subdivision of many of the historical river-lots into smaller parcels of rural residential development and the construction of new access roads as the municipality's proximity to the City of Winnipeg has made it a popular area for this form of development (Province of Manitoba, 2003b, p. 30; Province of Manitoba, 2003c). Furthermore, increased consolidation of farmland and improvements in farming operations substantially influenced landscape patterns by eliminating the earlier fence and treelines and lessening the demarcation of adjoining parcels (Province of Manitoba, 2003b, p.30). In 2016, Statistics Canada (2019) reported that 48,130 acres of farmland were present in the RM of Ritchot or 58.1% of the total land area. The result of this transformation was a modified landscape that saw large areas of land converted to agricultural uses.

This transformation created a more homogenous landscape with a reduced presence of natural landscape features. Appendix A includes historical maps from 1871 to 1999 that demonstrate the land transformation in the RM of Ritchot as a result of settlement. Nearly all the original grasslands in the area have been converted to other land uses but some of the original tree belts along the rivers have survived although greatly diminished (Agriculture and Agri-Food Canada, 1998, p. 261; Province of Manitoba, 2003a, p. 10). From the 19th to the 20th century there was reduction of grassland land cover from approximately 55% to nearly zero and a reduction of forest land cover type from 35% to 9% (Hanuta, 2006). Furthermore, many of the small and large wetlands present in RM of Ritchot are no longer present as a result of land drainage and development of crop land. A study completed by Hanuta (2001) of the Red River Valley, including the RM of Ritchot and the southern portion of the Winnipeg Metropolitan Region, determined that wetlands constituted 11.4 percent of the landscape in 1870, the second most common land cover type after prairie, but that by 1995 only 0.1 percent of the same landscape was occupied by wetlands. This makes apparent the strong force land uses have exhibited, and continue to, on natural lands and the formation of landscape spatial patterns in RM of Ritchot.

With commitments made by the RM of Ritchot's development plan and the WMR's regional growth strategy to address vulnerabilities caused by climate change though enhanced ecological connectivity, there is a need to understand why natural lands loss should be reduced to maintain biological material and ecosystem structure and characteristics. In doing so, the land use planning process may be able to better identify what and where natural ecosystems could be preserved and restored, the relationships between structures and the dynamics that shape their patterns, and how they could add resilience to climate change. Landscape ecology can assist with this as it focuses on the relationship between a landscape's natural system structures and functions, and their change through time. The landscape spatial scale refers to a spatially heterogenous area -- in at least one factor of interest-- large enough to distinguish ecological units from other areas and includes the broader human-modified ecosystem (Lovett, et al., 2005, p. 10; Farina, 2006, p. 5). This scale is a complex, higher hierarchical level ecological unit, which contains several lower-level sub-units, that together slowly exerts and adsorbs pressure on ecological process from across scales, which in turn shape landscape ecosystem structure characteristics (Farina, 2006; Leitao et al., 2006, p. 5). Applying landscape ecology to land use planning can assist in identifying the landscape spatial patterns and the functions of associated natural systems and resources, thereby clarifying areas that are ecologically significant and beneficial (Leitao et al., 2006). The following sections aim to provide a better understanding of ecologically significant and beneficial areas by investigating natural land loss and fragmentation with landscape ecology principles.

2.1.2 Natural Land Loss

Landscape modification results in a degree of natural land loss. Landscape ecology can provide insight into the implications of this as it is focused on the structure and function of natural systems. In understanding the structure and function of natural systems one is informed as to the characteristics that shape landscapes, the relationships that establish spatial patterns, and the benefits that may be subsequently provided. This can inform why natural lands loss should be reduced to maintain biological material and ecosystem structure and characteristics. Also, this can help identify the structure and functions in RM of Ritchot and inform what and where natural ecosystems could be preserved.

Generally, the term ecosystem is applied to ecological units, as it relates to a spatially-explicit bounded area, at any hierarchical scale, where dynamic and complex relationships are formed between an environment's biotic and abiotic components and form a functional unit (Lovett, Jones, Turner, & Weathers, 2005; Millennium Ecosystem Assessment, 2005). At the landscape scale, ecosystem structure is understood as three fundamental ecological units: patches, corridors, and the matrix (Forman, 1995; Forman and Gordon, 1986). A patch is considered a nonlinear, relatively homogenous area that differs from its surroundings in structure and function, and ultimately is determined according to its application and representation in the greater landscape (Leitao et al., 2006; Lovett, et al., 2005, p. 4). Forman (1995) describes a corridor as a linear land cover type that differs in context and physical structure from its surroundings (Forman, 1995). Finally, the matrix is considered the dominant land cover type that exerts control, effects connectivity and continuity over landscape dynamics, and in a way encloses patches and corridors (Leitao et al., 2006, p. 8; Forman, 1995, p. 277). Patches, corridors, and the matrix form a pattern of similar aggregated objects known as the land mosaic (Forman, 1995, p. 39).

Landscape ecology tells us that ecosystem structure characteristics develop according to two gradients: vertical structure and horizontal structure. Vertical structure refers to the stratification within a vertical space, whereas the horizontal structure refers to the variation across a horizontal space (Rutten, Ensslin, Hemo, & Fischer, 2015). Farina (2006) clarifies how landscape ecology is less concerned with vertical structure as not all vertical systems are hierarchal in their organization and is more interested with horizontal structure as it is a response to the biophysical environment (p. 65). Landscape mosaics are defined by the biophysical environment, where ecosystem structure shape, size, overall configuration, and interactions between structures are determined by the landscape's biophysical characteristics (Leitao et al., 2006; Mononen et al., 2016). In 2010, the International Institute for Sustainable Development (IISD) released a report exploring the idea of defining the landscape biophysical characteristics in the Red River Basin. The report explored data gaps that impeded establishing a decision support system that could be used to identify where natural lands should be preserved and maintained and inform ecological infrastructure investment in the Red River Basin (IISD, 2010, p. 5). Findings from the report provide criteria to use in defining biophysical characteristics in areas in the Red River Basin, like the RM of Ritchot and the WMR. To define the landscape in the Red River Basin, five key biophysical characteristics were identified:

- Elevation: clarifies how water flows across the landscape, how soils erode, and how vegetation establishes in certain areas;
- Bedrock: clarifies to some degree subsurface dynamics and their influence on soil formation and hydrological flows;
- Soil: clarifies how vegetation established in certain areas, how water infiltrates, and geomorphological processes;
- Hydrology: clarifies water resources including quantity and quality of surface and sub-surface water;
- Land Cover Types: clarifies existing natural lands and their connectivity (IISD, 2010, p.5).

Together with the conditions created by the prairie climate, these biophysical characteristics drive landscape dynamics, where the topography and soils of the region influenced the way hydrological landscapes were developed and subsequently influenced the establishment and distribution of vegetative communities and associated biological elements.

As a prairie region, the WMR and the RM of Ritchot display classic cold regions hydrology, where for much of the winter the area is continuously snow-covered, and soils are frozen (Fang et al., 2007, p.3). In such types of hydrologic cycles, snowfall, and its subsequent melt, play an important role. By melting, snow provides the soil landscape with moisture, recharges groundwater storage, and through run-off replenishes reservoirs, lakes, and rivers (Fang et al., 2007, p. 5). However, the patterns of these processes are highly influenced by the biophysical setting created by the local climate, topography, and soil conditions. Such factors create local heterogenous snowfall patterns as they influence landscape slope and vegetative cover types, which both induce variation in wind conditions and the redistribution of snow across the landscape (Fang et al., 2007, p. 4). Further, the biophysical setting affects the snow melt pattern as it determines the location of snow melt through snow redistribution processes as well as the potential for water soil infiltration. Soil infiltration depends on the potential for water to enter the soil surface, its ability to move through it, and the storage capacity soils provide (Fang et al., 2007, p. 5). Soils that are highly porous allow for water infiltration and result in no surface run-off, whereas soils that are saturated or heavy clays or soils restrict infiltration and result in snowmelt leaving the surface as run-off (Fang et al., 2007, p. 5). Additionally, the soil moisture content of the previous fall season and those of major mid-winter melt events further contribute to the ability of water to infiltrate the surface as spring melt water (Fang et al., 2007, p. 5). Seasonal rainfall also supplies the prairie hydrologic cycle and plays a similar role to snow melt in replenishing soil moisture and recharging groundwater, reservoirs, lakes, and rivers. However, with increased summer temperature evaporation rates grow. In the prairies, much of the rainfall is consumed by evaporation from wet surfaces, water bodies, and plant and soil surfaces (Fang et al., 2007, p. 6).

The RM of Ritchot is located in a drainage basin area that captures surface water as it flows northwest toward the Red River (Province of Manitoba, 2003a, p. 14). As part of the Red River Sub-watershed and the greater Lake Winnipeg Watershed, melt water from a vast area flows toward the Red River, in doing so flowing through the RM of Ritchot. The municipality’s large rivers and smaller streams capture surface waters within their watershed before discharging into the Red River. In their natural states, the creeks and rivers would regularly overflow their banks with the onset of the spring melt, sending water across the landscape. The topography combined with the poor soil infiltration capability of the area’s clay soils resulted in the pooling of water in surface depressions across the landscape and the formation of large shallow wetlands and of the Great Marshes (Province of Manitoba, 2003a, p.15). Wetlands would store melt water until surface storage was filled, where water would then spill and flow downstream across the landscape in a cascade fashion until it reached an outlet, a mechanism know as fill-and-spill runoff (Fang et al., 2007, p. 11). The gently sloping landscape would direct flow toward the northwest and again form distinct channels that meandered toward the Red River (Province of Manitoba, 2003a, p.14). Many of the smaller marshes formed by the snow melt would slowly dry away with the higher temperatures of the summer season, whereas the Great Marshes were permanent fixtures of the landscape (Province of Manitoba, 2003a).

Formation of ecosystems in the RM of Ritchot has historically been highly influenced by the landscape's biophysical characteristics (Fang et al., 2007; Province of Manitoba, 2003a). As discussed in Section 2.1.1, tall grass prairie, forests, and wetlands established as a response to drainage conditions, hydrological patterns, and soil characteristics and influenced the biological structures and subsequent biodiversity established. By definition, biodiversity includes all variability of biotic life from genes to communities to broad scale ecosystems across all spatial and temporal scales (Savard, Clergeau, & Mennechez, 2000; Ding & Nunes, 2014, p. 60). At its most rudimentary, biological elements are represented at various scales associated with size and related process rates, and spatially categorized and organized according to a hierarchy that reflects the connections between biological elements at varied scales, the patterns and processes that result, and how pressures across scales exert competitive or collaborative effects on lower or higher-level elements (Miller, 2007; Forman, 2008, p. 19). This hierarchical relationship between biological elements creates a situation where elements are simultaneously a component of a biological element or the whole of one. As a result, biodiversity represents several biological scales organized in an interlocked hierarchy (Savard, et al., 2000, p. 131). The interaction between the biotic and abiotic biophysical characteristics defines how ecological processes and functions are expressed.

Forman (1995) defines function the flow and movement of energy and material via food chains and cycles (p.75). Ecosystem structure and function are interdependent, where the structure established is both a cause of and response to established functions, which together form nested relationships that build closed-looped systems, or ecosystems (Farina, 2006, p. 9). Ecosystem structure reflects the nested relationship of the closed-looped system and is governed by two broad perspectives: feedback loops, either positive or negative, and proximate and ultimate factors (Forman, 1995). Feedback loops determine what the impacts of unit components have on one and another, whereas proximate and ultimate factors determine the impact of the environment on the biotic components of the unit (Forman, 1995). Through the interaction of biotic and abiotic components and determined feedback loops, the flow of energy and materials is established in the ecosystem. The perspectives that govern ecological processes relating to the transfer of energy, material, or organisms between ecosystems are processes that are consequently responsible for unit function, or their performance, and ultimately the delivery of ecosystem services (Lovett, et al., 2005, p. 4).

The Millennium Ecosystem Assessment (2005) identified ecosystem services as benefits provided to people from ecosystems (p. 40). Many ecosystem services are highly interlinked, but are broadly defined as four categories:

1. Provisioning services – yields that can be extracted or directly harvested by humans from ecosystems (e.g. agriculture, food, timber, fresh water);
2. Regulating services – indirect benefits provided to humans by ecosystem processes (e.g. climate regulation, water regulation, erosion regulation);
3. Cultural services – direct or indirect quality-of-life benefits to humans (e.g. recreation, spiritual and religious values, inspiration);

4. Habitat or Supporting services – indirect services that underly the production of all other ecosystem services (e.g. soil formation, primary production, water cycling) (Millennium Ecosystem Assessment, 2005, p. 40; Hester & Harrison, 2010; Ahern, 2013, p. 1203; Kabisch, Larondelle, & Artmann, 2014).

The services provided by ecosystems underpin human well-being, as the outcomes of ecosystem services provide benefits that directly relate to human welfare (Millennium Ecosystem Assessment, 2005, p. 49; Ojea, Martin-Ortega, & Chiabai, 2012, p. 4).

Human well-being has been defined in terms of five main components: the basic material needs for a good life, health, good social relations, security, and freedom of choice (Millennium Ecosystem Assessment, 2005, p. 50). Benefits provided by ecosystem services directly and indirectly impact human well-being by influencing both ecological and socioeconomic factors. Provisioning services directly contribute to the basic materials needs for a good life as they provide people access to products that enable them to secure an adequate livelihood, most often through resources-based industries (Millennium Ecosystem Assessment, 2005). Access to such products contributes significantly to employment and economic development, thereby having a significant influence on other human well-being components. While regulating services indirectly contribute to human well-being components, the benefits received could have substantial effects on ecological and socioeconomic factors as these ecosystem services provide benefits that relate to the regulation of ecosystem processes that underpin all ecosystem services (Millennium Ecosystem Assessment, 2005). Benefits like pollination, pest regulation, and water regulation can influence the supply of ecosystem products affecting provisioning services and associated human well-being benefits, whereas services like disease regulation can affect human health, and natural hazard regulation can impact security as it relates to safety of persons and possessions (Millennium Ecosystem Assessment, 2005). Cultural services provide either direct or indirect non-material benefits from ecosystems that contribute to human well-being by supporting physical and emotional health and facilitating the presence of social cohesion that allows for good social relations and security (Millennium Ecosystem Assessment, 2005). Maintaining these services can be especially important as they support a sense of place and help preserve spiritual and religious values, and knowledge systems (Millennium Ecosystem Assessment, 2005). Because supporting service benefits are indirect or have occurred over long period of time, they do not provide benefits like other ecosystem services, however, they are necessary for the production of all other ecosystem services (Millennium Ecosystem Assessment, 2005, p.40). Services provided like soil formation, photosynthesis, and primary production are key factors as to how ecosystem formed, thereby directly influencing which ecosystem services develop, and as a result impacting human well-being.

The biophysical characteristics of the historical landscape in the RM of Ritchot created conditions that enabled for historical natural ecosystems to deliver a number of ecosystem services. Table 2.1 provides a list of ecosystem services associated with natural ecosystems historically present in the RM of Ritchot. Settlement of the landscape over the last century has modified biophysical characteristics as a result of changes to drainage patterns, vegetation cover, and soils through agricultural activities. In riverscapes – areas where the river system is considered in combination with the broader landscape structures and functions (Zhou et al., 2014, p. 148) – like the RM of Ritchot, this is especially of concern as modification of the landscape alters the land: water interface. Riverscapes have strong connections between river systems and their surrounding terrestrial landscape structures and functions (Zhou, et al., 2014) where modification of the land: water interface can transform terrestrial habitat options and alter the movement and dispersal of nutrients and genetic material (Forman, 1995). Furthermore, modification of the land: water interface has been found to have substantial effects on water quality when as little as ten percent land cover change occurs (Wilson, 2015, p. 2). This is because areas of interaction between terrestrial land cover and the water channel facilitate

Table 2.1 **Ecosystem services associated with historical natural ecosystems**

Ecosystem Type	Ecosystem Service
Forest and Riparian Areas	All forest: Air filtration; Carbon storage; Carbon sequestration; Climate regulation; Disease regulation; Fibers; Food; Genetic resources; Habitat; Natural hazard regulation; Nutrient recycling; Opportunities for wildlife viewing; Pest control; Photosynthesis; Primary production; Soil erosion prevention; Recreation and exercise; Shade and cooling; Soil formation; Water filtration and purification. Additional riparian area services: Bank stabilization; Moderation of stream temperature; Provision of food inputs (e.g. organic debris); Provision of physical habitat (e.g. woody debris), Seasonal flow regulation (TD Economics & Nature Conservancy of Canada, 2017; Environment Canada, 2013; Postel, & Thompson, 2005; Millennium Ecosystem Assessment, 2005)
Range and Grasslands	Air filtration; Carbon storage; Carbon sequestration; Climate regulation; Fibers; Genetic resources; Habitat; Opportunities for wildlife viewing; Photosynthesis; Primary production; Soil erosion prevention; Recreation and exercise; Soil formation (Environment Canada, 2013; Millennium Ecosystem Assessment, 2005)
Waterbody	Food; Genetic resources; Habitat; Nutrient recycling; Photosynthesis; Primary production; Recreation and exercise; Water infiltration; Water supply; Water regulation (Millennium Ecosystem Assessment, 2005; Allan, 2007)
Wetland	Air filtration; Carbon storage; Carbon sequestration; Climate regulation; Fibers; Genetic resources; Groundwater discharge and/or recharge; Habitat; Moderation of stream temperature; Natural hazard regulation; Nutrient recycling; Opportunities for wildlife viewing; Photosynthesis; Primary production; Water filtration and purification; Water regulation (Environment Canada, 2013; Postel, & Thompson, 2005; Millennium Ecosystem Assessment, 2005)

beneficial ecological processes and minimize negative impacts associated with the input of dissolved substances and organic matter, and control erosion, nutrients, and sediments in aquatic environments (Forman, 1995, p. 235). Therefore, one can assume that historical land modification experienced in the RM of Ritchot has transformed terrestrial and aquatic environments and the interface between them. Subsequently, it can be assumed that the biological elements and ecological structures and characteristics that supported the delivery of historical ecosystem services has also changed.

While the modification of landscape biophysical characteristics has resulted in a loss of historical natural ecosystems, in many areas like the RM of Ritchot landscape modification and fragmentation has played a significant role in developing communities and often positively contributed to socioeconomic factors and improvements to human well-being (Millennium Ecosystem Assessment, 2005, p. 67). For example, provisioning services produced by a modified landscape benefitted the RM of Ritchot as they provided products essential to the agricultural resource-based industries in the area, which in 2016 was second largest industry sector employing people in the municipality (Province of Manitoba, 2017b). Furthermore, since settlement agriculture has had a strong presence in the RM of Ritchot (Province of Manitoba, 2003d) and has provided cultural services that have influenced the area's sense of place and community development. As a result, the socioeconomic implications involved with landscape modification and fragmentation pose substantial institutional and socioeconomic challenges to reducing biodiversity loss, enhancing connectivity, and building resilience into landscapes (Mooney, et al., 2009, p. 51).

2.1.3 Natural Land Fragmentation

Change alters landscape structure and function over time (Leitao et al., 2006, p. 14). Landscape transformation is driven by events, or disturbances, that alter the spatial pattern of landscape structures and functions (Forman, 1995, p. 38). In landscapes relatively untouched by human management, three land transformation stages are driven over time by five processes:

- Stage 1 – A) Perforation; B) Dissection;
- Stage 2 – C) Fragmentation; D) Shrinkage; and
- Stage 3 – E) Attrition (Forman, 1995, p. 407).

In the first stage of land transformation, the landscape is dissected by linear structures and perforated by the introduction of non-linear structures (Leitao et al., 2006, p. 17). In the second stage the landscape is continuously fragmented into disjunct fragments, where there's a gradual reduction in area and an increase in isolation of remaining structural fragments (Leitao et al., 2006, p. 17). Finally, in the third stage the remaining structural fragments are lost, revealing a new landscape matrix (Leitao et al., 2006, p. 17). These processes disrupt ecosystems by changing the resource and substrate availability as well as the physical environment, in doing so changing ecological processes at all hierarchical scales (Leitao et al., 2006, p. 15; Farina, 2006, p. 111). While all land transformation processes change the landscape over time, Forman (1995) identifies dissection and fragmentation as the two processes that decrease landscape scale connectivity (p. 407). Both processes break the landscape into smaller more isolated pieces, but typically the separating elements associated with fragmentation are more widespread and create fragments that are more widely and unevenly separated (Forman, 1995, p. 408; Battisti, 2003). As such, fragmentation has increasingly become a worldwide issue due to its effects on habitat and ecosystem loss (Farina, 2006; Leitao et al., 2006; Forman, 1995).

As a continuum process, landscape fragmentation is considered in terms of structural elements, notably patches and the matrix (Farina, 2006, p. 130). Fragmentation has the effect of reducing patch size and increasing their isolation (Farina, 2006), thereby affecting the configuration and composition of structural elements of the matrix and influencing the factors underlying landscape ecological processes. As a result, nearly all landscape ecological patterns and processes are affected (Forman, 1995, p. 415). Furthermore, fragmentation can increase the vulnerability of remaining landscape patches to external disturbance (Farina, 2006, p. 133). This triggers natural land transformation processes that play an important role in creating landscape heterogeneity and support ecological function. In fact, lack of disturbance has been found to have a depressing effect on landscape patch diversity, reducing landscape heterogeneity (Farina, 2006, p.112). In this sense, fragmentation increases landscape heterogeneity (Lovett, et al., 2005, p.100) by changing the composition and configuration of the landscape, triggering dynamic processes that create a shifting landscape mosaic.

The problem with fragmentation arises when there is an associated loss of patch, as such a loss effects species population abundance and distribution (Lovett, et al., 2005, p.100). Fragmentation changes the spatial configuration of patches by breaking them apart, however, in a natural system this triggers the shifting mosaic and creates new patches that accommodate species and associated ecological process. Meaning, composition is not lost even when configuration changes it simply shifts to a new location. This is typically not the case in human influenced landscapes, where composition is lost when configuration changes as a result of fragmentation. Human induced landscape fragmentation modifies the landscape, often irreversibly, by converting natural land to other uses like agriculture and urban centres, and in doing so changing the landscape's structure and function. Then, it becomes apparent that landscape fragmentation dynamics are highly affected by land use decisions and policy (Farina, 2006, p. 131) and that the land use context must be considered when trying to reduce fragmentation and enhance landscape connectivity. To this end, considering the landscape mosaic within the land use planning process can become an important tool in determining how to reduce or mitigate the effects of fragmentation (Farina, 2006, p. 139).

Landscape ecology tell us that landscape mosaics exhibit various spatial patterns, but in general landscape structures (i.e. patch, corridor, and/or matrix) are configured in a spatially recognizable, repeated pattern in a location, but vary across a landscape (Forman, 1995, p. 289). Traditionally, these patterns are represented by structural spatial elements like the composition of land cover types (Leitao et al., 2006, p. 20). However, ecosystem composition and configuration of the landscape mosaic both affect the level of function expressed by landscape ecological processes and have a direct impact on the ecosystem services provided (Leitao et al., 2006). Areas of interaction occur between ecosystem structures along boundaries or edges and are porous and act like filters rather than absolute boundaries that serve as either habitat, conduit, source or sink (Forman, 1995; Leitao et al., 2006; Lovett, et al., 2005). In this way, they exert a strong influence on the movement and flow of energy and materials that either facilitates or impedes processes, and directly influence ecosystem services produced. As ecological function relies on a level of interaction between landscape structures, the distribution of landscape structures affects areas of interaction between ecosystem structures and has a significant influence on ecosystem function (Leitao et al., 2006; Lovett, et al., 2005). Then, finding opportunities to facilitate the flow of energy and materials relies on identifying opportunities to better connect the landscape. This is possible by looking at not only landscape composition but also at landscape configuration as ecological processes are independently and interactively affected by both (Leitao et al, p. 21).

Landscape configuration is the spatial arrangement, position, and orientation of structural elements (Leitao et al., 2006, p. 21). Landscapes exhibit various spatial configurations, but in general landscape structures (i.e. patch, corridor, and/or matrix) are configured in a spatially recognizable, repeated pattern in a location, but vary across a landscape (Forman, 1995, p. 289).

Forman (1995) suggests that landscape configuration is dependent on the functions that bind ecosystems clusters, where visible boundaries are created between spatial elements that influence flows and movement (Forman, 1995, p. 289). As discussed, the landscape's biophysical characteristics shape the horizontal gradient and create the conditions necessary for land cover types to establish, creating a mosaic of various ecosystems. This response to the biophysical landscape results in ecosystems clustering to repeated landscape characteristics (Forman, 1995, p. 288). A spatially heterogenous landscape mosaic is the result, where land cover type structural characteristics are derived from abiotic factors and functional characteristics are derived from biotic assemblage, but are distributed in un-even, non-random pattern (Forman, 1995, p. 39; Lovett, et al., 2005, p. 11). Therefore, each mosaic is spatially arranged, or configured, according to a set of structural and functional characteristics repeated throughout the landscape (Forman, 1995, p. 289).

The degree of connectivity between natural ecosystems results in the degree of interaction between ecosystems across scales and patterns of patchiness, either facilitating or impeding ecological process and function between elements and scales (McRae, et al., 2012; Leitao et al., 2006). Each landscape structure recognizes connectivity within its structure, however the way it is expressed differs between elements. Patch connectivity is concerned with habitat composition and configuration, whereas corridor connectivity is focused on linear structure and the presence and aggregation of gaps, and finally, matrix connectivity is interested in landscape continuity of non-built areas (Park, 2015, p. 425; Forman, 1995, p. 155). To help guide planning for connectivity, Forman (1995) suggests practitioners use the "spatial-flow principle" to understand this, which states: "all ecosystems are interrelated, with movement or flow rate dropping sharply with distance, but more gradually between ecosystems of the same type" (p. 287). This guideline implies that function (i.e. flow and movement) is interlinked with asymmetric clusters of ecosystems, where clusters form as response to a structural horizontal gradient and biological elements are tied together by ecological process flows (Forman, 1995). Then, better understanding of ecosystem clusters and their spatial composition and configuration should be the keystone of landscape planning and design (Forman, 1995, p. 290) as it clarifies the arrangement and interaction between land cover types, both structurally and functionally, and identifies the landscape mosaic. In identifying landscape composition and configuration an understanding of the landscape's response to the horizontal gradient is possible and can inform approaches to reduce fragmentation and increase connectivity.

2.2 Building Resilience

To better understand how biodiversity can support building climate change resilience into the RM of Ritchot, this section discusses the relationship between climate change and biodiversity, the strategic climate change and biodiversity planning framework within the RM of Ritchot, and the role the municipal development plan can play in addressing climate change.

2.2.1 Introduction: Climate Change and Biodiversity

In the RM of Ritchot, climate change induced temperature increases are anticipated to affect annual precipitation patterns causing fluctuations in snowfall and rainfall rates and produce a greater potential for surface water evaporation (IISD, 2007; Sauchyn & Kulshreshtha, 2008). This is expected to create a more arid environment with an increased potential for drought while precipitation changes are expected to produce more frequent, intense rainfall events (IISD, 2007; Bush, Loder, James, Mortsch, & Cohen, 2014, p. 29). This would increase the probability of vegetation loss and soil cover and the subsequent ability of the soil to hold water, which when coupled with more intense but less frequent rainfall could create a situation ideal for enhanced erosion and slope failure (Sauchyn & Kulshreshtha, 2008).

These effects of climate change will cause differing responses from biological elements, where they will either shift their range or evolve to new conditions (Saskatchewan Watershed Authority, 2012). In the RM of Ritchot, a northward shift in vegetation zones because of shifting moisture patterns will result in biological elements reflecting those types currently found in the Great Plains Region of the United States (Saskatchewan Watershed Authority, 2012). Because of the increase in drought, grasslands will see a reduction in production and growth and could see a shift in composition if drought is extended (Saskatchewan Watershed Authority, 2012). Furthermore, climate change effects are expected to reduce the number and area of wetlands, as well as shift the composition of forests and reduce their regeneration potential (Saskatchewan Watershed Authority, 2012). These effects will change biodiversity, which could result in a loss of habitat, species, and genetic biological resources (Saskatchewan Watershed Authority, 2012).

Changes to biodiversity will result in changes to ecosystem composition and configuration and influence the way interactions occur between biological elements in ecosystems (Mooney, et al., 2009, p. 49). Because of the hierarchal nature of biological element organization, system scale impacts are possible where feedback loops become influenced and potentially exacerbated by climate change effects (Mooney, et al., 2009). For example, changes in the time of and intensity of freeze-thaw events, as well as diurnal temperature patterns will likely change the timing of biological events as they are a function of season and weather (Sauchyn & Kulshreshtha, 2008, p. 292). Such shifts in ecosystems and biological timing could bring associated changes in the abundance and distribution of weed and insect populations and increase the potential for pest invasion (Sauchyn & Kulshreshtha, 2008, p. 292; IISD, 2007).

This could add further stress to ecosystems weakened by reduced summer precipitation (IISD, 2007). Then, by reducing biodiversity loss and maintaining ecosystem composition and configuration, biotic components of ecosystems that reduce the potential for system scale impacts can be preserved. Furthermore, by conserving and restoring natural lands that have historically provided ecosystem services as listed in Table 2.1, natural ecosystems can provide added resilience to climate change by mitigating anticipated impacts.

However, the full impact of climate change on how biological elements interact is currently unknown (Sauchyn & Kulshreshtha, 2008; Mooney, et al., 2009). Generally, changes to ecosystem structure and function occur gradually, where most short-term change affects a small area and long-term change affects a large area (Lovett, et al., 2005, p. 4; Forman, 1995, p. 8). As ecosystems can absorb stresses for long periods of time and respond after the fact to an event, the way they respond to climate change may not be seen for some time, however, should a critical threshold be crossed rapid ecosystem and landscape modification may be seen (Sauchyn & Kulshreshtha, 2008, p. 290). All ecosystems have a threshold in their ability to respond to change. Various definitions are used to define the concept of thresholds but can broadly be understood as the ability to withstand a shift in ecosystem state (Guntenspergen & Gross, 2014, p. 2). Threshold concepts also incorporate the idea of critical load - - the ability of an ecosystem to absorb input - - as well as the impacts of extrinsic factors across hierarchical scales of interaction (Guntenspergen & Gross, 2014, p. 2). Regime shift occurs when ecosystems are pushed over thresholds into another stability domain, which often produces substantial and often irreversible changes to ecosystem processes (Millennium Ecosystem Assessment, 2005, p. 47; Mooney, et al., 2009, p. 52). Should this occur, it is expected that existing ecological communities will begin to disassemble and form new assemblages (Sauchyn & Kulshreshtha, 2008, p. 293).

Ecosystem services would then be impacted by changes in biodiversity as ecosystem structure and processes are affected by changing the composition and configuration of biological elements (Millennium Ecosystem Assessment, 2005, p. 46; Ding & Nunes, 2014, p. 60). While ecological function and ecosystem services are still maintained in ecosystems with reduced resilience, extreme events induced by climate change (e.g. flooding, heavy rainfall, and drought) may cause ecosystems to shift toward a less stable and desirable state (Mooney, et al., 2009, p. 51). As climate change threatens to cause substantial disturbance and reconfigure ecosystems and their associated functions thereby altering biodiversity and ecosystem capacity to produce services (Mooney, et al., 2009, p. 49). Because spatial heterogeneity and configuration consider ecological function, it is now recognized as one of the most significant aspects to incorporating functional connectivity into practice (Lovett, et al., 2005, p. v). As such, Henderson, Hogg, Barrow, & Dolter (2002) state that reducing the development of homogenous landscape may become especially important as "in a world of climate change, selection of protected areas may need to focus on site heterogeneity and habitat diversity (as these provide some buffer against climate change) rather than on representativeness" (p. 3). In this way, biodiversity can be understood to provide resilience to climate change as it supports site heterogeneity and habitat diversity.

Furthermore, biodiversity loss as a result of landscape conversion has the potential to exacerbate anticipated climate change effects (Mooney, et al., 2009, p. 48). Historic landscape conversion has altered regional temperatures, precipitation, vegetation and other climate variables that ultimately impacted global climate patterns (Pielke Sr, et al., 2002, p.1706;

Pielke Sr, 2005, p. 1625). As a result, land conversion has changed regulating ecosystem services that affect the carbon-carrying capacity of the landscape as well as the flux of greenhouse gases (GHG) between land and atmosphere (Dale, et al., 2011, p. 756). In North America, the magnitude of landscape conversion that has occurred may have resulted in it being a greater climate-forcing effect than GHG emissions (Pielke Sr, et al., 2002, p.1706). Currently, landscape conversion outweighs the response of climate change on species and ecosystems, but as climate change continues it will negatively interact with ecosystem loss and fragmentation (Mantyka-Pringle, et al., 2012, p. 1240). This will make biological elements more at risk to the effects of climate change and make ecosystem services that mitigate climate change more vulnerable to loss. As such, it is anticipated that climate change will eventually overtake land conversion as the determining factor of biodiversity loss (Mantyka-Pringle, et al., 2012, p. 1240). Then, reducing natural land loss by landscape modification can support the reduction of biodiversity loss and add landscape resilience to vulnerabilities presented by climate change effects.

To reduce the effects of climate change on biodiversity, one of the primary methods suggested has been to protect ecosystems and restore their connectivity through corridors (Mokany, Harwood, & Ferrier, 2013, p. 519). Protecting ecosystems helps retain viable biological populations and their associated complex biological interactions, whereas restoring landscape connectivity facilitates the movement and flow of energy, species, and processes (Mokany, et al., 2013, p. 520; McRae, et al., 2012). Together this creates ecosystems with greater integrity that can better support adaptation to environmental change associated with climate change and reduce their vulnerability to potential effects (Environment Canada, 2013, p. 11; Mokany, et al., 2013, p. 520). Integrating landscape ecology principles into land use planning will support this goal as it is concerned with the relationships between ecosystem structures and functions, their complex spatial patterns and dynamics, associated ecological processes across scales, and human-modified ecosystems, and is therefore highly applicable to landscape planning and management (Leitao et al., 2006, p. xx; Ahern, 2013, p. 1203; Farina, 2006, p. 5).

Land use planning aims to “secure the physical, economic, and social efficiency, health, and well-being of urban and rural communities” by “scientific, aesthetic, and orderly disposition of land, resources, facilities, and services” (Canadian Institute of Planners, 2018b). The Canadian Institute of Planners (CIP) has recognized the role land use planning has in climate change planning and has made mitigation and adaptation planning key attributes in how communities are to be built and function (Canadian Institute of Planners, 2018a, p. 2). Then, understanding how climate change and biodiversity are included in the current land use planning framework can help clarify how the framework could support efforts to integrate landscape ecology principles into the land use planning process to reduce natural ecosystem loss and fragmentation and build climate change resilience into the RM of Ritchot and ultimately the region.

2.2.2 Climate Change and Biodiversity Strategic Framework in the RM of Ritchot

In 1988, the United Nations Environmental Programme (UNEP) and the World Meteorological Organization acknowledged the need for independent, scientific, and technical information to support decision-making as it related to addressing the risk of human-induced climate change (Intergovernmental Panel on Climate Change, 2010, p. 4). This led to the formation of the Intergovernmental Panel on Climate Change (IPCC) and marked the beginning of global efforts to protect “the global climate for present and future generations of mankind” (Intergovernmental Panel on Climate Change, 2010, p. 4). The first comprehensive report produced by the IPCC was presented to the United Nations General Assembly in 1990 and proved instrumental in initiating the development of a framework convention on climate change. The 1992 *United Nations Framework Convention on Climate Change* (UNFCCC) established an international framework to stabilize GHG concentrations to avoid dangerous consequences by providing a foundation for multilateral action (United Nations Framework Convention on Climate Change, 2018). Around the same time, there was a growing recognition of the significant environmental, social, and economic value of biological diversity and of the benefits it contributed to human well-being. In 1987, UNEP recognized biodiversity as an important factor of present and future socioeconomic development and began exploring the potential of an international convention on biodiversity to address the threat to species and ecosystems from human activities (Secretariat of the Convention on Biological Diversity, n.d.). The 1992 *Convention on Biological Diversity* (CBD) acknowledged the value of conserving genes, species, and ecosystems for the benefit of human well-being and established international commitments to conserve biodiversity and encourage the sustainable use of biodiversity components to ensure the commercial benefits from biological resources is shared in a fair and equitable way (Secretariat of the Convention on Biological Diversity, n.d.). Canada was a signatory to both conventions and committed the country to realizing agreement objectives with the ratification of both agreements in 1992 (Government of Canada, 2017a; Government of Canada, 2017b).

Canada's ratification of the CBD and UNFCCC resulted in the development of national strategies to address biodiversity and climate change to meet the obligations of international conventions. A key obligation of the CBD committed Canada to preparing a National Biodiversity Strategy and Action Plan (NBSAP), and in 1995 Canada submitted the *Canadian Biodiversity Strategy* ("strategy") as its national strategy. The strategy provided a framework to guide the implementation of the CBD in Canada and harmonize national activities that promote the conservation of biodiversity to maintain and enhance productivity, diversity, and integrity of natural systems that facilitate sustainable development and economic opportunities (Government of Canada, 1995). Strategic directions included aimed to maintain ecological integrity, and conserve and restore ecosystems, and acknowledged the importance of biodiversity to maintaining ecosystem services important to human well-being. The strategy also acknowledged the intersectionality of climate change and biodiversity and how atmospheric induced climate change will have direct effects to ecosystems, making Canada increasingly vulnerable to the impacts of a changing climate. As a result, the strategy called for more linkages between implementation processes for the CBD and UNFCCC (Government of Canada, 1995). Canada's action plan, *2020 Biodiversity Goals and Targets*, released in 2016 reflects this ambition as a target has been set to better adapt ecosystems to climate change by prioritizing adaptation measures (Government of Canada, 2016a). As reducing biological diversity loss can mitigate the degradation of ecological processes, supporting ecosystem-based approaches to land use and management can help adapt ecosystems to climate change by reducing their vulnerability to effects. The strategy supported the reduction of biodiversity loss by including a target that prioritized better integration of biodiversity considerations into municipal planning, thereby incorporating municipalities into the strategy to implement the CBD and support Canada's commitment to meeting obligations.

While the *Canadian Biodiversity Strategy* was released fairly shortly after the ratification of the CBD, Canada's national climate change strategy, the *Pan Canadian Framework on Climate Change and Clean Growth,* was only released in 2016 despite the UNFCCC being ratified in the same year as the CBD. This delayed delivery of a national framework reflected the nature of the UNFCCC's implementation since its ratification. When established, the UNFCCC was initially largely focused on mitigating climate change and its objective to "stabilize GHG emissions at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system" (United Nations Framework Convention on Climate Change, 2018) reflected this. Since this goal was set, signatory nations met to discuss their progress toward achieving this objective and negotiate next steps, which resulted in the adoption of the *Kyoto Protocol* in 1997and its full ratification in 2005 (United Nations Framework Convention on Climate Change, 2018). With the objective to operationalize the UNFCCC, the Protocol established agreed upon individual GHG emissions reduction targets for industrialized countries and committed those countries to adopting polices and measures that supported reduction efforts (United Nations Framework Convention on Climate Change, 2018). Following this, the *Paris Agreement* was adopted in 2016 and aimed to "combat climate change and accelerate and intensify the actions and investments needed to a sustainable low carbon future" (United Nations Framework Convention on Climate Change, 2018) and move the global community toward increased climate change action. Mitigation obligations under the Kyoto Protocol initiated international climate action by setting binding targets and establishing flexible market mechanisms, while the Paris Agreement set a binding requirement for nations to prepare and communicate a nationally determined contribution (NDC), which includes their strategy to achieve mitigation objectives and submit to regular reporting (United Nations Framework Convention on Climate Change, 2018).

Although Canada withdrew from the Kyoto Protocol in 2012, it has adopted the Paris Agreement and in 2016 submitted the *Pan Canadian Framework on Climate Change and Clean Growth* ("framework") as its first NDC. The framework is Canada's response to its commitment to mitigating GHG emissions and implementing adaptation measures and sets the strategic direction for the country to meet its obligations under the Paris Agreement. The framework reflects international objectives set by the UNFCCC to ultimately limit global temperatures and reduce the rate of warming and has established policy actions that include both mitigative actions like carbon pricing and GHG emissions reductions, and adaptive measures like those that build climate change resilience and accelerate economic innovation (Government of Canada, 2016b, p. 2). Biodiversity can provide both mitigative and adaptive capacity, as biological resources provide the foundation for climate regulating services that mitigate atmospheric climate change and for other regulating and supporting services that can adapt ecosystems to climate change effects and support the continued delivery of provisioning and cultural services necessary to human well-being (Millennium Ecosystem Assessment, 2005). The Pan Canadian Framework has acknowledged the importance of biodiversity in addressing climate change, where the benefits for ecosystems and biodiversity were a main consideration in developing policies (Government of Canada, 2016b, p. 9). To support biodiversity and climate regulating services the framework made the protection and restoration of natural areas a priority, in doing so providing the national policy directive to reduce biodiversity loss.

Since the ratification of the CBD and UNFCCC, federal, provincial, and territorial governments have worked toward implementing supporting laws, policies, and programs (Government of Canada, 1995). The national strategies developed as a result not only commit the federal government to pursuing strategic directions based on the objectives set in both national frameworks, but also commit provincial and territorial governments. Manitoba's response to obligations set in both national frameworks has been the *Made-in-Manitoba Climate and Green Plan* ("plan") (Government of Canada, 2017c, p. 3; Biodivcanada, n.d.).

Adopted in 2017, the plan sets the strategic direction for the province to reduce GHG emissions and adapt Manitoba to climate change impacts (Province of Manitoba, 2017c, p. 8). The plan has acknowledged the importance ecosystems goods and services and the need to implement programs that support the continued delivery of benefits necessary to human well-being in the province, where many of the goals set in the plan rely to some degree on services provided by ecosystems. As a result, the plan recognizes the importance of biodiversity to these goals and has made biological resources the focus of the *Nature* pillar, one of the pillars upon which the plan is founded. In this way, the province has set ambitions that attempt to address both the national obligations set by the CBD and UNFCCC.

While provincial strategic plans reflect the interest of the province to meet international climate change and biodiversity obligations, policy direction to integrate these concept into land use planning is provided by provincial land use policies (Province of Manitoba, 2011). Provincial land use policies not only include provisions for general development and standard planning topics like settlement areas and transportation, but also include provision for maintenance of natural lands that support biodiversity and ecological processes that may offset and abate potential effects of climate change (Province of Manitoba, 2011). Policy Area 4, Section 1 aims to:

> "Permanently protect a representative sample of each of the Province's natural regions and subregions and conserve biodiversity in Manitoba" (Province of Manitoba, 2011).

Policies include provisions for development to avoid fragmentation of critical and significant wildlife habitats and support the establishment of corridors and encourage the conservation of critical and significant habitat on private lands. Therefore, the provincial land use planning framework directs land use planning practices in the RM of Ritchot to reduce biodiversity loss and support the continued delivery of ecosystem services that add resilience to climate change.

As land use planning is largely concerned with the spatial impact of the physical environment and the spatial coordination of various functions (Hodge, 2003, p. 127), integration of landscape ecology concepts into the planning process could encourage the development and coordination of landscape spatial patterns that best protect natural ecosystems and their support connectivity. In this way, land use planners could reduce natural ecosystem and biodiversity loss and support the continued delivery of ecosystem services. Therefore, planning for enhanced ecological network connectivity, and ultimately to maintain and enhance network function and biodiversity, becomes an exercise in planning for the physical environment.

2.2.3 Physical Land Use Planning Framework

Physical land use planning is a long-term strategic exercise that is addressed by municipal planners by means of the comprehensive community plan. As the cornerstone of planning in Canada, comprehensive community plans set the strategic policy direction for development in a community by providing a long-range guide for public and private development and sets the general physical plans for the landscape and the provisions for land use patterns and intensity (Hodge, 2003, p. 139; Friedmann, 1971, p. 315). Comprehensive community plans achieve this by presenting the essential physical developments in the community, both with text through policy statements and graphically with maps, to ensure development considers the community’s major physical elements and achieves a desired relationship between them (Hodge, 2003). They are considered comprehensive because they are “based on local economic, social, cultural, biophysical, political, and demographic forces within a spatial and temporal context” (Dale, et al., 2011,

p. 756), and as such can rationally organize and direct physical development by addressing the social, economic, and political forces that factor (Hodge, 2003). In Manitoba, comprehensive community plans are known as development plans, and are required for all municipalities and planning districts (Province of Manitoba, 2017a, p. 44), including the Macdonald-Ritchot Planning District. Then, integrating elements of the ecological network, as they relate to the RM of Ritchot's ecosystem structures and spatial patterns, within the development plan would be an appropriate approach to protect natural ecosystems, better connect the landscape and support building climate change resilience into the landscape.

Fundamentally, comprehensive community plans reflect the economic and social objectives of a community (Hodge, 2003, p. 190). With the increasing adoption of climate change policy by organizations like the CIP, it has been demonstrated that planning for climate change has increasingly become a social and economic priority. Furthermore, Canada's ratification of international conventions has resulted in national and subsequently provincial climate change and biodiversity policy priorities. As such, the comprehensive community plan offers a way to consider how the physical environment can support climate change action and presents an opportunity for land use planners to consider the role of significant landscape physical features beyond growth and development and better consider their role in building climate change resilience into the landscape. As the natural environment is considered a basic element of the physical environment, identifying the significant natural features in the landscape can be considered a key component in producing a comprehensive community plan (Hodge, 2003). This provides an avenue to consider a landscape's ecosystem structures as key components to community planning and guide growth and development towards uses and patterns that support ecological network connectivity.

However, the use of development plans to integrate elements related to climate change and biodiversity does present challenges. Although comprehensive community plans attempt to consider the broad spectrum of influencing forces, they have been criticized for expressing a given perception, interest, and value of the observer at a point in time (Friedmann, 1971, p. 317). Despite attempting to be an interface of the ideals and goals of a community, such an influence has the potential to limit the scope of development plans as well as limit their ability to respond to the dynamics of land and building development (Hodge, 2003, p. 185). Furthermore, planners developing comprehensive community plans are often limited in knowledge relevant to the situation with which they are concerned and rely heavily on their capacity to centrally coordinate planning activities, an assumption often misguided (Friedmann, 1971, p. 318). As a result, there is more potential for emerging issues, like climate change and biodiversity, to not be given the required time for reflection and for decisions on policy to be made expeditiously (Hodge, 2003, p. 187; Battisti, 2003, p. 241).

Friedmann (1971) suggested that to address emerging issues, like biodiversity loss and climate change, community plans will increasingly need to complete comprehensive planning at the interface of conflicting systems and enlarge “the relevant compass of knowledge” included in the planning process (p.323). By widening the expertise included in the planning process, experience and knowledge may be made available that may not have been otherwise, reducing the potential for limited perspectives, interests, and values to be reflected. Furthermore, including other expertise in the planning process decentralizes the knowledge gathering involved in planning as it reduces the load of information gathering and processing required from land use planners, increasing their capacity to understand systemwide phenomenon and develop policy accordingly (Friedmann, 1971). Then, incorporating measures to address climate change and biodiversity into the development plan will not only rely on the provision to include natural elements into plans for growth and development, but also requires the integration of landscape ecology expertise into the planning process. If these objectives can be systematically coordinated to reduce the typical siloed nature involved in their planning, increased support for the inclusion of their cross-purpose objectives may be possible in the comprehensive community plan (Beckwith, 2014).

Manitoba's land use policy framework has attempted to address concerns related to integration and siloed functions in development plan. In Manitoba, development plans must generally be consistent with Provincial Land Use Policies and provide local authorities with direction for a comprehensive, integrated, and coordinated approach to land use planning (Province of Manitoba, 2011). These policies acknowledge the ability for natural lands to support ecological processes as well as their potential to offset and abate climate change (Province of Manitoba, 2011, p. 23). By acknowledging these key abilities of natural lands, the Provincial Land Use Policies attempt to ensure development plans follow policies meant to integrate natural land considerations into land use growth and development strategies. Furthermore, the Provincial Land Use Policies explicitly refer to watershed management and the importance of incorporating Integrated Watershed Management Plans (IWMP) into development plans. Developed by conservation districts, IWMP address development and management of water, land, and aquatic systems within a watershed and provide municipalities a roadmap for developing land use plans that consider watershed priorities (Province of Manitoba, 2011). The RM of Ritchot is located within the Red River Watershed and contains three sub-watersheds: Rat-Marsh River Watershed, La Salle River Watershed, and Seine River Watershed; the Seine River Watershed occupies almost the entire land area of the municipality covering a total land area of 2,509 square kilometres (Seine-Rat River Conservation District, 2009, p. 5). The Seine River IWMP has made the improvement of biodiversity a key objective in improving the riparian health of the watershed (Seine-Rat River Conservation District, 2009, p. 26). Although local authority over watersheds rests with local conservation districts, including IWMP in Provincial Land Use Policies ensures land use planners consider the plans key features and effects on the landscape, thereby integrating watershed objectives, like biodiversity improvement, into the land use planning framework.

By integrating provisions for natural lands, Provincial Land Use Policies provide development plans with the policy framework needed to consider strategies that reduce biodiversity loss and increase ecosystem connectivity. The Macdonald-Ritchot Planning District Development Plan (the Plan) has included natural land considerations and has committed the Planning District to objectives that include sustainable development and conservation of agricultural and natural environmental assets (Lombard North Group, 2011). Released in 2011, the Plan sets a twenty-year vision for the RM of Ritchot and includes policies to identify and protect natural areas like waterways, wetlands, and wood lots in order to sustain the integrity of the environment and ecosystems (Lombard North Group, 2011). In this way, an opportunity is provided for the development plan's supporting documents like secondary plans, zoning by-laws, and permitting processes to also consider natural land considerations. Reflective of this, the Plan has developed a land use designation classification system that includes *Green/Agricultural* and

Environmental Policy Areas, which aim to address the protection and enhancement of the natural environment and protect agricultural lands from urban land uses while recognizing significant natural and ecological areas like flood plains, rivers, parks and wildlife corridors (Stantec, 2016, p. 148). Furthermore, the Plan encourages engaging consultation with conservation districts in dealing with issues of habitat and ecosystem conservation to ensure appropriate environmental protection measures are considered in the development review process (Lombard North Group, 2011). As such, the development plan provides the planning framework for land use planners to consider issues of ecosystem protection and connectivity. Then, land use planning requires an approach that reduces biodiversity loss and increase ecosystem connectivity while also considering the human land use context. Ecological network planning may offer this approach.

2.3 Ecological Network Planning

This section introduces ecological network planning, discusses the process of developing an ecological network, and investigates how the ecological network is identified and defined.

2.3.1 Introduction: What is Ecological Planning

First introduced as a conservation tool, ecological network planning was developed to recover and maintain ecological connectivity (De Montis, et al., 2016, p. 313). Early ecological network planning was informed by a rich theoretical framework offered by numerous disciplines of ecology, including landscape ecology, and emerged as a prominent approach to conserving natural ecosystems, increasing connectivity, and increasing the permeability of the landscape matrix to species and processes (Battisti, 2003; Battisti, 2013). Ultimately, ecological network planning attempts to better connect a fragmented network of natural and semi-natural lands to support more biological diversity and ecological function (Battisti, 2013; Gonzalez, et al., 2017, p. 187). Ecological network planning is interested in landscape connectivity because it helps understand the most critical network linkages to ensure resilience of the whole network, which adjacent areas best support ecological flows, and the consequences land use change and fragmentation have on the network (Theobald, et al., 2011). Understanding these underlying factors assists in identifying what and where natural lands should be preserved and restored, clarifies landscape spatial patterns, and identifies opportunities to link existing natural lands of benefit and where to "fill" the gaps to add landscape resilience (Benedict, & McMahon, 2006, p. 3). In this way, ecological network planning becomes an approach to consider the conditions necessary for natural ecosystems to function and survive in a fragmented landscape (Battisti, 2003, p. 241; Zhang, & Wang, 2006, p. 449).

To better protect and connect ecosystems, landscape managers have implemented ecological network planning by following either a physiographic approach centered on maintaining and enhancing different ecological structures or a functional approach concerned with ecological process management (De Montis, et al., 2016, p. 313). Historically, land use managers have focused on the physiographic approach, and largely directed their efforts to protecting and maintaining specific areas or features (Benedict, McMahon, & Conservation Fund, 2006). These concepts have historically been found in the realm of conservation planning, where efforts were directed towards natural resource protection and conservation. However, with the growing recognition of the importance of connectivity to restoring ecological processes and maintaining biodiversity, ecological network planning has increasingly aimed to make a fragmented natural system more coherent and has directed efforts toward better connecting natural lands and semi-natural lands to the spaces between them (Lovett, et al., 2005; Battisti, 2013). Yet, until recently ecological concepts have not been readily applied to land use planning practice (Leitao et al., 2006, p. 27).

Land use planning and management has traditionally focused on the human elements of the landscape, with practice focused on planned cities and regions (Forman, 2008). Traditionally, there has been low integration between land use planning and conservation, which has been suggested as reason why planning approaches have not adequately managed natural resources and substantially advanced land use planning sustainability objectives (Leitao, et al., p. 28). As land use planning practice increasingly moves towards planning for climate change, physical land use planning is challenged to maintain ecologically beneficial spatial arrangements of land cover types that reduce natural land loss and increase connectivity (Leitao et al., 2006, p. xvii). As a result, more recent ecological network planning approaches have considered the physical network of core areas and other key structures, the corridors that link them and the buffer zones that support them and implemented strategies that configure land use in ways that maintain and restore biological diversity and ecological function to the network (Gonzalez, et al., 2017, p. 187; Battisti, 2013, p. 216). This has led to in the integration of conservation theories into the planning process and a shift in focus from one heavily centred on ecological network elements to one that includes the human elements of the network like recreation, aesthetic, etc. (De Montis, et al., 2016).

The shift in focus from the traditional conservation focus has adapted the ecological network planning approach in a number of ways. Zhang, & Wang (2006) have identified that a more multifunctional perspective has resulted in ecological network planning looking to not only improve the ecological value of natural and semi-natural spaces as they relate to ecological function and biodiversity, but to also contribute to the socioeconomic value of these spaces and of the network. A landscape spatial pattern is considered multifunctional when at least one of the following four conditions is met: 1) increased spatial heterogeneity; 2) land use functions are increasingly intertwined; 3) the third dimension of land is used (i.e. vertical space); and 4) the fourth dimension of land is used (i.e. time) (Priemus, et al., 2004, p. 270; Kato & Ahern, 2009, p. 799). Such conditions allow these approaches to develop landscapes that provide multiple functions and serve many planning objectives, goals, and values (Kato & Ahern, 2009, p. 799). As such, multifunctional landscape planning approaches have been suggested as key to achieving functional integration of land uses and advancing sustainable development objectives (Kato & Ahern, 2009; Priemus, Rodenburg, & Nitjkamp, 2004; Brandt & Vejre, 2004, p. 1). These approaches attempt to integrate all land use aspects into a common framework by better understanding the complex links between land uses, their competing and complementary aspects, and ultimately increase the number and diversity of function within an area (Brandt & Vejre, 2004; Priemus, et al., 2004, p. 270).

Benedict & McMahon (2006) demonstrated that the shift in ecological network planning focus has resulted in the approach being interested in creating a system of open space hubs and links that can provide both ecological and human value. This is important because according to Leitao, et al. (2006), planning approaches lie along a continuum defined by three landscape resources: abiotic, biotic, and cultural (p. 27). Traditionally, planning disciplines have approached landscape resource planning in an isolated, single purposed approach and segregated land uses. Spatial land use segregation has been a common approach for decades as it has been seen as the most economically efficient land use strategy as it was believed to be the most rational way to intensify land use (Brandt & Vejre, 2004, p. 7). As a result, this approach has been heavily promoted through economic incentives and land use designation strategies, which have homogenised landscape resources and created monofunctional landscapes that are increasingly in conflict with landscape ecological dynamics (Brandt & Vejre, 2004, p. 7).

However, since the 1990s practice has shifted toward a broader, more comprehensive view of the landscape and greater integration between landscape resource planning disciplines (Leitao, et al., 2006, p. 28). This has resulted in planning approaches that have attempted to reduce focus on functional segregation and move towards functional integration. Moving towards functional integration offers an opportunity to address negative environmental impacts associated with past land use planning practices and better link the human land uses with landscape ecological processes and functions. This can lead to more efficient use of space and time and support a spatial pattern that allows for both compatible and competing land uses and create synergies between economic vitality and environmental quality (Kato & Ahern, 2009, p. 800).

Battisti (2013) identified how the shift in ecological network planning focus resulted in the approach addressing the risks posed to biodiversity and ecological processes caused by human-induced fragmentation. As a conservation tool, ecological network planning focused connectivity efforts on fragmentation sensitive targets (i.e. species, communities, and processes), but with further integration into land use planning it has taken on a site-based focus built around politically defined study areas and used fragmentation sensitive targets as indicators (Battisti, 2013, p. 217). The integration and change in focus has resulted in ecological network planning becoming a tool that considers ecological processes through the spatial physical design of the landscape. As a result, land use planning has been provided with a spatial and dynamic approach to analyze the impact of human-induced fragmentation across a whole landscape and identify ways to enhance the spatial landscape pattern to improve the connectivity of the ecological network (Battisti, 2003; Lewis, 1996, p. 21).

Multifunctional planning approaches, like ecological network planning, are expected to be increasingly important in growing metropolitan regions trying to address climate change.

According to Priemus, et al. (2004), spatial planning in these regions requires a broader focus than creating complementary land use patterns as these areas need approaches that better link different projects and functions (p. 272). In peri-urbans like the RM of Ritchot, such innovative planning approaches are needed to address the mix of urban and rural land uses as these areas will increasingly be challenged with space limitation because of competing demands between agricultural production, urbanization, and natural area protection (Kato & Ahern, 2009, p. 800; Wandl, & Magoni, 2017, p. 2). Planning approaches likes agricultural urbanism have attempted to link economic development, community identity, and urban planning and design with issues of food and agricultural systems (de la Salle & Holland, 2010). Others like Conservation Design have attempted to implement a ‘density-neutral’ approaches to community growth and guide rural development to conserve open space and natural features (Arrendt, 2014). Such approaches recognize the role and value both the human and ecological dimension play in conserving natural land and maintaining ecological function, yet both approaches lack focus on the spaces found between landscape structures and the network they form. Ecological network planning offers an approach to investigate the network formed by landscape structures as it integrates landscape resources (i.e. abiotic, biotic, cultural) in the planning process and addresses the shortcoming presented by other approaches.

2.3.2 Process of Developing an Ecological Network

When developing the comprehensive community plan, planners are concerned with identifying the components of concern, what is involved and what scale is of importance (Hodge, 2003, p. 168). Determining these factors is driven by data collection and aims to provide clarity on the issues of concerns, their larger context, current condition and whether change is anticipated (Hodge, 2003, p. 168). Developing the ecological network complements the process to identify and define the network is also data driven and attempts to fulfill similar ambitions. To develop an ecological network, Benedict, McMahon, & Conservation Fund (2006) identify five basic steps to follow: 1) develop network design goals and identify desired features; 2) gather and process data on landscape types; 3) identify and connect network elements; 4) set priorities for conservation action; and 5) seek review and input (p. 113). Each of these five steps are discussed next in further detail.

Develop network design goals and identify desired features:

Step 1 is centered around defining what should be included in the ecological network and addressing goals and objectives of the plan (Benedict, et al., 2006, p. 113; Leitao, et al., 2006, p. 42). Ecological network planning needs explicit goals and objectives set as the wide range of different contexts, spatial scales, species and process responses to fragmentation, and the mix of abiotic, biotic, and cultural variables inherently make it a complex exercise (Battisti, 2003). Goals and objectives should be clearly stated as they outline the focus of associated research and provide the rational that guides decisions made during the network development process (Benedict, et al., 2006, p. 114). As goals and objectives set the direction of the planning efforts, they also support the identification of network attributes. Identified attributes then, should reflect goals and objectives and classified by the primary benefits they provide, whether that be to ecosystem value and function or to human beings (Benedict, et al., 2006, p. 114). In terms of ecosystem value and function this could include benefits to watersheds or natural ecological systems, whereas human benefits could be considered in terms working landscapes and their resource-based industries like agriculture, forestry and tourism (Benedict, et al., 2006, p. 116). Regardless of what form the network is defined by, this exercise is critical as it will inform all network development steps that follow.

Gather and process data on landscape types:

To develop the ecological network, it is necessary to identify the attributes that characterize the study area, as characterizing attributes will provide direction on the abiotic, biotic, and cultural resources to consider in the ecological network (Benedict, et al., 2006). As such, Step 2 in developing an ecological network is focused on gathering and analyzing data on key attributes. This step begins by considering the ecological network in terms of the geographic extent of a project area, required scale, and desired outcomes, with the objective to identify the landscape and attributes to be used in designing the ecological network (Benedict, et al., 2006). Generally, ecological network planning involves the use of cartographic tools (Battisti, 2003), therefore, once attributes have been identified it will be necessary to gather data and map information. Data can be gathered from a multitude of sources and combined with the aid of mapping instruments like Geographic Information Systems (GIS) that allow for more complete and accurate maps and subsequent analysis (Hodge, 2003). Gathered data should ideally cover the entire project area to avoid any complications presented with the use of hybrid data sets created by compiling various data sources and should be collected at a scale and resolution suitable for the project (Benedict, et al., 2006). Finally, data should be current as much as possible to avoid outdated, incomplete, and inaccurate data (Benedict, et al., 2006). Once the relevant data has been gathered and mapped, landscape attributes can be categorized to reflect the goal and objectives of the ecological network (Benedict, et al., 2006).

While these steps do identify ecological network attributes and clarify how they should be categorized, this approach has raised some concern. As the ecological network planning approach has been integrated within land use planning it has increasingly become focused on landscape structural features and design, and less so on the original ecological focus based on the dynamics of complex ecosystems and landscape function (Battisti, 2013, p. 218; Battisti, 2003). This has resulted in less focus directed toward fragmentation sensitive species or processes of concern, and more towards a pattern-oriented approach that in a sense “freezes” a pattern on a map (Battisti, 2013, p. 220). It has been argued that by doing so land use planning maps risk excluding the more ephemeral and scattered land cover types or those in different successional phases, and risks reducing complex ecological systems to polygons on a map (Battisti, 2013). Ecologists raise this concern as ecosystems are dynamic open systems whose processes and function are not limited by closed systems as generally depicted on land use planning maps (Battisti, 2013, p. 217).

Although these points are valid, a pattern-oriented structural analysis does offer an opportunity to evaluate non-spatial composition as well as spatial configuration, which allows for a degree of function to be considered (Battisti, 2003). As ecological function is considered in the concept of spatial heterogeneity and configuration, a pattern-oriented structural analysis can enable land use planning to recognize underlying ecological function through its analysis of ecosystem structures (Lovett, et al., 2005; Forman 1995). Although this could still exclude less detectable ecosystems, scale and resolution can be better considered in the planning process when attempting to include more detailed ecosystem structures (Benedict, et al., 2006, p. 121). What becomes important then, is using landscape ecology-based metrics as indicators to measure the landscape. Using landscape metrics can provide land use planning quantitative ecological tools that consider compositional factors like patch type, size, and their functional relation to the matrix, as well as identify configurational factors like landscape mosaic pattern, areas of human-induced fragmentation, gaps, and corridors (Battisti, 2003; Zhang, & Wang, 2006). In this way, land use planning maps can better reflect core ecological concepts and consider ecological function in analysis. Although maps may still “freeze” landscape attributes, including landscape metrics in the analysis attempts to better represent the dynamic nature of the landscape and consider function.

Identify and connect network elements:

As ecological network planning is largely concerned with landscape connectivity, once landscape attributes have been identified, mapped, and characterized, the next step to planning an ecological network is to identify and connect elements (De Montis, et al., 2016, p. 314; Benedict, et al., 2006, p. 123). This is typically done using tools like GIS, where the various layers created in the previous step are combined and used to identify key patches and areas for improved connectivity. Generally, key patches are categorized according to their importance relative to attributes related to project goals and objectives (Benedict, et al., 2006). Landscape metrics help categorize patch importance according to the value they provide the ecological network and are generally labeled with terms like priority, significant, or lower priority, and serve to guide where linkages should be established (Benedict, et al., 2006). By considering both patches and linkages, ecological network planning not only considers the important landscape structures but attempts to consider the areas between them. Furthermore, as value is determined through the integration of landscape metrics within the network analysis, value is determined in a quantitative manner that enables the assessment of the current situation and provides justification for network design decisions (Zhang, & Wang, 2006). In doing so, maps created reflect a coherent ecological network that provides land use planners with data driven information to include in the comprehensive community plan and guide landscape patterns.

Set priorities for conservation action:

Once reflected in the comprehensive community plan, significant natural features can be conserved, and development can be guided to reduce fragmentation and impacts to the ecological network (Firehock, 2015). However, before finalizing the ecological network in the comprehensive community plan, Benedict, et al. (2006) suggest as a fourth step to complete an ecological assessment of the proposed network to ensure it meets goals and objectives as well as to set priorities for preservation and restoration (p. 131). The assessment should consider the value provided by the proposed design to both the network as a whole as well as to the structures and the spaces between (Benedict, et al., 2006, p. 131). The expectation is that by having integrated landscape metrics within the network analysis, the proposed ecological network developed will reflect the interplay between spatial patterns and processes and ultimately support the project goals and objectives.

While determining if the proposed ecological network is meeting goals and objectives, planners should concurrently focus assessment efforts on clarifying where the network is most vulnerable to development, degradation, and fragmentation (Benedict, et al., 2006, p. 131). To do this a number of factors should be considered like scale, governance, and projected development. Scale is an important factor to consider when evaluating the ecological network as a whole, as the network design should address the particular needs of the project and ensure examples of all ecosystems that support biodiversity and ecological processes are represented (Benedict, et al., 2006, p. 132). Governance is also important to consider, as it clarifies the institutional arrangements that govern land use and management within the ecological network (Benedict, et al., 2006, p. 132). This can highlight the opportunities and constraints that might exist in setting priorities for preservation and restoration. Finally, to understand the geographic distribution of development threats to the network, planners should understand the factors that are contributing to land conversion like proximity to urban centres, infrastructure, water bodies and open space, as well as property ownership factors (Benedict, et al., 2006, p. 132). Once these issues have been clarified, priorities for ecological network preservation and restoration can be established.

Seek review and input:

With priorities set, the ecological network design is now ready for external review and input. This step is critical to take prior to being included in the comprehensive community plan as it is important to understand how the ecological network might affect people who were not involved in the design process (Benedict, et al., 2006, p. 135).This secondary form of data helps provide planners with unique community information that may not be possible to achieve through primary more quantitative data, and can help provide a more complete picture of a place (Hodge, 2003). Consultation with appropriate people can then ensure the proposed network design meets goals and objective and that the information included is accurate (Benedict, et al., 2006, p. 135) In collecting this information, the ecological network can be adjusted to reflect community concerns. However, Benedict, et al. (2006) note that this step in designing the ecological network is often not taken in this sequential order but rather is often applied throughout the design process (p. 135). This could be of benefit as consulting with community member early in the process could better highlight where efforts should be focused, if characteristics of the study area have been missed or misrepresented, the political context, and available resources (Leitao, et al., 2006; Benedict, et al., 2006, p. 135). Regardless of when consultation occurs, it is a key step in developing the ecological network design and ensuring it meets goals and objectives of the project.

Because this project is interested in how the ecological network is identified and defined, the following section will focus on how to inform the first four steps as it relates to developing an ecological network. While step five is a key step in developing an ecological network, this research will not explore seeking community input. However, the intent is to understand how to develop a product that could inform consultation as it seeks to develop a visual tool to better understand, define, and communicate ecological network planning.

2.3.3 Identifying and Defining the Ecological Network

To identify the natural lands that an ecological network could conserve and restore, objective, quantitative, and replicable scientific information is required as it allows for analysis be completed and ensures land use planners identify the relevant land use patterns and trends required for the comprehensive community plan (Ahern, 2013; Hodge, 2003, p. 122). This can inform what natural lands should be conserved, which are the most valuable, which are most feasible to conserve, and how much natural land should be conserved. This will help the comprehensive community plan reflect the context of the local ecological network and ensure the structures and functions important to the ecological network are protected and restored by guiding development to appropriate areas (Firehock, 2015). In identifying and defining the ecological network to reflect local context opportunities can be presented to enhance the network by proactively selecting areas for restoration and clarifying where land use planning mechanisms, like land acquisition or conservation easements, may be needed to re-link the disconnected landscape (Firehock, 2015, p. 20). In this way, the comprehensive community plan becomes a tool that ensures development meets the current and future needs of the ecological network. Identifying and defining the ecological network within a community, then, becomes a technical exercise aimed at gathering and processing data to identify and develop an ecological network that can set priorities for the comprehensive community plan (Benedict, et al., 2006).

Developing an ecological network to relies on two main activities: conserving existing ecosystems and restoring ecosystems to enhance connectivity. While restoring ecosystems is necessary to "fill the gaps" of ecological networks, conservation of existing ecosystems through their protection is seen as the most important, efficient and effective method of ecological network planning (Environment Canada, 2013, p. 6). In peri-urban areas like the RM of Ritchot where the urban and rural land conversion has caused ecosystem loss, conservation of remnant ecosystems is important as they are key to maintaining and supporting biological material (Environment Canada, 2013, p. 6). This creates a need to conserve these ecosystems above minimum levels to ensure they do not disappear when pressures from land modification increase.

In areas where land use conversion has been drastic and resulted in significant landscape change, restoration of ecosystems may be required as it can be used to re-establish ecosystems and their associated biological materials and processes, and re-link the landscape. However, in many modified areas this is often impossible or undesirable as these areas have disrupted ecological integrity for economic and social gains that humans have come to rely upon (Swetnam, Allen, Betancourt, 1999, p.1202). As such, restoration should only be undertaken as a way to address anticipated ecosystem loss, to increase the surface cover of particular land cover type, or when other options for conservation have been fully considered (Environment Canada, 2013). Then, land use planners are challenged to identify appropriate areas that conserve existing remnant natural lands and are suitable to restore lost ecosystems to and enhance network connectivity.

Understanding the landscape mosaic can clarify where to conserve and restore natural lands as it provides insight into the composition and configuration of landscape elements. Identifying the land mosaic formed by current land cover types is determined by identifying ecosystem structure characteristics and applying landscape metrics to measure their spatial composition and configuration and quantify ecosystems (Leitao et al., 2006; Environment Canada, 2013, p. 6). While conservation of natural lands can be informed by clarifying the ecosystem structures present through the identification of land cover types, restoring ecosystems requires a deeper understanding of relationships and dynamics between all biophysical characteristics (Environment Canada, 2013). Given the biophysical dynamics in the RM of Ritchot previously discussed, it would be especially important to understand the relationship between land cover type and hydrology, soil, and topography when considering restoration of natural lands. In the absence of this knowledge, understanding of historical process and structure can be of particular value as it can provide a point of reference to guide management actions that can be used to set realistic targets and select appropriate locations for restoration (Swetnam, et al., 1999; Environment Canada, 2013). Often, this results in using historic land cover type present prior to land conversion as a reference point to determine locations suitable for restoration as well as the appropriate level of cover to restore (Environment Canada, 2013). Because this research is interested in the biological aspects of the ecological network it will continue to explore defining an ecological network as it relates to the land cover type biophysical characteristic. However, it is acknowledged that to fully define an ecological network and select appropriate sites for restoration requires the definition and consideration of abiotic biophysical characteristics.

Land cover types are generally identified in landscape ecology by the vegetative community established by an ecosystem's primary production as for example forests or grasslands (Smith, & Smith, 2001). At the landscape scale, they can serve as a proxy for an ecosystem and a representation of associated biodiversity and function. However, land cover types can also include human elements that can be interpreted in a landscape ecology context. For example, Forman (2008) describes peri-urban area form at a broad-scale and characterises spatial structure in terms of patches and background matrix, as for example: cropland matrix or low-density residential area matrix (p. 108). Additionally, human elements like roads, trails, railroads, and powerlines can be interpreted as corridors as nearly all have a strong transport or conduit function that facilitates flows between nodes (Forman, 1995, p. 160). Like ecosystems these structural forms are associated with function, which the human dimension associates with land use. As such, spatial landscape elements like composition and configuration will vary and affect landscape spatial patterns. This is important to consider when identifying and defining an ecological network as these human elements often reside in the spaces between natural lands and must be considered when identifying natural lands to conserve and restore as they have substantial impact on ecological structures and function.

Landscape metrics can be used to quantify land cover type composition and configuration. Long used by landscape ecologists, landscape metrics have helped better understand the relationships and interplay between spatial patterns and processes and have been applied in urban ecology, sustainable landscape planning, and planning scenario assessment (Leitao, et al., 2006; Zhang, & Wang, 2006, p. 450). Used to characterise and measure a broad array of spatial patterns, landscape metrics are a quantitative method that provides insight into individual and collections of biological landscape structures, their current state in the landscape, and the effects patterns have a on an array of ecological processes, thereby facilitating the comparison of patterns through time (Leitao, et al., 2006, p. 48; Zhang, & Wang, 2006, p. 455). As such, they have an ability to act as an environmental indicator or proxy for complex difficult-to-measure ecological variables and can provide a value for evaluation that supports planning decisions (Leitao, et al., 2006, p. 49; Zhang, & Wang, 2006, p. 455). This allows for clarification as to where conservation should be focused, as well as allows for comparison of the current landscape to the historical context that enables clarification as to conservation and restoration potential. This makes landscape metrics especially valuable in applications beyond ecology like land use planning, as they can provide the tools for land use planners to make sound, evidence-based decision that the comprehensive community plan requires.

While landscape metrics can be helpful in trying to determine where to conserve and restore ecosystems in a peri-urban area like the RM of Ritchot, criteria is needed to define what to measure with landscape metrics. In 2013 Environment Canada released a guidebook that sets conservation and restoration targets for wetland, riparian, forest, and grassland ecosystems to reduce biodiversity loss and conserve associated ecosystem services and includes guidelines on how to achieve these goals. While the guidebook is focused on Great Lakes areas of concern in Ontario, in the absence of such a guide for Manitoba it can be used for the RM of Ritchot. The guidebook guides the evaluation of landscape composition and configuration as it identifies criteria for a variety of ecosystem types to measure five general themes: 1) Type; 2) Area; 3) Size; 4) Location; and 5) Proximity. Identifying the type of ecosystems that occupy a landscape can clarify the diversity present, which enables better understanding of vegetative structures, the unique assemblages of species and the ecological functions that may exist (Environment Canada, 2013, p. 16). Determining the area occupied by ecosystems supports better understanding of existing land cover proportional representation, enabling comparison to historical reference points and facilitates determining an appropriate level of land cover each ecosystem should occupy and their minimum land cover threshold required to support biodiversity and ecosystem functions (Environment Canada, 2013). As patches are major physical and functional components of landscapes and have substantial effects on ecological processes that affect biotic composition and diversity, identifying patch size has been recognized as key component to understanding landscapes and can serve as indicator of ecosystem fragmentation (Leitao, et al., 2006, p. 88). Location of ecosystems can include a variety of components depending on the ecosystem in question, however, in general understanding location will provide insight into where ecosystems occupy area in the landscape and what are adjacent ecosystems, clarifying landscape configuration and heterogeneity (Environment Canada, 2013). Finally, measuring proximity enables better understanding of distances between patches and to the nearest productive patch, allowing for better understanding of landscape fragmentation and patch isolation, and clarifying opportunities for connectivity (Environment Canada, 2013).

Quantifying landscape structures in relation to these five themes provides empirical data that can clarify landscape composition by characterizing patch richness, abundance, and diversity and clarify landscape configuration by characterizing the effects of distance, clumping, and degree of contrast along edges of structural elements (Leitao et al., 2006). In understanding the current landscape context, quantitative data can be compared to guidelines developed to protect natural lands and reduce fragmentation. The Environment Canada Guidebook developed such guidelines relevant to the historical ecosystems present in the RM of Ritchot that are intended to guide land use planning and ecosystem restoration to protect, restore and connect ecosystems – see Table 2.2. These guidelines provide the criteria needed to evaluate the current state of the landscape against guidelines aimed to support biological materials and diversity and enhance connectivity. This can inform what natural land cover types are present in a landscape, their need for conservation as it relates to percent area cover, patch size, and heterogeneity. Furthermore, this informs where sites may be best restored for increased connectivity as it relates to land cover type proximity.

Table 2.2 **Wetland, Riparian, Forest, and Grassland Ecosystem Guidelines** (Environment Canada, 2013)

	Wetland	**Riparian Ecosystem**	**Forest Ecosystem**	**Grassland Ecosystem**
Percent Area Cover	At minimum, 6% of sub watershed	Minimum 30m wide naturally vegetated riparian area along 75% of stream length	Minimum 30% cover at watershed scale	Maintain native grassland range
Patch Size	Capture full range of wetland sizes, especially those that support ecosystem heterogeneity		Various, but maintain at minimum one 200-hectare patch	Various, but maintain average patch size of 50-hectares and at minimum one 100-hectare patch
Proximity	Priority given to wetlands in close proximity to each other and other natural land structures		Patches within two kilometers of one another	
Heterogeneity	Capture all wetland types, especially those that support ecosystem heterogeneity		Accommodate corridors with 50-100m widths, include full diversity of natural occurring forest types	Encourage clusters or aggregated patches located adjacent to hedgerows, riparian and wetland ecosystems

These findings can be further informed by considering their context as it relates to Forman's (1995) four indispensable patterns:

- Maintain large patches of natural vegetation;
- Maintain wide riparian corridors;
- Maintain connectivity between patches, especially large patches; and
- Maintain heterogenous small patches within human-developed areas.

These patterns are deemed indispensable because they accomplish major ecological objectives that have no known substitute and as such should be the foundation of land use plans (Forman, 1995). Incorporating their consideration toward achieving targets set by guidelines like those discussed above can help set priorities for conservation and restoration by clarifying natural lands of value and guiding where these activities should take place to support spatial patterns that would “fill the gaps” in the ecological network. This enables the ecological network to be defined in a way that would protect biological materials while enhancing ecological flows. When integrated into the land use planning process, insights can be gained as to the feasibility of conserving and restoring such lands by highlighting the spatial physical layout of the network as compared to land use policy framework established. In this way, constraints or opportunities can be presented as to how the existing land use policy framework could support or hinder the establishment of an ecological network and inform strategies to protect and restore important natural lands.

2.4 Summary

Land use planning has been recognized as one of the most effective ways in adapting municipalities to climate change (Government of Canada, 2012, p. 1). The chapter has attempted to understand this by exploring how the comprehensive community plan can be used to support ecological network planning and provide strategic direction to growth and development that protects ecosystems and enhances their connectivity. This chapter outlined how new land use planning approaches that better integrate landscape ecology with planning theory like ecological network planning can help to conserve and restore natural lands to protect biological material and reduce fragmentation. The chapter discussed how protecting biological material and reducing fragmentation can provide resilience to climate change by supporting ecological structures and functions that reduce vulnerability to potential effects. The chapter provided a review of the policy framework surrounding climate change and biodiversity planning, highlighting the international framework guiding Canada's national and provincial priorities and how municipalities can respond to meet objectives. The chapter discussed key landscape ecology concepts that provided the scientific background to ecological network planning and the foundation to developing sustainable landscape patterns that may protect and restore ecosystems in a modified landscape. The research demonstrated that the human dimension also plays a key role in ecological networks, especially when considered in a peri-urban land use context. To address this, the chapter attempted to clarify the benefits of biodiversity to human well-being by defining the human dimension of ecological networks and providing a better understanding of importance of multifunctional landscapes. Finally, the chapter discussed how ecological network planning was an appropriate multifunctional approach to reducing risk to climate change and provided the key steps to consider when planning an ecological network. The next chapter discusses the research approach and methodology applied.

Chapter 3: Research Methods and Strategy

The following sections describe the methods used to address the research objectives to: Define the ecological network and its relationship to biodiversity in the Rural Municipality of Ritchot; and, Develop a visual tool to communicate ecological network planning to municipal and regional planners and decision-makers. The goal of the research is to explore how landscape ecology can support a better understanding of ecological network planning, and be used quantify existing land cover types, define the ecological network, and identify opportunities for connectivity, and inform the land use planning process on how to build resilience into the landscape as it relates to biodiversity. The anticipated outcome is a visual output that identifies opportunities for ecosystem connectivity that could reduce biodiversity loss. The intent of the visual output is that it could be used as a tool to inform the land use planning process and inform the comprehensive community plan on how to support the development of an ecological network that supports biodiversity and builds resilience into the landscape.

Chapter 2 Literature Review has provided information on the context and history of the municipality that clarified its land modification over the last century and the associated natural land loss and fragmentation and has provided information on ecological network planning including relevant terms, concepts, and its relation to biodiversity and climate change planning. The literature review chapter also provided insight into how to define an ecological network, where five basic steps to follow were provided as well as guidelines that provide the criteria needed to evaluate the current state of the landscape against guidelines aimed to enhance biological materials and diversity and enhance connectivity. While this chapter informed the research as to how to answer research questions relating to defining and ecological network and developing an associated visual tool, it did not provide examples of how other municipalities have attempted to apply ecological network planning nor did it provide a framework to follow while completing such an exercise.

To address these gaps, the research will apply two methods: 1) Precedent Review, and 2) Quantitative Mapping Analysis. The Precedent Review is used to gather lessons on how ecological network planning could be applied in the RM of Ritchot and the Winnipeg Metropolitan Region. This research will examine three precedent plans from municipalities that have attempted ecological network planning:

- Ottawa – Greenspace Master Plan: Strategies for Ottawa's Urban Greenspaces
- Halifax – Green Network Plan
- Edmonton – Breathe: Edmonton's Green Network Strategy

To address concerns in developing an ecological network design relating to knowledge and human resource capacity as discussed in the literature review, it is essential to have a research method that provides planners a framework to follow that adds knowledge and capacity. As such, this research will use the Sustainable Land Planning Framework to undertake the Quantitative Mapping Analysis and develop a visual tool for the RM of Ritchot, based on a sample site, that reflects an ecological network that supports reduced biodiversity loss.

3.1 Research Strategy

The precedent review is used for this research to gather insight from the selected plans regarding how other municipalities have applied ecological network planning and incorporated concepts of biodiversity and ecological function to their land use planning framework. Furthermore, this will provide insight into how other municipalities have applied ecological network planning to reduce natural land loss and fragmentation and the factors that guided their approach. By understanding this, the research will identify how landscape ecology principles have guided the development of ecological networks, what components of the landscape compose the ecological network, and how natural lands were evaluated to identify their value to preservation and restoration. Finally, this will enable a better understanding of how the plans were integrated into the planning process to enhance ecological connectivity in their differing municipal and regional contexts. Although these plans differ in context, scale, and approach, they all consider network connectivity as a core objective and attempt to maintain and protect ecologically and culturally important landscapes. In addition, they have developed maps to assist in communicating the network concept to decision-makers which have served as the basis for the development of strategies and associated actions to better protect, maintain, and enhance the network.

The Sustainable Land Planning Framework (SLPF) is used for this research because it offers an approach and tools to integrate landscape ecology principles and concepts with planning practice and can support efforts to build a visual tool that illustrates an ecological network. At its most basic, the framework is concerned with the pattern-process relationships necessary for understanding landscape ecological function (Leitao, et al., 2006). The SLPF recognizes that pattern-process relationships are a product of landscape functions and processes, which it understands as the relationship between landscape structures (i.e. matrices, patches, corridors) and abiotic, biotic, and cultural (ABC) resources (Leitao, et al., 2006, p. 31). The SLPF provided a way for planners to measure these relationships with landscape metrics and build a comprehensive understanding of the landscape to anticipate the ecological consequences of planning decisions. When applied, landscape metrics offered by the SLPF help build a comprehensive picture of the spatial landscape pattern, its dysfunctions and changes through time, and ultimately assist in developing a spatial concept design that can be used to evaluate ecological landscape components (Leitao, et al., 2006, p. 49). By integrating these considerations with planning theory, the SLPF presents a multifunctional land use planning approach that facilitates the communication of scientific concepts and enhances the understanding of ecological landscape spatial patterns and processes in an easily accessible form that addresses the typical needs of planners (Leitao, et al., 2006). In doing so, the framework facilitates the identification of key ecological and land use factors, both in the current context and through time, and clarifies how to organize and define land use to guide growth and shape landscape patterns towards those that protect biodiversity and enhance the ecological network.

The Sustainable Land Planning Framework consists of five planning phases that integrate ABC resources and landscape metrics with the planning process: *focus, analysis, diagnosis, prognosis, and sinteresis* (Table 3.1). To evaluate pattern-process relationships, it applies landscape ecological concepts and metrics to planning phases to identify potential land use conflict and synergies with ecological preservation. With the aim being to avoid ecological consequences, it develops a landscape vision that inherently considers ecological concepts by integrating and building on the data from each previous planning phase. Finally, it considers methods to implement, monitor, and adapt landscape visions. The research methods for this practicum is adapted from the first four phases of the framework: *focus, analysis, diagnosis, and prognosis*. The *sinteresis* planning phase addresses planning processes related to implementation and monitoring, planning processes beyond the scope of this research. As such, the research methods for this practicum will not include that planning phase.

As the SLPF planning phases follow similar steps as those identified to develop, analyse, and identify an ecological network, the SLPF can complement the basic steps outlined by Benedict, et al. (2006) to develop an ecological network design based on quantifiable

Table 3.1. **Sustainable Land Planning Framework Phases** (adapted from Leitao, et al., 2006).

Phase	Description
Focus	Identifies the issue; Defines and addresses the goals and objectives of the plan; Informs analysis undertaken as part of the process; Dynamic process subject to review.
Analysis	Characterizes the study area; Provides landscape context (environmental, economic, and social); Assesses ABC resources; Assesses landscape composition and configuration, Assesses landscape history and temporal dynamics.
Diagnosis	Determines values and issues of concern; Assesses current and future concerns; Evaluates landscape metrics to indicators of concern; Identifies main landscape value and spatial dysfunctions or conflicts and their location.
Prognosis	Develops potential vision addressing identified issue; Considers spatial design concepts and supporting criteria for planning strategies; Considers "possible" future landscape achieved through restoration and regeneration; Proposes changes that could achieve goals and objectives.
Sinteresis	Develops plans and actions to respond to issues identified in the *diagnosis* phase; Implements plan; Monitors processes and changes; Adapts plan.

data acquired with landscape metrics. The framework uses a series of landscape metrics adapted from ecological planning application to provide planners with a set of indicators that can be used to base land use planning strategies and decisions. Although the value provided to land use planning by landscape metrics in measuring landscapes has been widely accepted, their application to land use planning has been somewhat minimal, a result often attributed to the large selection of metrics available and the confusion surrounding their selection and interpretation (Zhang, & Wang, 2006, p. 455). The SLPF attempts to address this challenge by providing land use planners with a set of ten core metrics to evaluate the two key components of landscape spatial pattern, landscape composition and landscape configuration. Metrics were developed based on literature and expert consultation and attempt to provide land use planners a tool for the comparative measure of the landscape condition and facilitate the ecological interpretation of landscape patterns and processes (Leitao, et al., 2006, p. 52). In this way, land use planners are provided with a reduced selection of landscape metrics, simplifying their selection and interpretation to those most needed to capture the key composition and configuration factors of the ecological network. Within the framework, landscape metrics are applied to phases across ABC resources, where those applied are dependent upon the scope of the land use planning exercise and determined through a focused analysis and description of landscape spatial patterns.

3.2 Methods of Data Collection and Analysis: Precedent Review and Planning Phases

3.2.1 Precedent Review

The precedent review consisted of examining the three plans and strategies from the municipalities of: the City of Ottawa, the Halifax Regional Municipality, and the City of Edmonton. The information gathered from the examination was summarized relating to three themes: 1) Plan overview; 2) Characterizing the Ecological Network and Connectivity; and 3) Integrating ecological connectivity into the planning process. The examination attempted to clarify how ecological networks were defined by providing insight into classification and characterization of network components as well as the sources used to build the visual representation of the network. The examination identified how ecological networks were defined to reflect elements of biodiversity and ecological function and how natural lands were identified and prioritized for protection and restoration. Finally, the examination identified how the ecological network planning was applied to the land use planning framework, its relationship to other municipal and regional priorities and strategies, and its ability to support the organization of the landscape.

3.2.2 Planning Phase: Focus

As outlined by the SLPF, the first step of this research began with defining the focus of the proposed ecological network in the RM of Ritchot. Defining the focus of the ecological network helps establish explicit goals that can address the research's objectives and provide the rationale that will guide future planning phases (Benedict, et al., 2006) and the development of the visual tool. The research had as an objective to define the ecological network and its relationship to biodiversity in the RM of Ritchot and to develop a visual tool for municipal and regional planners and decision-makers to better understand, define, and communicate ecological network protection. As the Focus planning phase is concerned with completing a preliminary analysis and diagnosis of the landscape to describe the current spatial patterns (Leitao, et al., 2006, p. 50), it can help distill the necessary information required to inform subsequent planning phases and help achieve the research objectives. As a first step in defining the Focus planning phase the research aimed to determine what the emphasis of subsequent landscape evaluation would be, as this would guide what landscape metrics to apply to quantify existing land cover types and define the ecological network. To do this, the research used information distilled from Chapter 1 Introduction and Chapter 2 Literature Review, and the Precedent Review as a way to complete the preliminary analysis and diagnosis of the RM of Ritchot and determine the components of importance.

As the research aimed to focus on a sample site in the RM of Ritchot, following this first step the preliminary analysis and diagnosis consisted of developing a better understanding of the historical and current landscape land cover type context of a sample site. The analysis focused on the community of St. Adolphe as its sample site, a community identified in the Macdonald-Ritchot Development Plan as an urban centre. Chapter 2 Literature Review discussed how identifying areas of the ecological network to protect and enhance connectivity relies on an understanding of both the current land cover types as well as the historical context. To identify the historical context, historical maps of the community of St. Adolphe were collected and examined to identify land cover types and significant features. To identify existing land cover types present a base map was created for the sample site. This is a key step in developing an ecological network as using cartographic tools provides way to identify the landscape and its attributes within a geographic area (Benedict, et al., 2006; Battisti, 2003). Furthermore, the process of creating a map requires the researcher to develop an appropriate classification system for land cover types as they relate to planning objectives. Leitao, et al. (2006) identified the establishment of an appropriate classification framework as critical to ensuring the right landscape metrics are used in future planning phases and has an important influence on what attributes are evaluated in the landscape pattern analysis (p. 55). As such, any classification framework that is established needs to be explicit, needs to reference the appropriate resolution, and should include the key landscape elements relevant to the research (Leitao, et al., 2006, p. 55).

Determining the classification framework began by gathering the available datasets for land cover types in the RM of Ritchot and building a base map for the municipality using the ArcGIS digital mapping program. The Province of Manitoba Land Initiative was accessed to collect applicable ArcGIS datasets, or shape files. Using these shape files as map layers, a base map was created for the RM of Ritchot using ArcGIS spatial analysis tools. Because this research is interested in the biological aspects of the ecological network, the shape files used to build the base map related only to the land cover type biophysical characteristic. The base map did not incorporate shape files relating other biophysical characteristics including hydrology, topography, and soil type. The land cover type shape files used contained numerous land cover type classifications; only land cover types found within the RM of Ritchot were applied to the classification system used for the research. Following this, the base map was refined to focus on the sample site of St Adolphe by using ArcGIS spatial analysis tools; the classification system used for the research was refocused to include only land cover types found within the sample site. To ensure consistency in how land cover type classification is represented, any remaining similar land cover types that were sub classes to a larger class were represented in the classification system by the larger class and attributes of sub classes joined under the larger class. Land cover types identified in the classification system represented patch types present in the site and were the foundation of subsequent landscape analysis.

3.2.3. Planning Phase: Analysis

As outlined in the SLPF, the second planning phase undertakes an analysis of the landscape. In general, the Analysis planning phase is centred on characterizing the project area and assessing ABC resources by measuring individual resources (Leitao, et al., 2006, p. 43). With the use of landscape metrics, land cover type composition was measured in the Analysis planning phase. With the use of landscape metrics, this planning phase provided a way to identify land cover type structure and quantify them in an objective, quantitative, and replicable way. The Analysis planning phase evaluated landscape composition using the following landscape metrics: Patch Richness, Class Area Proportion and Shannon's Index.

Patch Richness:

Leitao, et al. (2006) define Patch Richness (PR) as a landscape level measure that evaluates "the number of different patch types or classes present in the landscape" (p. 52). Determining PR helps planners quantify land cover types, determine their abundance in the landscape, and compare diversity over a geographical area (Leitao, et al., 2006, p. 63; Smith, & Smith, 2001, p. 390). The PR landscape metric facilitates the evaluation of temporal compositional change by providing a metric to examine the transformation of patch type richness through time. In this way, the PR landscape metric can bring increased clarity as to how spatial land use decisions impact compositional change though time. However, the PR landscape metric does not consider the spatial character, placement or location of land cover types within the landscape (Leitao, et al., 2006, p. 63). In the SLPF, the PR landscape metric is used to count the number of different land cover types in the landscape. Each land cover type present in the landscape was considered one patch type. To calculate PR, Leitao et al. (2006) provide equation one (p. 64):

$$PR = m \tag{1}$$

where: m = Total number of patch types present in the landscape

PR was calculated by applying the total number of land cover type classifications determined in the Focus planning phase to equation one. To identify patch richness change through time, historical maps (Appendix A) reflecting six different time periods were referred to. To calculate historical PR, the number of land cover types identified in historical maps were applied to equation one.

The PR equation was also applied to determine the maximum potential richness of the landscape, also know as Relative Patch Richness (RPR). Leitao et al. (2006) describe how RPR provides a greater understanding of PR as it allows for comparison of the study area's PR to the maximum possible PR for the greater region (p. 67). The greater region was defined by the area included in the land cover type dataset. This clarifies the level of diversity and heterogeneity present in the study area as compared to the greater region included in the dataset (Leitao et al., 2006, p. 67). To calculate RPR, equation two is provided:

$$RPR = PR_{(max)} = m_{(max)} \tag{2}$$

RPR was determined by applying equation two to the original land cover type classification system (i.e. pre-refinement).

Class Area Proportion:

Leitao, et al. (2006) describe Class Area Proportion (CAP) as fundamental to landscape structural analysis and emphasizes the importance of it as a landscape descriptor as it quantifies landscape composition. The CAP landscape metric is defined as "the proportion of the landscape comprised of a particular patch or class type" (Leitao et al., 2006, p. 52) and is typically represented as a percentage. Like the PR landscape metric, it does not consider the spatial character, placement or location of land cover types within the landscape (Leitao et al., 2006, p. 68). In the SLPF, the CAP landscape metric is used to determine the surface area occupied by each land cover type and is expressed as a proportion. To calculate CAP, Leitao et al. (2006) provide equation three (p. 71):

$$CAP_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} \tag{3}$$

where: CAP_i = Class Area Proportion for the i^{th} land cover types

a_{ij} = Area (m^2) of patch j for the i^{th} land cover types

A = Total landscape area (m^2)

Generally, CAP is presented as a percentage, a factor more commonly known as a Percentage of Landscape (PLAND). To calculate PLAND, equation four is applied:

$$\text{PLAND} = CAP_\text{i} \text{ X } 100 \tag{4}$$

where: CAP_i = Class Area Proportion for the i^{th} land cover types

By identifying the represented proportion of a land cover type in a landscape, the CAP landscape metric provides insight into the evenness or the distribution of land cover types across the landscape and provides a way to determine the dominant land cover types in the landscape. By doing so, the CAP landscape metric makes it possible to identify whether there is a landscape matrix and if so, quantify its extent (Leitao, et al., 2006). Determining the matrix can clarify what landscape structure has a dominant role over landscape function. Conversely, the CAP landscape metric can identify the less represented land cover types and clarify if special planning considerations are required. Like the PR landscape metric, the CAP landscape metric can facilitate the evaluation of temporal compositional change through the examination of representative proportions of land cover types through time.

To determine CAP the research used the base map developed in the Focus planning phase. To do this, the researcher began by gathering the necessary information needed to populate CAP by using ArcGIS and exporting the attribute table associated with the land cover type shape files used to populate the base map. Attribute tables provide information about the features included in the shape files and included fields that contained surface area information. Using Microsoft Excel, features were sorted according to the land cover type classification determined in the Focus planning phase. Each feature's associated surface area value was summed to determine a total surface area value for each land cover type. Total landscape surface area was determined by adding individual patch land cover type surface area values of the same class. To determine land cover type CAP values, equation three was then applied using determined surface area values, and equation four was then applied to the determined land cover type PLAND values.

Shannon's Index:

To better understand landscape diversity, the PR and CAP landscape metrics are often completed in conjunction with other landscape diversity metrics, notably the Shannon's Index. The Shannon's Index is a common way to quantify diversity and evenness within a landscape and facilitate their comparison (Smith, & Smith, 2001, p. 389). The Shannon's Diversity Index is used to determine the uncertainty, or probability that a species, or ecosystem, occurs in a community and does this by measuring the number of different species and their proportional distribution of area across specie types (Smith, & Smith, 2001, p. 389; Zhang, & Wang, 2006, p 452). When applied to the landscape context, the Shannon's Diversity Index is an important component in evaluating patch richness, and as such should be completed in conjunction with the PR landscape metric (Leitao, et al., 2006, p. 68). To calculate the Shannon's Diversity Index, Smith & Smith (2001) provide equation five (p. 389):

$$\mathrm{H} = -\sum_{i=1}^{s}(p_i)(\log_2 p_i), \tag{5}$$

where: H = Shannon's Diversity Index
s = Number of species
p_i = Proportion of species of the total sample belonging to the i^{th} species

A Shannon's Diversity Index was calculated for patch types identified in the classification framework, where patch types represented *species* in the equation. To determine the Shannon's Diversity Index, the PR value determined by equation one and the CAP values determined by equation three were applied to equation five.

The Shannon's Evenness Index is used to compare patch abundance in the landscape to the maximum possible evenness and does this by evaluating the determined Shannon's Diversity Index value to the maximum value that could be achieved if patch types occupied similar proportions across the landscape (Smith, & Smith, 2001, p. 389; Zhang, & Wang, 2006, p 452). Like the diversity index, the Shannon's Evenness Index is an important component in evaluating the distribution of area of patch types in a landscape and support the interpretation of the CAP landscape metric findings. To calculate the Shannon's Evenness Index, Smith, & Smith (2001) provide equation six (p. 390):

$$J = \frac{H}{Hmax} = \frac{-\sum p_i ln p_i}{ln\ s} \qquad (6)$$

where: J = Shannon's Evenness Index

H = Actual species diversity of the community

H_{max} = Maximum possible diversity for a community

p_i = proportion of species of the total sample belonging to the i^{th} species

s = number of species

A Shannon's Evenness Index was calculated for patch types identified in the classification framework by applying the PR value determined by equation one and the CAP values determined by equation three to equation six.

3.2.4 Planning Phase: Diagnosis

As outlined in the SLPF, the third planning phase attempts to interpret how landscape dysfunctions affect the functional category of concern. The Diagnosis planning phase is based on the previous Focus and Analysis planning phases and is focused on identifying the main landscape values of concern and their spatial conflicts, and where they are located in the landscape (Leitao, et al., 2006, p. 43). This is achieved by measuring landscape configuration. As landscape configuration considers the spatial arrangement, position, and orientation of landscape structures, measuring configuration can provide insight into the interaction between landscape structures and identify areas of opportunity or conflict to enhancing connectivity between landscape structures. By doing so, the planning phase can identify opportunities to define and enhance the ecological network in a way that considers the existing land cover type configuration. Landscape configuration was analyzed using the landscape metrics: Patch Number, Patch Density, Mean Patch Size, and Proximity.

Patch Number and Patch Density:

Leitao, et al. (2006) describe Patch Number (PN) as a key component to understanding landscape fragmentation as it quantifies the spatial character of the landscape by clarifying the degree of land cover type subdivision. Leitao et al. (2006) define the PN landscape metric as "simply the total number of patches" (p. 77). Unlike the PR and CAP landscape metrics, it considers the spatial character, placement or location of land cover types within the landscape and as such is a measure of landscape configuration (Leitao et al., 2006, p. 77). In the SLPF, the PN landscape metric is used to count the number of patches within a land cover type category and within the landscape. To calculate PN, Leitao et al. (2006) provide equation seven (p. 78):

$$\mathrm{PN} = \sum_{i=1}^{n} P_i \tag{7}$$

where: P_i = patch of type $_i$

By identifying the number of patches represented in a landscape, the PN landscape metric provides insight of landscape structure and can be considered a fragmentation index (Leitao, et al., 2006). The PN landscape metric can then be normalized by expressing PN on a per unit basis. In the SLPF, this is completed by determining Patch Density (PD), where PD equals PN divided by the total landscape size (Leitao, et al., 2006, p. 77). To calculate PD, Leitao et al. (2006) provide equation eight (p. 78):

$$\mathrm{PD} = \frac{PN}{A} X\ (10{,}000)\ {}^{m^2}\!/_{ha.}\ X\ 100 \tag{8}$$

where: A = total landscape area in m^2

The PN and PD landscape metrics make it possible to identify spatial patterns and distribution of existing patches and offers a way to understand how past land use planning practices have subdivided land cover types (Leitao, et al., 2006). This can facilitate the evaluation of temporal configurational change through the examination of representative land cover type patches through time.

The researcher considered patches as contiguous areas of the same land cover type and aimed to apply equation six to these areas. However, the land cover type shape files used did not aggregate contiguous spatial features (i.e. polygons) of the same land cover type, where features were individually illustrated thereby resulting in feature attributes classified individually despite being found next to one another. To capture patches as contiguous areas of the same land cover type, ArcGIS spatial analysis tools were used to aggregate polygons of similar land cover type found within a 1m buffer of one and another. Aggregated polygons were considered one patch, and feature attributes joined as one feature. To note: the PN spatial analysis recognized that patches present in the sample site may extend into areas beyond the established boundary, therefore patches were represented in the spatial analysis in their entirety. This enabled the associated patch ArcGIS attribute tables to capture a complete dataset and not artificially influence the patch attributes included in subsequent analyses as a result of the site boundary. The attribute tables generated by the spatial analysis clarified the number of patches of each land cover type, which was then applied to equation seven to determine a class and landscape level PN value. A landscape level PN value was determined by summing class level PN values. These values were then applied to equation eight to determine PD.

Mean Patch Size:

Leitao el al. (2006) describe Mean Patch Size (AREA_MN) as “simply the average size of patches of a particular land cover type (class level) or across the entire landscape (landscape level)” (p. 83). Like the PN landscape metrics, AREA_MN considers the spatial character, placement or location of land cover types within the landscape and as such is a measure of landscape configuration (Leitao et al., 2006, p. 52). In the SLPF, measuring AREA_MN identifies the surface area occupied by discrete patches and provides insight into patch fragmentation as it serves as a way to measure patch subdivision (Leitao et al., 2006, p. 88). To calculate AREA_MN, Leitao, et al. (2006) provide equation nine (p. 86):

$$AREA\_MN = \frac{\sum_{j=1}^{n} aij}{ni} \tag{9}$$

where: a_{ijs} = Area (m^2) of patch_{ij}

n_i = number of patches in the landscape of patchy type $(\text{class})_i$

By measuring AREA_MN, patches can be identified as either small or large and evaluated against desired outcomes. AREA_MN at the class level attempts to interpret the impact patches have on the ecology of the landscape and at the landscape scale attempts to interpret the overall patchiness of the landscape (Leitao, et al., 2006, p. 88).

To determine AREA_MN the researcher utilized the ArcGIS attribute tables associated with the PN map layer. First, a total patch area was determined for each land cover type and summed to provide a landscape total patch area. The total patch area was determined from the attribute tables generated by the spatial analysis associated with PN that included total surface area for each patch. To note: this total area measurement is different from the CAP value as the CAP value is defined by the sample site boundary, whereas the AREA_MN value is not defined by the boundary and reflects patch area that might extend beyond the sample site. The determined total patch value and the class level PN values were applied to equation nine to determine AREA_MN for each land cover type. To determine the landscape level AREA_MN, class level AREA_MN values were summed, and this determined value and the total patch area were applied to equation nine. Because the land cover type shape file had a resolution of 30 metres (Province of Manitoba, 2013a; Province of Manitoba, 2013b), the lower limit patch size possible in the landscape equaled 900 square meters.

Proximity:

Leitao et al. (2006) define Proximity (PROX) as “a unitless measure of patch isolation that integrates information on the size and distance of like patches from a specified ‘focal patch’ within a defined radius” (p. 148). Measuring the PROX value identifies the degree of patch isolation, or fragmentation, by quantifying the spatial distribution of specific land cover type patches within a class and across a landscape. This allows for the comparison of spatial configuration between patches within a landscape (Leitao et al., 2006, p. 153). In the SLPF, PROX is calculated by combining the measured distance between like patches to a “focal patch” of similar class and integrating these values with the area occupied by these patches to calculate a composite PROX value (Leitao et al., 2006, p. 148). To calculate PROX for a focal patch, Leitao et al. (2006) provide equation ten (p. 150):

$$PROX = \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}} \tag{10}$$

where: a_{ijs} = the area of the *s*th? patch within the species search radius of $patch_{ij}$
h_{ijs} = the distance from $patch_{ij}$ to the *s*th? neighbouring patch of the same type, based on edge-to-edge distance

The PROX value can also be calculated at the class and landscape levels. The research only calculated PROX at the class level as the landscape level is used to compare values between landscapes, and as a landscape comparison was beyond the scope of this project only the class level value was calculated. At the class level, focal patch PROX values are averaged to provide a PROX_MN value. To calculate PROX_MN for a land cover type at the class level, Leitao et al. (2006) provide equation eleven (p. 151):

$$PROX\_MN = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} \frac{a_{ijs}}{h_{ijs}}}{n_i} \tag{11}$$

where: a_{ijs} = the area of the sth? patch within the species search radius of patch_{ij}
h_{ijs} = the distance from patch_{ij} to the sth? neighbouring patch of the same type, based on edge-to-edge distance
n_i = the number of patches within a class

Because PROX considers surface area and distance, large patches near a focal patch will have a greater influence on PROX values than patches that are smaller and further away from the focal patch (Leitao et al., 2006, p. 148). The metric is initially calculated at the "focal patch" level to quantify patch arrangement within an applicable radius in a way that is relevant to an ecological process of interest (Leitao et al., 2006, p. 148). PROX values calculated at this level can then be used to support patch class level calculations and provide a configuration component to discussions of patch richness, proportion, and structural complexity. Furthermore, the PROX value is a helpful metric in understanding landscape transformation processes. As the patch composition changes through time, their spatial arrangement will correspondingly change. PROX values provide a way to evaluate these changes as it considers patch size and the distance between them, providing insight into composition and configuration changes through time and an opportunity to detect current change and contrast in the landscape (Leitao et al., 2006, p. 158).

To determine PROX, the research utilized ArcGIS spatial analysis tools to determine the relationship between a focal patch and its neighbouring patches within a 500m buffer of the focal patch; this relied on an understanding of the surface area size of a neighbouring patch and their distance to the focal patch. A buffer of 500m was selected as it represented an average distance for a number of different wildlife species needed to maintain a positive relationship between patches and its associated functions, and thereby offset the effects of fragmentation (Environment Canada, 2013). The PROX ArcGIS spatial analysis utilized the map layer generated as part of the PN landscape metric analysis as the spatial representation of patches in the landscape and the basis of focal and neighbouring patch selection. The PROX value of each patch from each land cover type class was determined by measuring the distance from a focal patch to each neighbouring patch of similar type within a 500m buffer. To measure this, a model was built within ArcGIS to generate a calculated value. The model began by processing a sub-model that measured the distances of neighbouring patches to a focal patch and generating a "Near Table" that listed the calculated distances; this was completed for each patch within each land cover type category (Figure 3.1). A map illustrating each land cover type's "near lines" was created using ArcGIS spatial analysis tools and the PN map layer as its basis. The near tables created in the sub-model to determine distances were applied to equation ten as part of the parent model. For the area measurement required in equation ten, the parent model used the surface area field included in the PN map layer feature attribute table. ArcGIS spatial analysis tools were built into the parent model to apply equation ten to process data and calculate a PROX value for each focal patch (Figure 3.2). This included first calculating a PROX value for each neighbouring patch to the focal patch and then summing the PROX value of each neighbouring patch to give a composite PROX value for the focal patch. A PROX value for every focal patch was determined by applying the model to all patches within a land cover type class.

Figure 3.1. **Proximity Calculation: ArcGIS Sub-model**

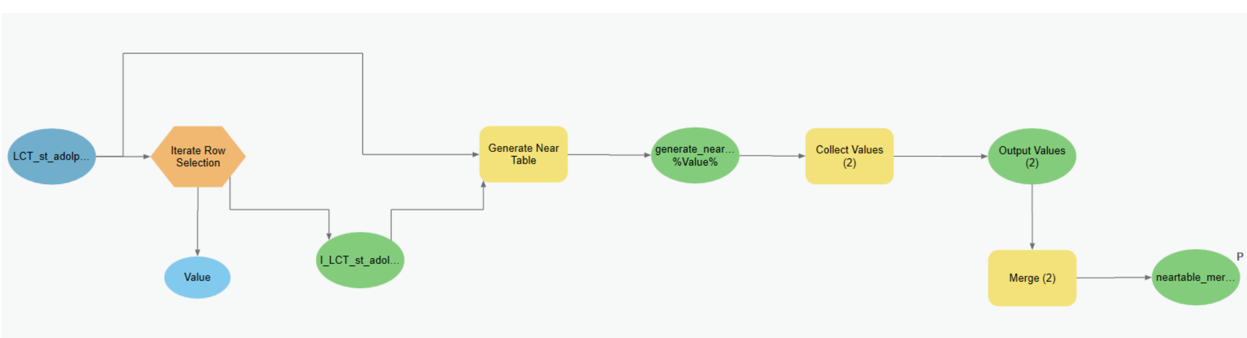
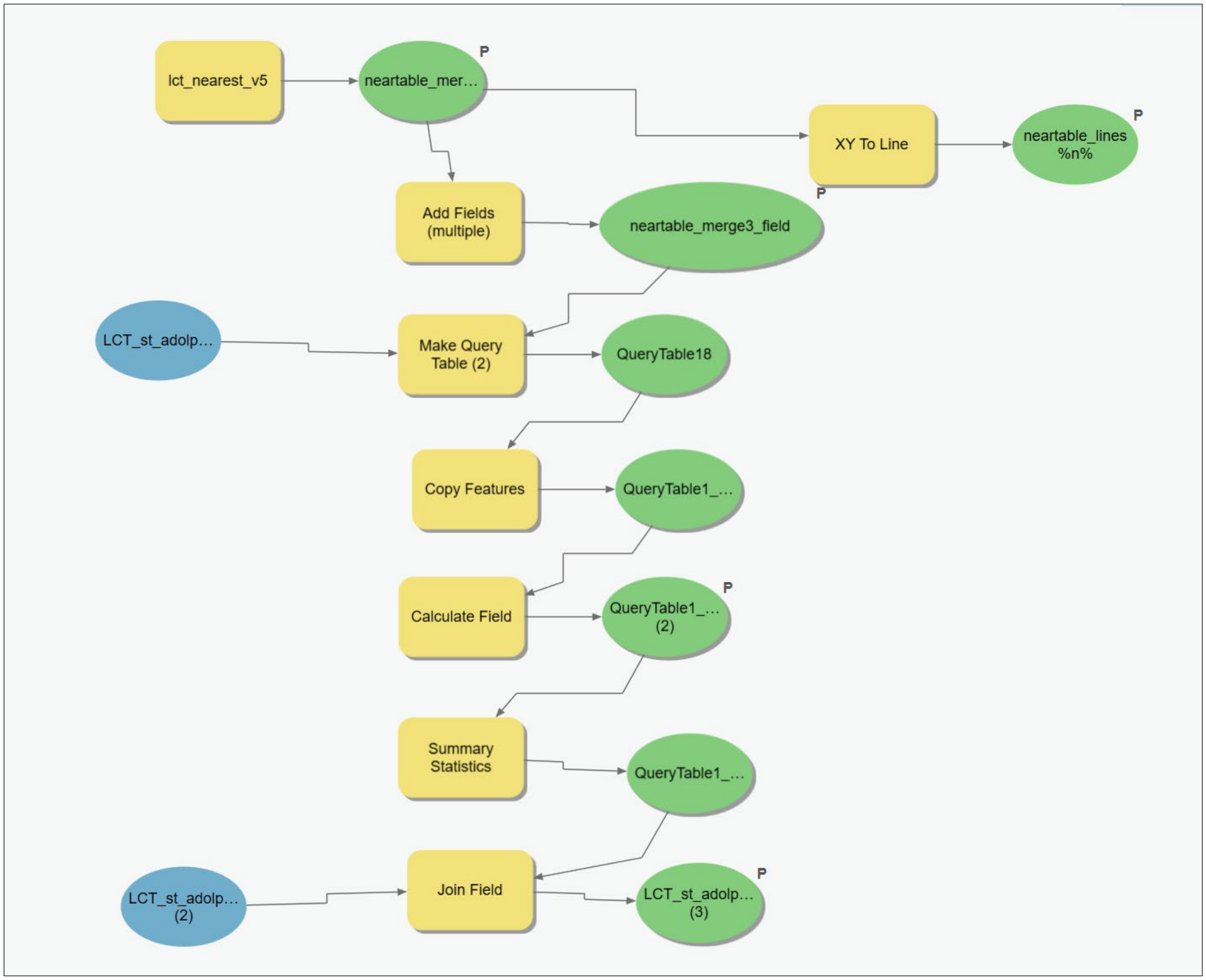


Figure 3.2 **Proximity Calculation: ArcGIS Parent Model**



3.2.5 Planning Phase: Prognosis

As outlined in the SLPF, the fourth planning phase attempts to apply determined information from previous planning phases and develop a potential vision for how to address the issue of focus. Building on this information, the Prognosis planning phase takes a strategic approach to developing a landscape plan that is based on spatial concepts and prior assumptions and goals and attempts to propose recommendations to achieve objectives (Leitao, et al., 2006, p.45). By doing so, the planning phase can develop a visual tool that is based on quantitative landscape data that identifies ecological network components, what natural ecosystem land cover types should be conserved and where they should be restored, and what opportunities and barriers exist to protecting important natural areas and enhance their connectivity.

To achieve the objectives of the Prognosis planning phase, the research identified key areas to conserve and restore by identifying areas of most value to support biodiversity and maintain ecological structures and characteristics. Patch clusters serve to identify key areas to conserve patches and enhance their connectivity as they represent areas with patch conglomeration within fairly near distances of each other. Therefore, patch clusters area important areas that support biodiversity and maintain ecological structures and characteristics. To identify clusters, the research began by utilizing the PN map layers generated for each natural ecosystem patch land cover type (see Section 4.2.3) to illustrate associated patches in combination with the "near lines" generated as part of the PROX analysis (see Section 4.2.3). The researcher created a new feature layer using ArcGIS spatial analysis tools to identify clusters of near patches as illustrated by clusters of "near lines" identified in the PROX analysis. While patch clusters provide information on where to focus conservation of natural lands and enhance their connectivity, they do not clarify what patches are perhaps more important to conserve as compared to others. As the PROX landscape metric considers both patch number and patch area within its calculation and integrates key patch spatial characteristics within one analysis, it served to identify key patches and "near lines" as they relate to patch size and nearest distance. Then, key patches were considered those with high PROX values as they are larger in size and found in close proximity to other like patches, whereas key "near lines" were those areas found between key patches and represent the greatest opportunity to enhance connectivity. Key patches and "near lines" were evaluated against guidelines listed in Table 2.2 to further identify priority sites for conservation and restoration.

To identify opportunities and barriers that may exist to protecting important natural areas and enhance their connectivity, two ArcGIS maps were built using the map layers generated in previous planning phases in combination with new shape files: 1) land use policy framework map, and 2) discrete natural ecosystem patch network in relation other land cover types map. To build the land use policy framework maps, the research began by creating a new map layer that demonstrated the planning context in relation to discrete natural ecosystem patch land cover type clusters. This new map layer included a Macdonald-Ritchot Development Plan land use designation system dataset as well as a waterway and wetland buffer layer created by the researcher. Using ArcGIS spatial analysis tools, the buffer layer was created to reflect the Provincial Land Use Policies' minimum set-back requirement of 30m upslope from the normal high water mark along all natural waterways and of 30m from all wetlands (Province of Manitoba, 2011, p. 28). Finally, the researcher considered the Designated Flood Area Regulation, which establishes the criteria for land development relating to flood protection and mitigation and identifies the area in the Red River Valley subject to the regulation. The map generated identified key patches and "near lines" in relation to this policy framework. This map highlighted the spatial arrangement of policy areas in relation to key areas identified for conservation and restoration and provided an understanding of the land use policy framework context that may support or impede patch protection and connectivity.

Next, the researcher created a new map layer that demonstrated the discrete patch network for the identified terrestrial natural ecosystem land cover types patches in relation to identified key patches and "near lines". To build the map, the researcher combined the cluster map layer and the PN map layer generated in the Diagnosis planning phase. A distinct map was created for each natural terrestrial ecosystem patch type identified with associated key patches and “near lines” highlighted, and other patch types, including bother natural ecosystem and human-influenced, identified for comparison. This map highlighted the spatial arrangement of each discrete patch type cluster key patches and “near lines” in relation to the spatial arrangement of other patch types and provided an understanding of their spatial relationship.

Finally, a map was created to identify the natural ecosystem ecological network of the sample site, its key patches for conservation and key “near line” areas for restoration. To build this map, the researcher combined the map layers generated as part of identifying natural land clusters of near patches. Using ArcGIS spatial analysis tools clusters were joined. This identified the spatial location and arrangement of joined clusters and served to define the ecological network of the sample site. Distinct land cover type key patches and “near lines” were highlighted to identify patches and areas to prioritize for conservation and restoration as it relates to the ecological network of all natural land patch types.

3.3 Limitations

While the precedents reviewed provided valuable insight into how ecological network planning has been applied in other municipalities, the following limitations are identified. First, the precedent reviewed are plans and strategies. These plans are lower hierarchy planning documents that are subject to pre-existing planning and policy documents like provincial land use policies, laws and regulations, and the comprehensive community plan. As such, they are subsets of the comprehensive community plan and respond to the policies that it includes. This differs from the land use planning discussed in the literature review, as this discusses how underlying land use policies included in the comprehensive community plan could support an ecological network rather than respond to those policies.

Second, the precedents reviewed included various forms of land tenure. While the Halifax Regional Municipality and Ottawa plans included both private and public lands, the Edmonton plan only considered public lands. Furthermore, the Edmonton and Ottawa plans were only concerned with parks and greenspaces and did not consider the full spectrum of land uses like the Halifax Regional Municipality plan. This differs from the research in that the research is concerned with all land types, not just public lands, and all uses not just those related parks and greenspaces. This means that while the City of Edmonton and City of Ottawa consider the ecological network as it relates to greenspaces, they fail to recognize the spaces between greenspaces and therefore do not reflect a comprehensive model of what the research is trying to achieve.

Finally, the precedents differ from the research in that they did not use the SLPF to undertake a quantitative mapping analysis to identify the ecological network. While precedents used similar sources to quantify and map the ecological network, plans used different methods to assess and classify the ecological network (discussed in Appendix D). This means that natural lands used to define the ecological network were determined by methods that may be directly comparable to each other and to the methods employed in this research. Furthermore, the evaluation of these lands was completed in the context of a full spectrum of uses, values and objectives of these lands, including human uses like recreation, and did not focus only on ecological function and values. Therefore, the ecological network defined in precedents represent a somewhat more limited type of natural land and land tenure as compared to the research, but a broader spectrum of uses, values, and objectives than that of the research.

Though the landscape metrics discussed provide effective ways to understand landscape composition and configuration and contribute to better integration of ecological concepts into planning, they do present some limitations. First, all metrics are sensitive to the land cover type classification system applied. Classification systems used may be detailed or broad and may be further complicated with the use of human influenced land cover types, thereby affecting how land cover types are defined and represented in maps as well as the landscape metric applied. Furthermore, land cover type datasets are affected by the classification systems applied and data used to generate land cover type data thereby impacting how land cover types are expressed in maps. This means that it is important to recognize that any value calculated will only be as valuable as the maps used to produce them and will only be meaningful with land cover types relevant to the desired application (Leitao et al., 2006, p. 75). As such, an explicit land cover type classification system is needed to ensure a consistent comparison of land cover types (Leitao et al., 2006, p. 66). As the landscape analysis relied on existing ArcGIS shape files, the classification system was reliant on what data was publicly available. Because of this the researcher used shape files that are likely outdated, and as a result collected data may no longer reflect the current state. As well, the shape files present a limitation in that they are generated at a 30 metre pixel resolution, which may limit the accuracy of the data included and therefore may have affected the representation of land cover types on maps and in landscape metric calculations.

A limitation presented with all landscape metrics is that when analysed they provide limited landscape interpretation by themselves. When analyzed, Patch Richness (PR) and Class Area Proportion (CAP) only consider landscape composition and do not consider configuration, revealing nothing about the spatial character of the landscape. Therefore, these landscape composition metrics are most useful when used in conjunction with a spatial configuration metrics. However, configuration metrics present limitations in and of themselves. While Patch

Number (PN) and Patch Density (PD) present information on patch subdivision, they do not clarify spatial characteristics related to distribution of patch areas. Mean Patch Size (AREA_MN) presents a similar limitation in that it does not offer any insight into spatial distribution of patches. As a result, these landscape metrics provide limited context to patches as they relates to their isolation, clustering, and fragmentation. While the Proximity (PROX) landscape metric does address these limitations as they relate to spatial distribution, it also presents certain limitations. The PROX landscape metric is a unitless measure and does not provide an intuitive and straightforward interpretation of spatial configuration (Leitao et al., 2006, p. 157). Though it can provide useful information on landscape change, its main use is as a comparative tool that relies on other factors like distance between patches and total and proportional area of patches, and as such provides limited information as a stand-alone value (Leitao et al., 2006, p. 157). Its reliance on distance between patches also presents a limitation in that it uses Euclidean distances. In this way, it only quantifies straight line distances between patches without regard for intervening land cover types (Leitao et al., 2006, p. 156). When using PROX it is important to recognize that other land cover types may be playing a role in fragmenting patches and consider it in the greater landscape context. Finally, PROX presents a limitation in that a specified radius must be used in to determine “focal patch” PROX and as such must be relevant to the application at hand (Leitao et al., 2006, p. 157).

Chapter 4: Results and Analysis

This chapter analytically evaluates the St Adolphe sample site to interpret what calculated landscape metrics are revealing about landscape composition and configuration. To capture quantitative results from measuring the landscape with selected metrics and to identify and comprehend landscape structural and spatial characteristics the chapter is divided into two broad categories: Results and Analysis. The chapter sets out to understand how landscape metrics may support defining the ecological network and identifying opportunities to enhance connectivity, and ultimately reduce the loss of biodiversity in the sample site.

4.1 Results

The following section is organized in five sub-sections. The first subsection presents a summary of key results from the precedent analysis; the full suite of results are found in Appendix D. The results from the Focus, Analysis, Diagnosis, and Prognosis Planning Phases are each presented in the following four sub-sections.

4.1.1 Results: Precedent Review

Appendix D includes the examination summaries of the precedents reviewed. The following list includes key results from these summaries:

- The City of Edmonton and City of Ottawa focused these network plans on parks and greenspaces, whereas the Halifax Regional Municipality (HRM) focused on all lands;
- The City of Edmonton focused its network plan on public lands, whereas the City of Ottawa and the HRM focused on a combination of public and private lands;
- All plans were developed to support the protection and extension of the network in the face of expanding population growth, urbanization, and development;

- All plans used landscape ecology principles and an ecosystem approach to analyze the network and ensured the concept of ecological network connectivity was considered in the network design;
- Plans considered ecological structures as the base of the ecological components of their network, and defined the landscape in terms of patches, corridors, and the matrix;
- All plans evaluated the ecological function of spaces included in the network to preserve and maintain land environmental function and diversity;
- Plans varied on how ecological function was evaluated. All included the evaluation of biodiversity, whereas the City of Edmonton and the HRM also included evaluation of functions such as water and climate regulation.
- All precedents considered the ecological and human functions that spaces provided, where spaces were evaluated in terms of the role or function they provide to the network. Spaces with higher functional value were prioritized for preservation;
- Because all plans considered the human function that spaces provide, plans were multifunctional in nature. As a result, plans considered uses that were not only ecological in nature and extended to uses like recreation, leisure, and agriculture;
- While all plans developed primary data to some extent to inform the design of the network, all plans utilized data sources from existing documents likes municipal development plans, by-laws, secondary plans, land use inventories, scientific studies, planning studies, and provincial databases;
- All plans reviewed were subsets of higher hierarchy land use planning documents;
- Plans developed included strategies to implement the defined ecological network and support continued ecological function amongst supporting human use and function of the spaces included in the network.

4.1.2 Results: Focus Planning Phase

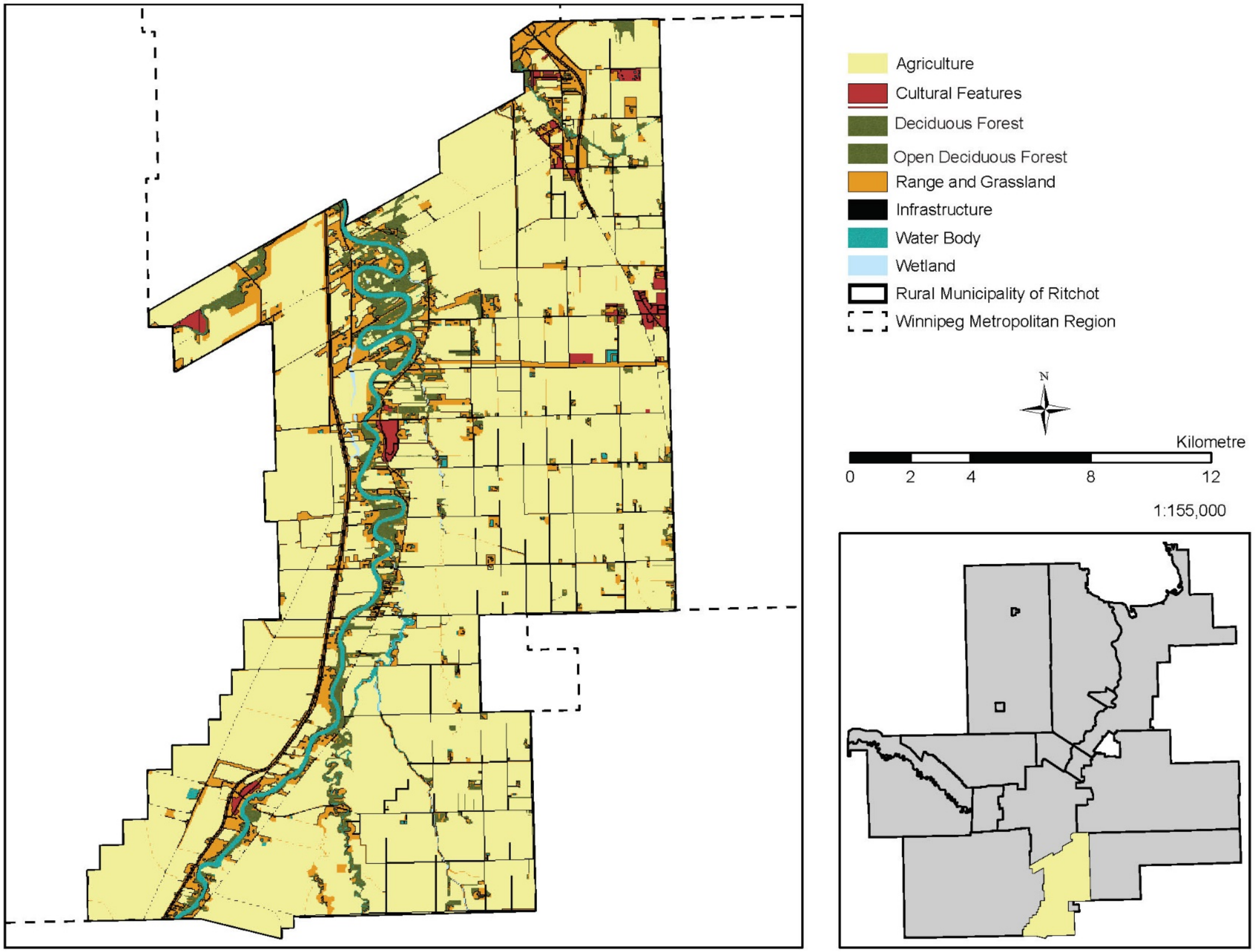
To support a preliminary analysis and diagnosis of the RM of Ritchot, the first step of the research was to determine an appropriate functional category to frame subsequent landscape evaluation and be the emphasis of landscape measurements. By completing a preliminary analysis and diagnosis on the appropriate functional category, better understanding of ecosystem and/or human attributes relevant to the process of concern can be realized as evaluation will be better tailored to measure the landscape as they relate to objectives. The Precedent Review demonstrated that to develop a network with a focus on the functions of overlapping ecological and human elements and the networks they form; ecological network planning strategies would benefit from broadly classifying networks into functional categories to simplify the planning process of developing networks. As such, the preliminary landscape analysis and diagnosis began by determining a functional category and ABC resource components of concern.

The Precedent Review identified how networks can focus on a variety of functional categories, like ecology, working landscapes, cultural landscapes, etc., and are chosen depending on the scope of the project. Chapter 1 Introduction demonstrated the objective to reduce biodiversity loss through protection of ecosystems and enhanced connectivity and build resiliency into the landscape. Chapter 2 Literature Review demonstrated how identifying areas to preserve biodiversity and remove barriers to connectivity can support achieving this goal. The chapter also demonstrated how reducing biodiversity loss has the ability to preserve ecological processes, thereby allowing for continued function and delivery of ecosystem services that benefit human-well being and provide landscape resilience to the effects of climate change. Chapter 2 also demonstrated how understanding the landscape through the lens of landscape ecology can offer an opportunity to interpret the landscape quantitatively as it relates to biodiversity and can provide insight into where ecosystems should be conserved, restored, and better connected. As the research is interested in reducing biodiversity loss to ensure the continued delivery of ecosystem services and build climate change resilience into the landscape, it is concerned with the ecology of the landscape and its biological resources. As such, the research focused on the biotic ABC component and evaluated the land cover type biophysical characteristic.

Following this, the preliminary analysis and diagnosis was interested in developing a better historical and current understanding of land cover types in the municipality. As a second step, this planning phase was concerned with collecting historical maps of the municipality to gain a better understanding of the past context. An effort was made by the researcher to collect maps from various time periods in attempt to best capture the land transformation process through time. Six historical maps were collected ranging from the year 1871 to 1999 – see *Section 4.2.1 Analysis: Focus and Analysis Planning Phases*. It should be noted that the 1871 map is missing land cover type information of the sample site on account that the map was focused on areas where the Dominion Land Survey was applied. As the sample site is found in an area where the Parish River Lot Survey was applied land cover type data is missing; however; it was assumed that the sample site had similar land cover types present as the surrounding area captured in the map.

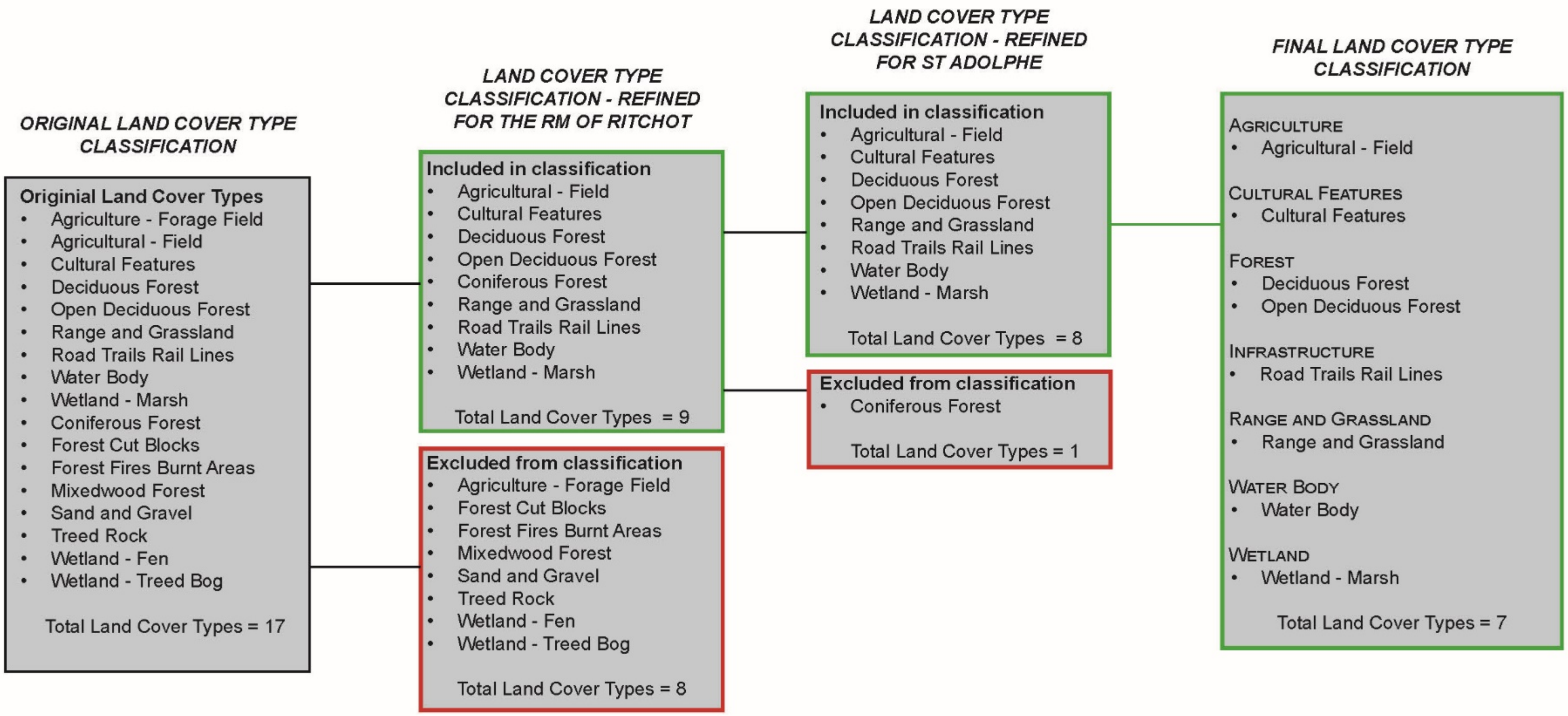
The third step of the preliminary analysis and diagnosis was to develop an understanding of existing land cover types in the municipality; this consisted of building a base map and classification system of land cover types for the sample site of St Adolphe. Using the collected shape file datasets, a base map (Figure 4.1) and classification system (Figure 4.2) was created for the RM of Ritchot. The shape file dataset used represents land use or land cover displayed at the landscape scale. Appendix C presents the description of land use and land cover included in the dataset and includes a description of the vegetative community comprised in the classification. However, the description does not include information relating to species richness, maturity or

Figure 4.1 **RM of Ritchot Land Cover Type Base Map**



Source: Province of Manitoba, 2013a, Province of Manitoba, 2013b, Province of Manitoba, 2018

Figure 4.2 **St Adolphe Sample Site Land Cover Type Classification System**



other biological species types. The land cover type shape file datasets used to build the base map extended beyond the RM of Ritchot boundary and contained 17 land covers types. The classification for the RM of Ritchot was refined and excluded 8 land cover types from the greater regional classification system because they were not located within the municipal boundary (Figure 4.2). The RM of Ritchot base map was refined to the St Adolphe sample site (Figure 4.3) and an associated refined classification system developed (Figure 4.2); this is the final output. The final classification system excluded the *Coniferous Forest* land cover type from the sample site classification system as it was not located within the sample site boundary; a total of 8 land cover types were included in the final classification system. Of the remaining 8 land cover types, 2 were considered sub class categories to a larger class: *Deciduous Forest* and *Open Deciduous Forest* were considered subcategories to the Forest land cover type. The two subcategories were joined under the larger Forest land cover type (Figure 4.2). A total of 7 land cover types were included in the final classification system. Three human-influenced land cover types were identified: Agriculture, Cultural Features, and Infrastructure, whereas four natural ecosystem land cover types were identified: Forests, Range and Grasslands, Waterways, and Wetlands.

4.1.3 Results: Analysis Planning Phase

Three landscape metrics were applied to analyze landscape composition in the sample site of St Adolphe: Patch Richness, Class Area Proportion, and Shannon's Index. This section will present the results gathered from these landscape metrics.

Patch richness:

The patch richness (PR) metric was used to calculate the number of different patch types found in the sample site of St Adolphe. Generally, greater diversity and spatial heterogeneity is achieved with greater richness, where when one land cover type dominates the landscape PR will equal one (Leitao, et. al., 2006, p. 64). The Focus planning phase established the land cover type classification system applied to the sample site; the final classification system included seven patch types (Figure 4.2). This value was applied to equation one:

$$PR = m \tag{1}$$
$$PR = 7$$

To determine Relative Patch Richness (RPR), equation two was applied to the original land cover type classification system used to build the base map prior to its alteration.

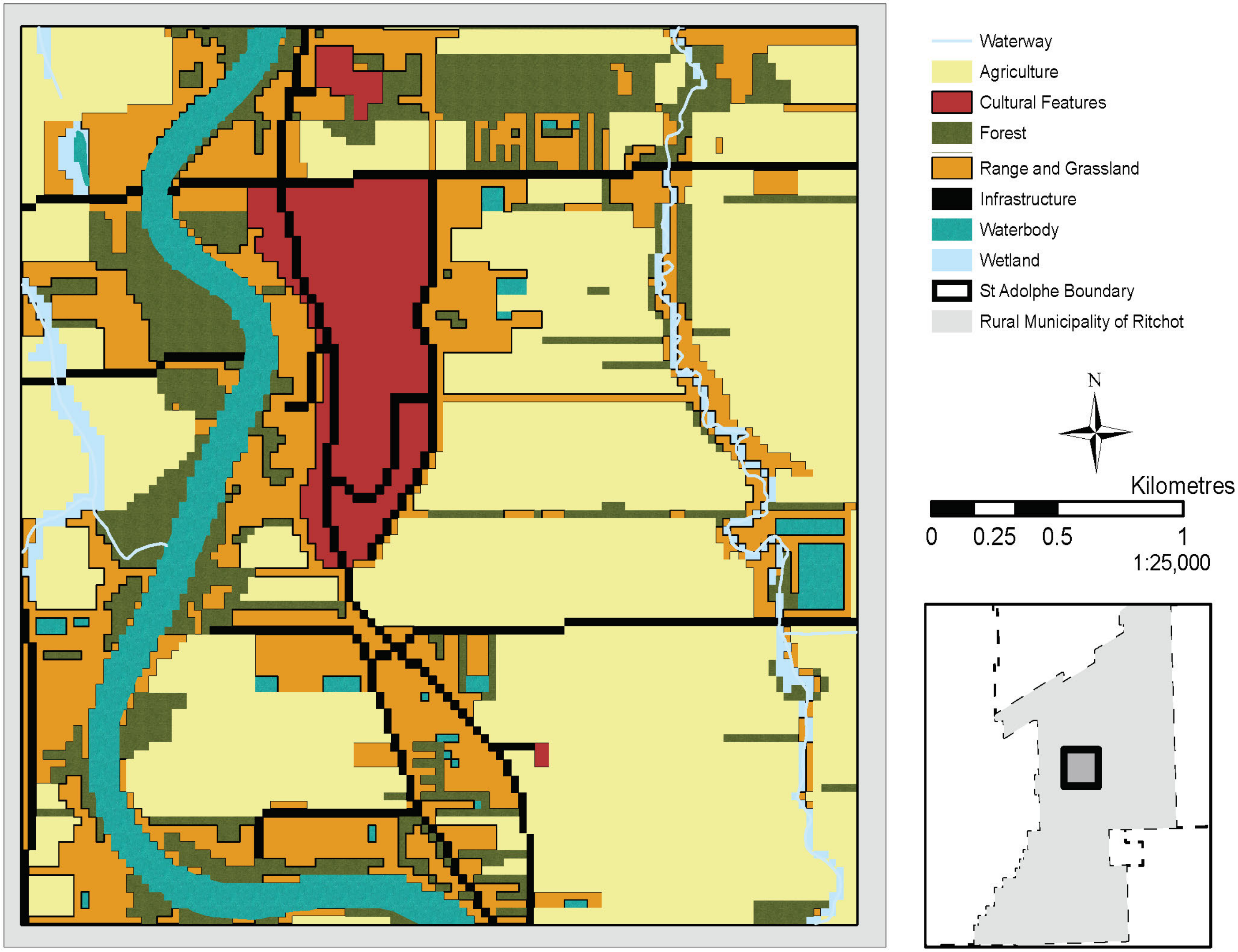
$$RPR = PR_{(max)} = m_{(max)} \tag{2}$$
$$RPR = 17$$

While historical land cover types were not quantified by using methods outlined in the SLPF, historical photographs were used to provide insight into past land cover type composition and make assumptions as to historical PR. Appendix A Figure A-1 and Figure A-2 illustrate land cover types present in the RM of Ritchot prior to the year 1900 and suggest a sample site PR value of one to four. Figure A-3 illustrates land cover types present in the RM of Ritchot from 1930 and suggest a PR value of two to four. Figure A-4 and Figure A-5 illustrate land cover types present in the RM of Ritchot from 1950 and 1969 respectively and suggest a PR value of four to five. Finally, Figure A-6 illustrates land cover types in the RM of Ritchot from 1999 and suggests a PR value of six.

Class Area Proportion:

Class Area Proportion (CAP) was calculated to determine the proportion each patch type occupied in the landscape. CAP was calculated using the surface area data identified from the feature attribute table generated from the ArcGIS land cover type base map; the calculated total surface area for each land cover type and the total landscape surface area were applied to equation three to determine CAP values. CAP values were applied to equation four to determine PLAND. Table 4.1 list CAP and PLAND values. When land cover type patches are rare in the

Figure 4.3 **St Adolphe Sample Site Land Cover Type Base Map**



Source: Province of Manitoba, 2004; Province of Manitoba 2013b; Province of Manitoba 2018 landscape CAP values will approach zero, whereas when a landscape is occupied by a single patch CAP values will approach one. Optimal PLAND values for natural lands are included in guidelines for percent area cover listed in Table 2.2.

Table 4.1 **St Adolphe Sample Site Calculated Class Area Proportion Values**

Land Cover Type	**Total Area (m^2)**	**CAP**	**PLAND**
Agriculture	5,045,602	0.4696	46.96
Range and Grassland	2,290,412	0.2132	21.32
Forest	1,381,746	0.1286	12.86
Water Body	706,415	0.0657	6.57
Cultural Features	639,000	0.0595	5.95
Infrastructure	461,113	0.0429	4.29
Wetland	220,331	0.0205	2.05
Total Landscape	*10,744,620*	*1.0000*	*100.00*

Shannon's Index:

The Shannon's Diversity Index was calculated to quantify diversity as it relates to the number of land cover types and their proportional area distribution across land cover types. Calculated PR and CAP values were applied to equation five to determine the sample site's Shannon's Diversity Index; Table 4.2 lists the calculated values. The Shannon's Evenness Index was calculated to compare patch abundance in the landscape to a maximum possible evenness. Calculated PR and CAP values were applied to equation six to determine the sample site's Shannon's Evenness Index; Table 4.2 lists the calculated value. Generally, the lower a Shannon's Diversity Index equals, the greater the probability that patch types are the same (Smith, & Smith, 2001, p. 389) suggesting a less diverse landscape. In terms of the Shannon's Evenness Index, when the landscape displays the maximum possible evenness the value of the Shannon's

Evenness Index equals one, whereas if the landscape is dominated by one patch type the index will approach zero (Smith, & Smith, 2001, p. 390).

Table 4.2 **St Adolphe Sample Site Calculated Shannon's Diversity Index Values**

Land Cover Type	**CAP**	**Shannon's Diversity Index**	**Shannon's Evenness Index**
Agriculture	0.4696	0.51	
Cultural Features	0.0595	0.24	
Forest	0.1286	0.38	
Infrastructure	0.0429	0.48	
Range and Grassland	0.2132	0.19	
Water Body	0.0657	0.26	
Wetland	0.0205	0.11	
Total Landscape	*1.0000*	*2.18*	*0.7759*

4.1.4 Results: Diagnosis Planning Phase

Four landscape metrics were applied to analyze the landscape configuration in the sample site of St Adolphe: Patch Number, Patch Density, Mean Patch Size, and Proximity. This section will present the results gathered from these landscape metrics.

Patch Number:

Patch Number (PN) was calculated to determine the number of patches at the class and landscape levels to better understand how land cover types are subdivided across the sample site of St Adolphe. PN was calculated using land cover type feature attribute tables generated from PN ArcGIS spatial analysis; equation seven was applied to each land cover type to determine land cover type class level PN values (Table 4.3). The landscape level PN value was determined by adding all class level PN values (Table 4.3). The researcher did not include the "waterbody" and "infrastructure" land cover types in the PN analysis. While these land cover types occupy surface area in the sample site, the Diagnosis planning phase analysis identified that they have an ecological structure described as a linear corridor rather than a patch. As such, they were not included in the PN analysis; this will be further discussed in *Section 4.2.2 Analysis: Diagnosis and Prognosis Planning Phases*. To determine Patch Density (PD), calculated PN values and total surface area as listed in Table 4.3 were applied to equation eight. The landscape level PD value was determined by adding all class level PD values (Table 4.3). PN and PD value ranges will depend on the landscape being analysed. When a landscape is occupied by a single patch PN and PD values will be at their minimum value, whereas they will be at their maximum possible value when all patches equal the smallest resolution possible (Leitao, et al., 2006, p. 79). Appendix E illustrates patch networks as determined by the PN analysis.

Table 4.3 **St Adolphe Sample Site Calculate Patch Number and Patch Density Values**

Land Cover Type	Patch Number	Patch Density
Agriculture	23	2.14 patches/100 hectares
Cultural Features	3	0.27 patches/100 hectares
Forest	68	6.33 patches/100 hectares
Range and Grassland	47	4.37 patches/100 hectares
Wetland	8	0.74 patches/100 hectares
Total Landscape	*149*	*13.85 patches/100 hectares*

Mean Patch Size:

Mean Patch Size (AREA_MN) was calculated to determine the average size of patches of particular land cover types and across the landscape to better understand patch subdivision and landscape fragmentation. AREA_MN was calculated using discrete patch surface area values included in the land cover type feature attribute tables generated from PN ArcGIS spatial analysis as well as the calculated PN values; equation nine was applied to each land cover type class using these values (Table 4.4). Generally, large patches are desired as they better support important ecological functions that are less supported by smaller patches, however, benefits associated with smaller patches in human fragmented landscapes has also been noted (Leitao, et al., 2006). As per the shape file dataset description (Appendix C), minimum patch size equaled 900 square meters. Optimal patch size for natural lands is included in guidelines for patch size listed in Table 2.2.

Table 4.4 **St Adolphe Sample Site Calculate Mean Patch Size Values**

Land Cover Type	Mean Patch Size (m^2)
Agriculture	432,352
Cultural Features	213,000
Forest	23,996
Range and Grassland	68,783
Wetland	42,975

Proximity:

Proximity (PROX) was calculated to measure patch isolation and better understand contiguity of patches within a land cover class in the sample site. PROX was calculated using land cover type feature attributes generated by processing the ArcGIS spatial analysis model (Figure 3.2). As a first step, a 'near table' was generated by the sub-model (Figure 3.1) which produced for each land cover type distances between like patches to a 'focal patch' within a 500m buffer. Appendix F provides the maps produced to illustrate 'near lines' associated with focal patches of each land cover type. These neighbour patch distances in combination with their discrete surface area value were processed into the parent model to generate a distinct PROX value for each neighbour patch. The parent model then applied equation ten by processing neighbour patch information and generated a composite PROX value for each 'focal patch'. Table 4.5 lists class-level PROX_MN values calculated for each land cover type class, whereas

Figures 4.4 to 4.8 demonstrate the distribution of PROX values for each focal patch within each land cover type. Higher PROX values are associated with more contiguous patches as these are generally larger in size and closer together, thereby implying less isolated and fragmentated patches, whereas lower values are associated with more disconnected and smaller patches.

Table 4.5 **St Adolphe Land Cover Type PROX_MN Values**

Land Cover Type	PROX_MN Class-level Value
Agriculture	1212
Cultural Features	5
Forest	52
Range and Grassland	416
Wetland	30

Figure 4.4 **Agriculture Land Cover Type: Distribution of PROX Values**

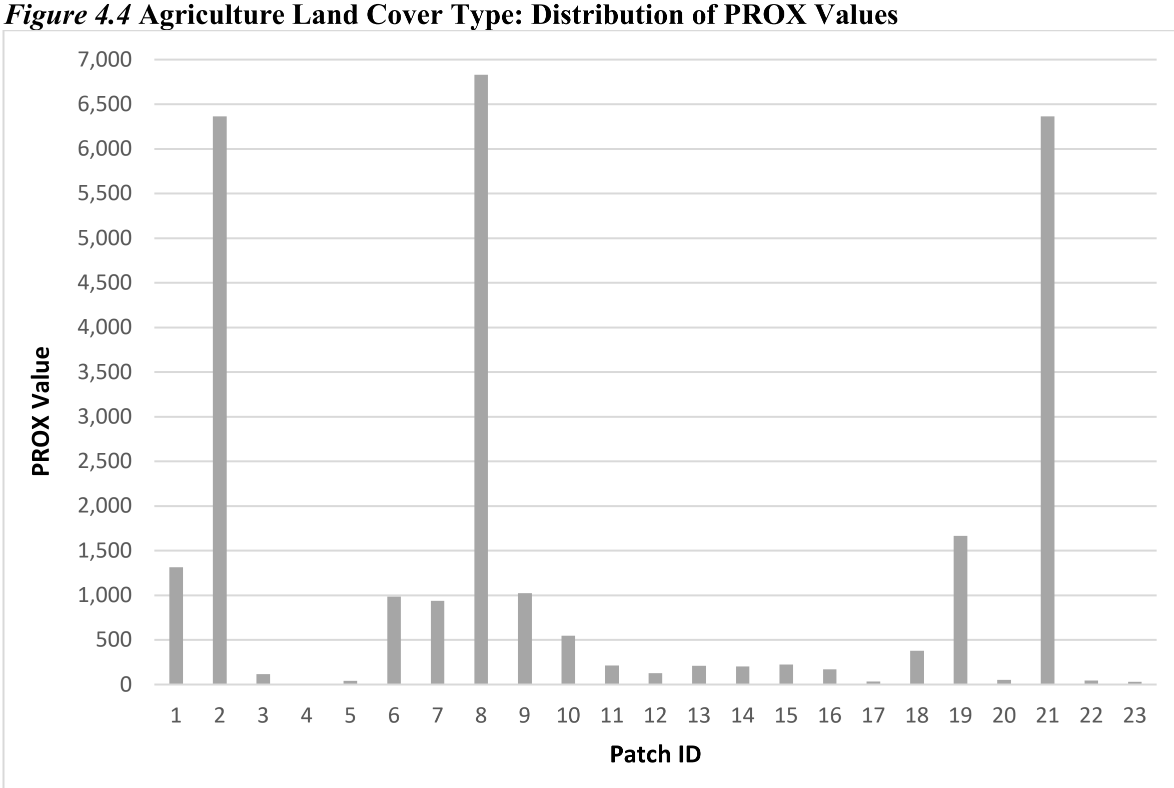


Figure 4.5 **Cultural Features Land Cover Type: Distribution of PROX Values**

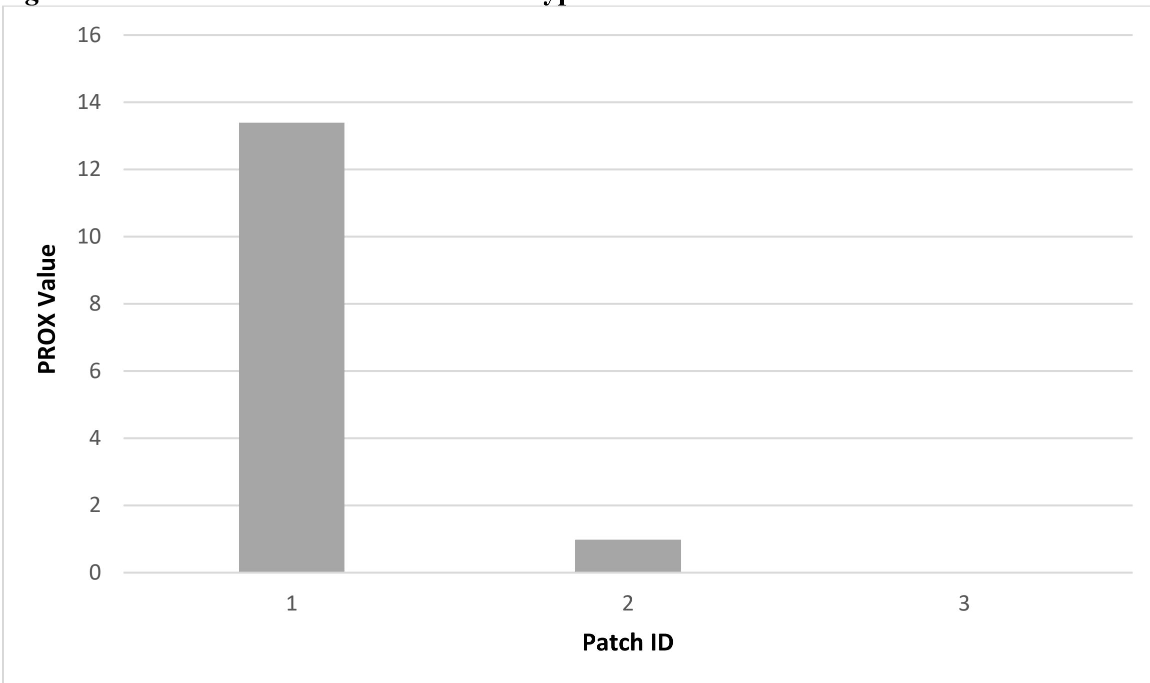


Figure 4.6 **Forest Features Land Cover Type: Distribution of PROX Values**

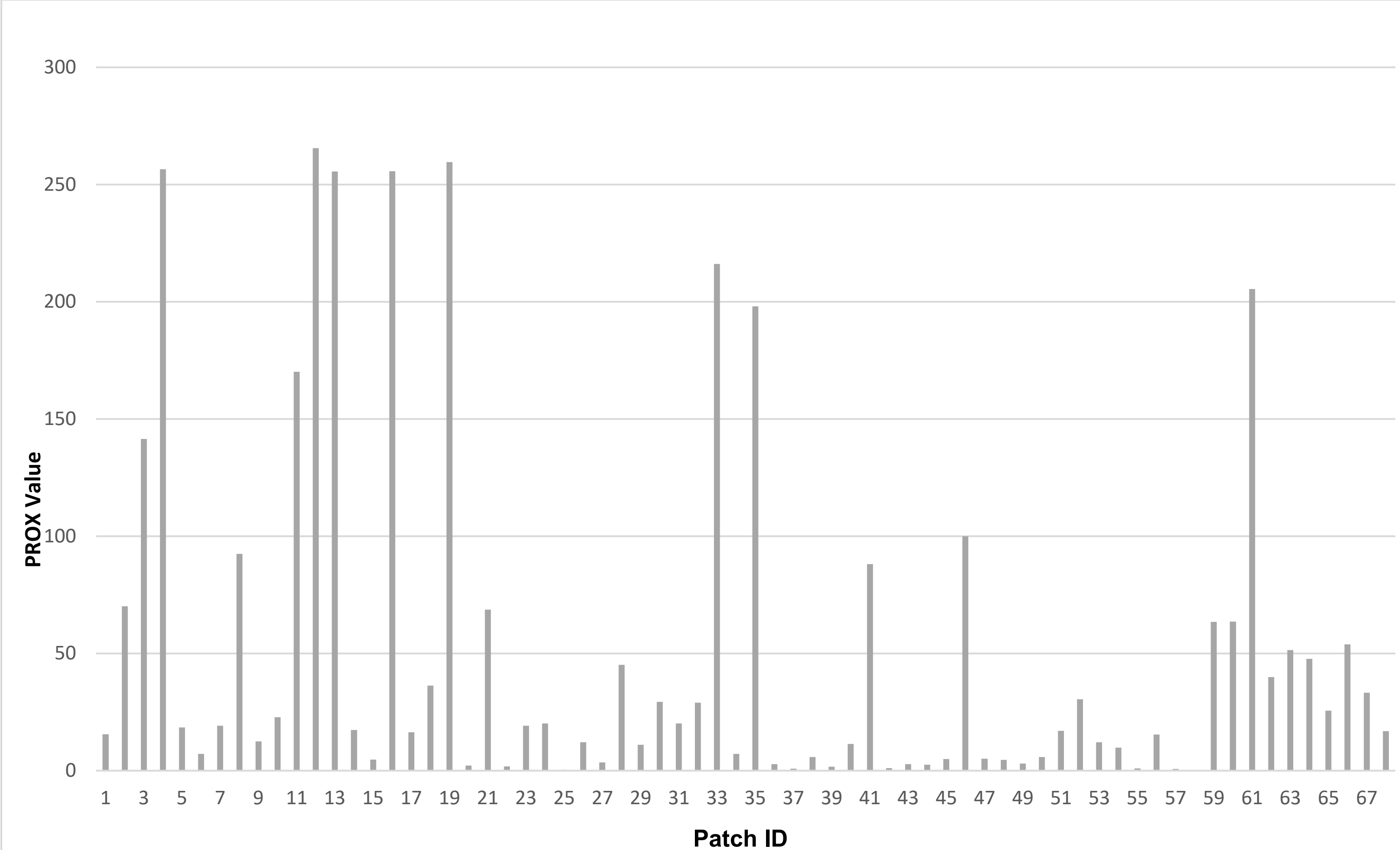


Figure 4.7 **Range and Grasslands Land Cover Type: Distribution of PROX Values**

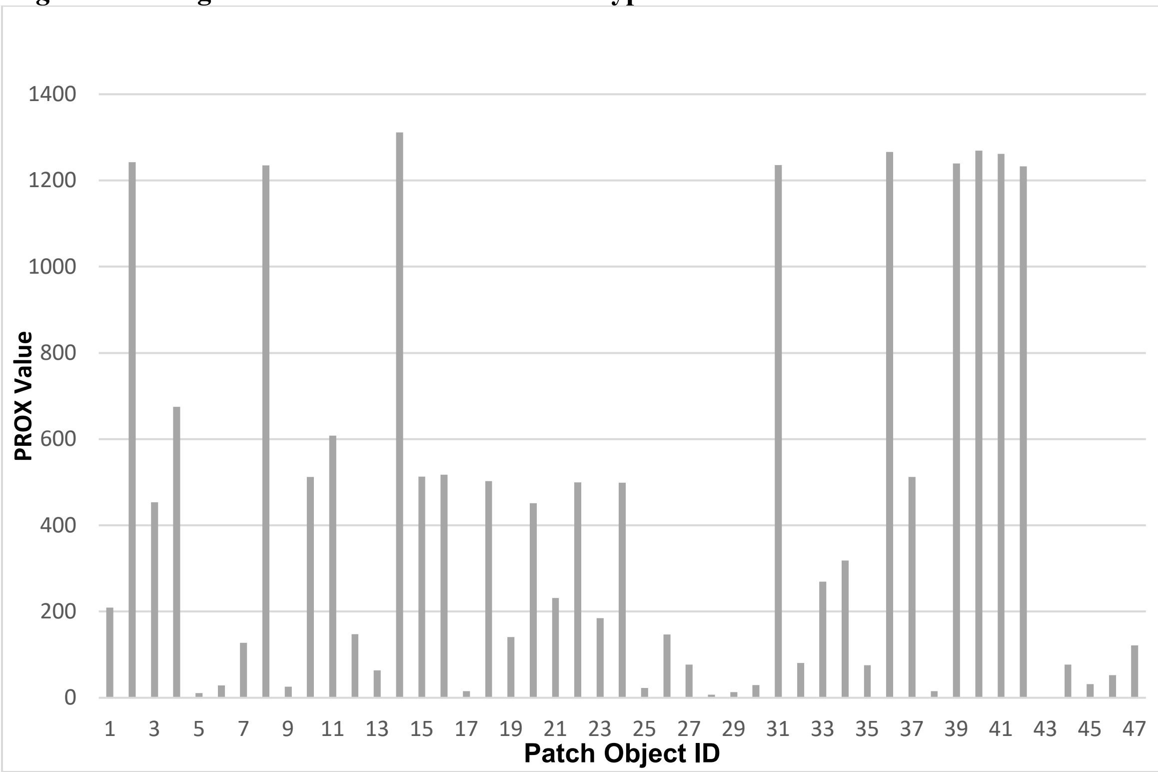
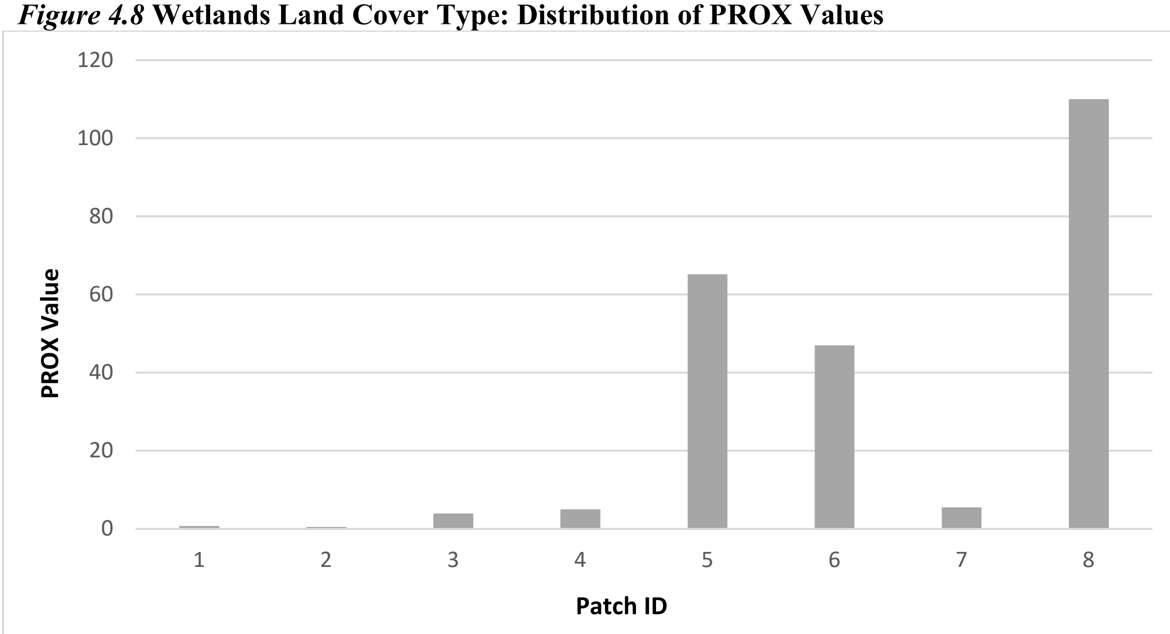


Figure 4.8 **Wetlands Land Cover Type: Distribution of PROX Values**



4.1.5 Results: Prognosis Planning Phase

The objective of the Prognosis planning phase was to develop a landscape plan based on spatial concepts and assumptions determined in prior planning phases and propose recommendations on which natural lands should be conserved and restored and where, as well as identify opportunities and barriers to natural land protection and enhancement of connectivity. Because the research is interested in identifying areas to reduce natural land loss and fragmentation, the first step completed as part of the Prognosis planning phase consisted of building maps that demonstrated areas that would clarify sites of most value to focus conservation and restoration activities. Using the *Forest, Range and Grasslands*, and *Wetland* land cover type map layers generated in the PN analysis (Appendix E) in combination with the "near lines" map layers generated as part of the PROX analysis (Appendix F), a series of maps were created for the sample site (Figure 4.9, 4.10, 4.11). Within each map, clusters of near patches were illustrated by identifying the clusters of "near lines" generated in the PROX analysis. Although near patches were found in areas outside clusters, the identified clusters represented areas in the sample site where a higher concentration of near patches existed. The number of clusters varied between land cover types:

- Forest: 6 clusters
- Range and Grasslands: 5 clusters
- Wetland: 2 clusters

As clusters were based on PROX values and the near lines generated, they represented the straight-line distances between patches without regard for the intervening land cover types and simply demonstrated concentrations of similar near patches present in the landscape. These clusters do not necessarily represent patches, but rather an area of high connectivity potential as the near lines represent a direct path between patches within a 500m buffer where the denser the cluster the more patches are associated.

The next step completed as part of the Prognosis planning phase consisted of identifying key patches and "near lines" as determined by the quantitative analysis of the previous planning phases. The patch clusters identified areas in the landscape to focus conservation and restoration

Figure 4.9 **Forest Land Cover Type: Ecosystem Clusters**

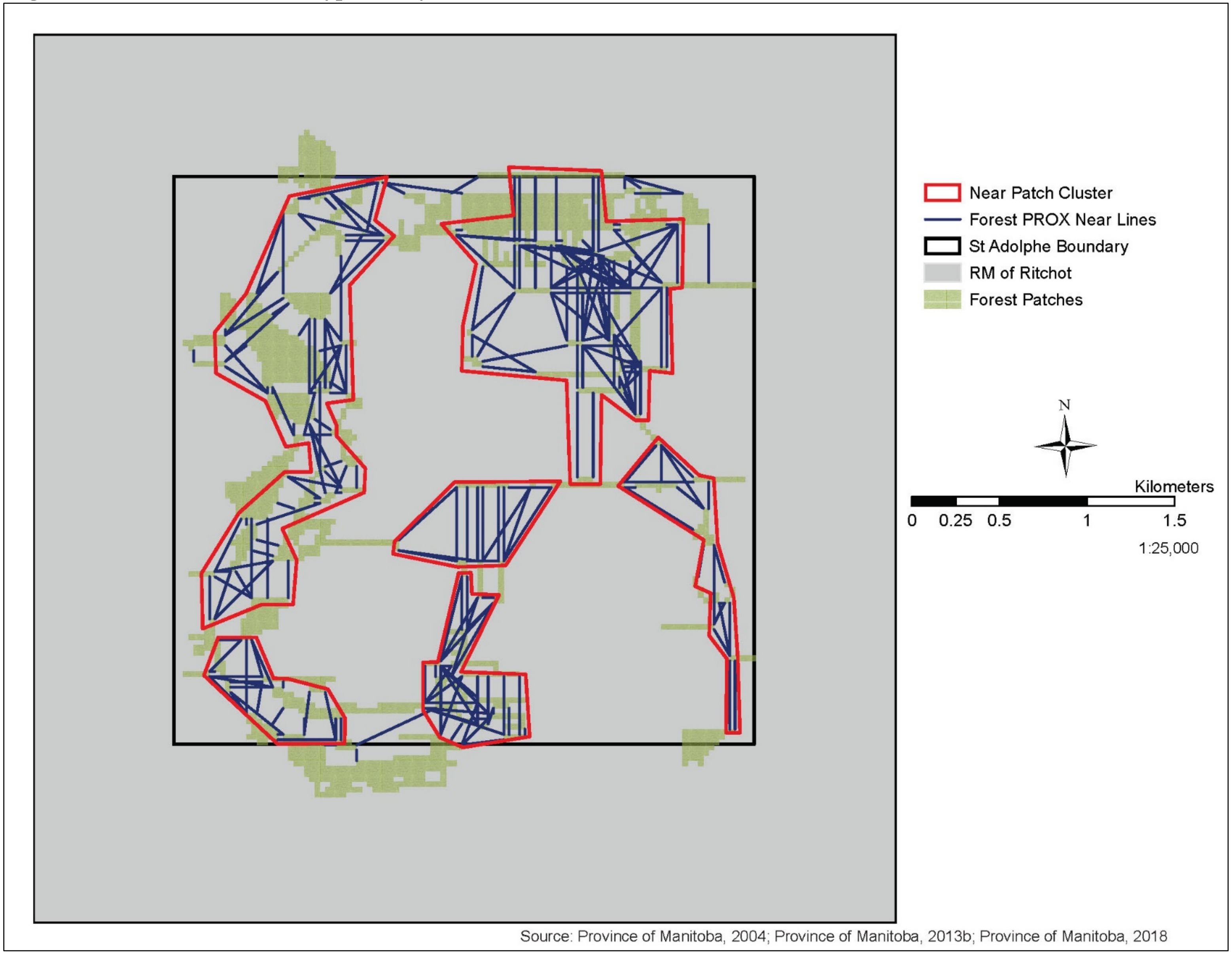


Figure 4.10 **Range and Grasslands Land Cover Type: Ecosystem Clusters**

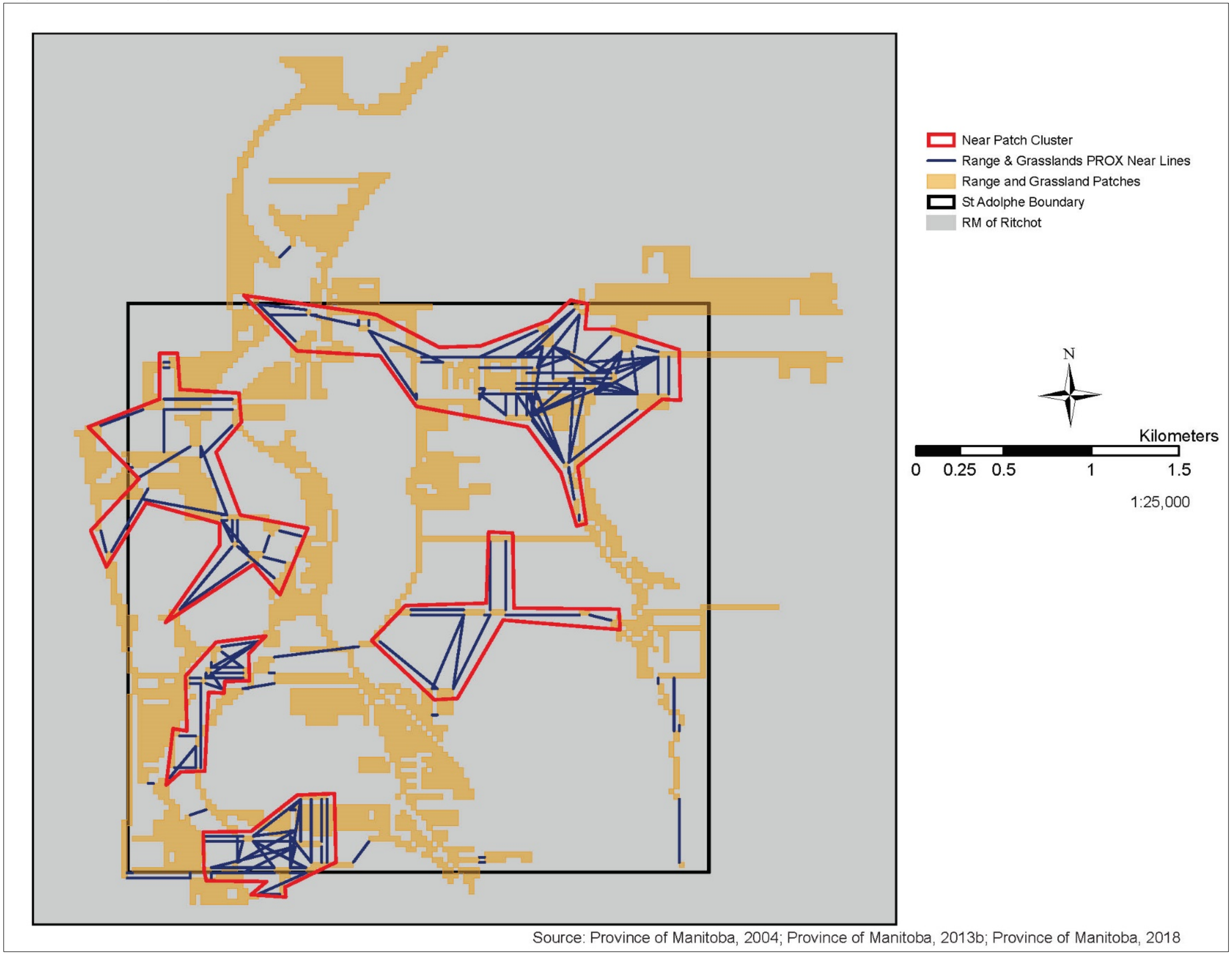
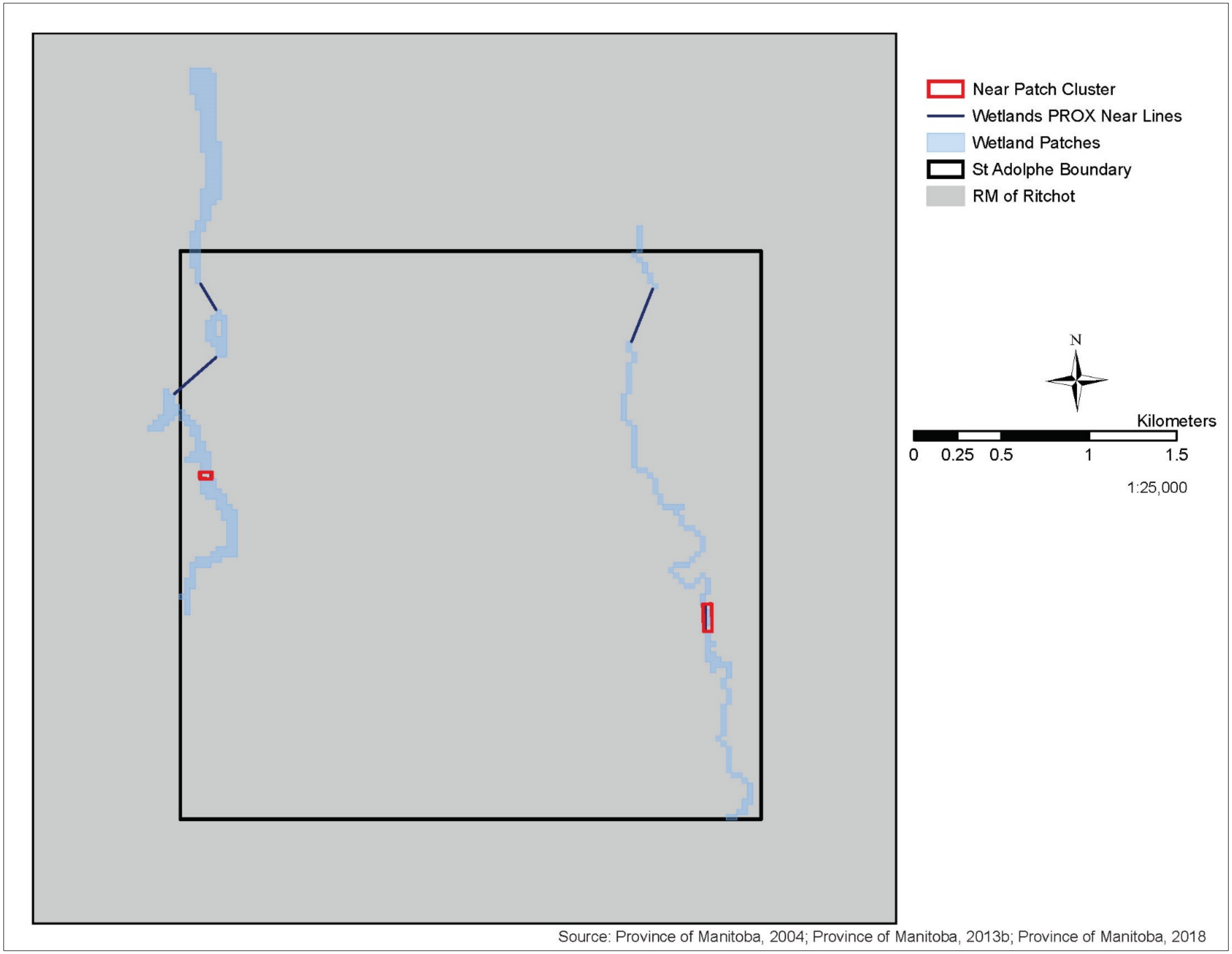


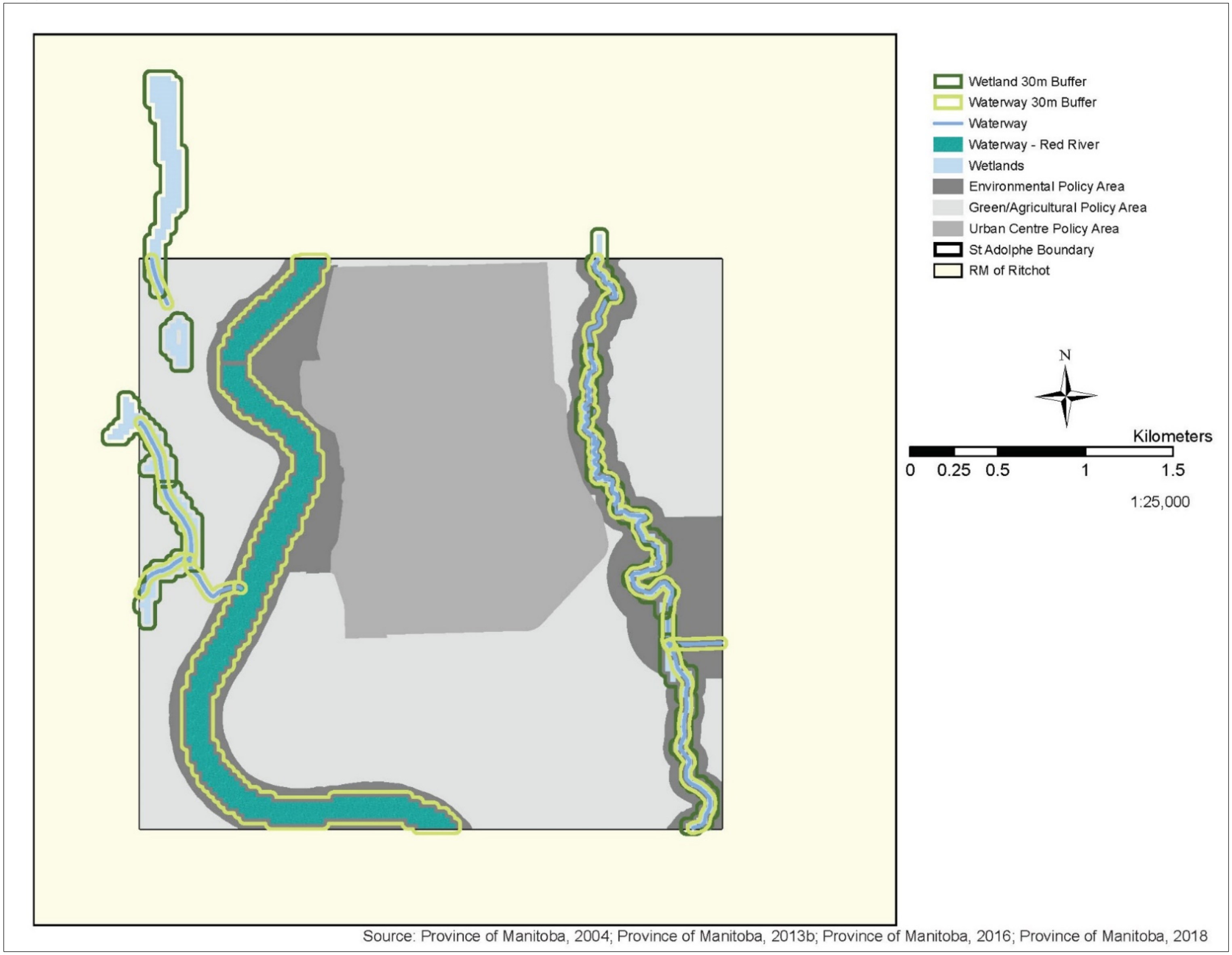
Figure 4.11 **Wetland Land Cover Type: Ecosystem Clusters**



activities as they represent areas with greatest potential to support biodiversity and maintain ecological structures and characteristics. As such, patches and “near lines” associated with clusters were considered as more valuable to conserve and restore. Furthermore, key patches were considered those with high PROX values as they are considered larger and closer together and key “near lines” represent the greatest opportunity to enhance their connectivity as they reflect more contiguous patches. The identification of specific key patches and key “near lines” was determined by analyzing patch size and PROX values; this is discussed in *Section 5.2.2*.

Next, an ArcGIS map layer was created to understand the land use policy framework present in the sample site. Using the Land Use Designation dataset and the waterway and wetland buffer layers generated, a Land Use Policy Framework map was created for the sample site (Figure 4.12) The Land Use Policy Framework map demonstrated that the site had three land use designations present: Environmental Policy Area, Urban Centre Policy Area, Green/Agricultural Policy Area. It should be noted that this differed from the Macdonald-Ritchot Development Plan in that the Urban Centre Policy Area shown in the built map contains both the Urban Centre Policy Area and the Urban Centre Hold Policy Area; the land use designation dataset used did not distinguish the two policy areas. The waterway and wetland buffer layers generated to represent the Provincial Land Use Policies requirements demonstrated that the majority of the buffer layers fell within the areas designated as Environmental Policy Areas (Figure 4.12). The Environmental Policy Area aims to ensure development respects the prescribed setbacks near riverbanks and minimize disruptions to aquatic habitat including wetland and riparian areas (Lombard North, 2011, p. 22). As a result, the buffer layers were not shown in future maps when they fell within areas designated as Environmental Policy Areas. Finally, the research considered the Designated Flood Area. The entirety of the RM of Ritchot

Figure 4.12 **Land Use Policy Framework Map**

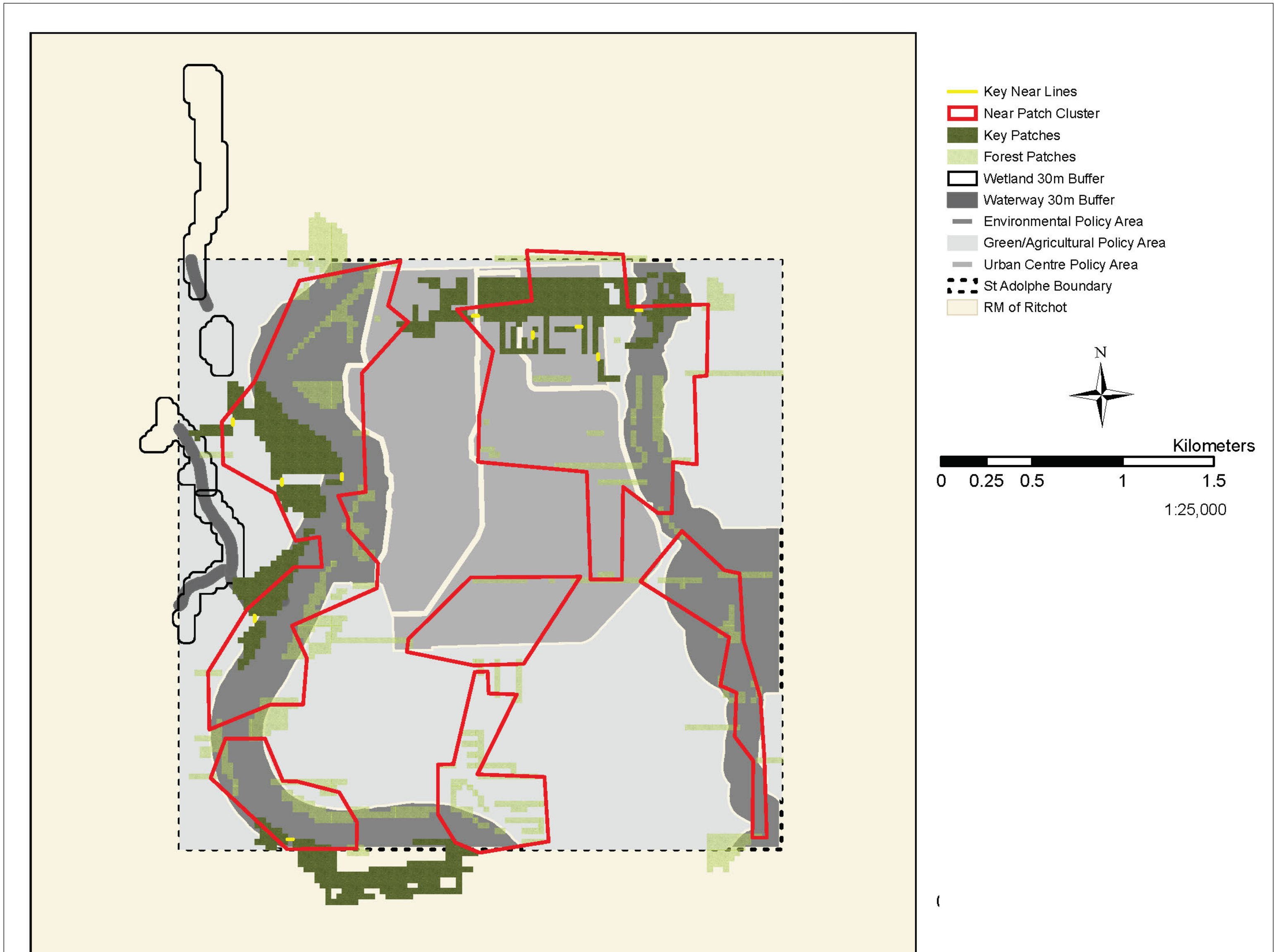


was found to be located in the Red River Designated Flood Area (Appendix G). The Land Use Policy Framework map does not display the Designated Flood Area, but it is understood that the entirety of sample site falls within this policy area.

The next step completed as part of the Prognosis planning phase consisted of building maps that identified the land use policy framework in relation to the key patches and “near lines” identified. The maps were built by combining the patch cluster map layers with the Land Use Policy Framework map layer, see Figure 4.13, Figure 4.14, and Figure 4.15. The maps built in this step identified natural ecosystem land cover type patch clusters and associated key patches and “near lines”, identifying the spatial arrangement of patch clusters as they related to land use designations and waterway and wetland buffer layers. Figure 4.13, Figure 4.14, and Figure 4.15 demonstrate that patch clusters almost all capture key patches and near lines with the exception of one *Range and Grassland* key patch and “near line”. However, patch clusters also contain lower PROX value patches and near lines. What becomes apparent is that patch clusters reflect the spatial pattern of patches in the landscape that demonstrate a form reflective of the nearest distances between like patches. Key patches, “near lines” and patch clusters were located in all land use designations represented in the sample site with many occupying space in either Environmental Policy Areas or within a waterway and wetland buffer layer area. This was more apparent in the *Forest* and *Wetland* land cover types as compared to the *Range and Grassland* land cover type.

The next step of the Prognosis planning phase including building a map that demonstrated natural ecosystem land cover type patch clusters in relation to other land cover types in the sample site; see Figure 4.16, Figure 4.17 and Figure 4.18. The key “near lines” demonstrate the nearest distance area to connect high PROX value patches and the maps

Figure 4.13 **Forest Land Cover Type: Patch Clusters and Land Designation Policy Areas**



Source: Province of Manitoba, 2013b; Province of Manitoba, 2016; Province of Manitoba, 2018

Figure 4.14 **Range and Grasslands Land Cover Type: Patch Clusters and Land Designation Policy Areas**

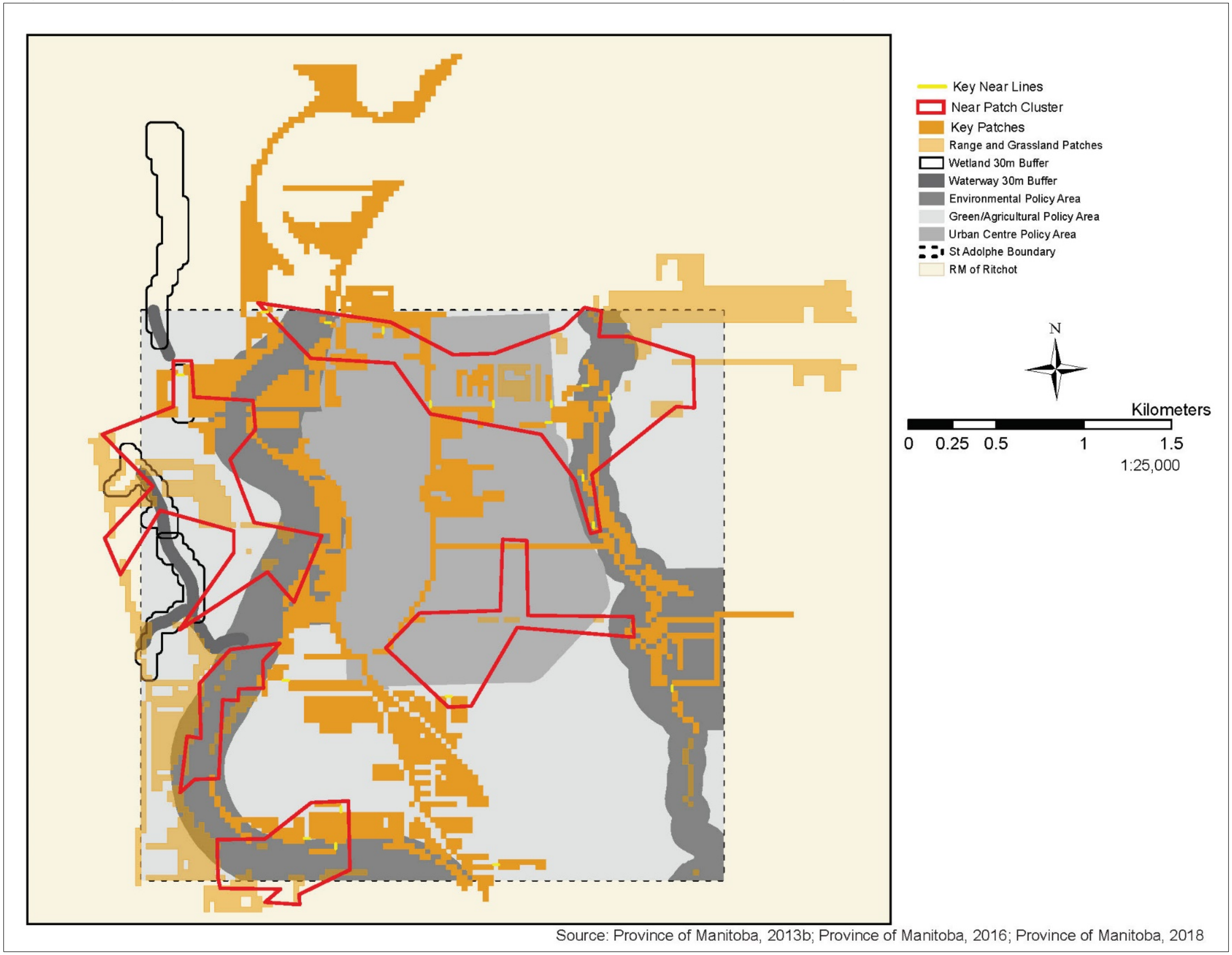
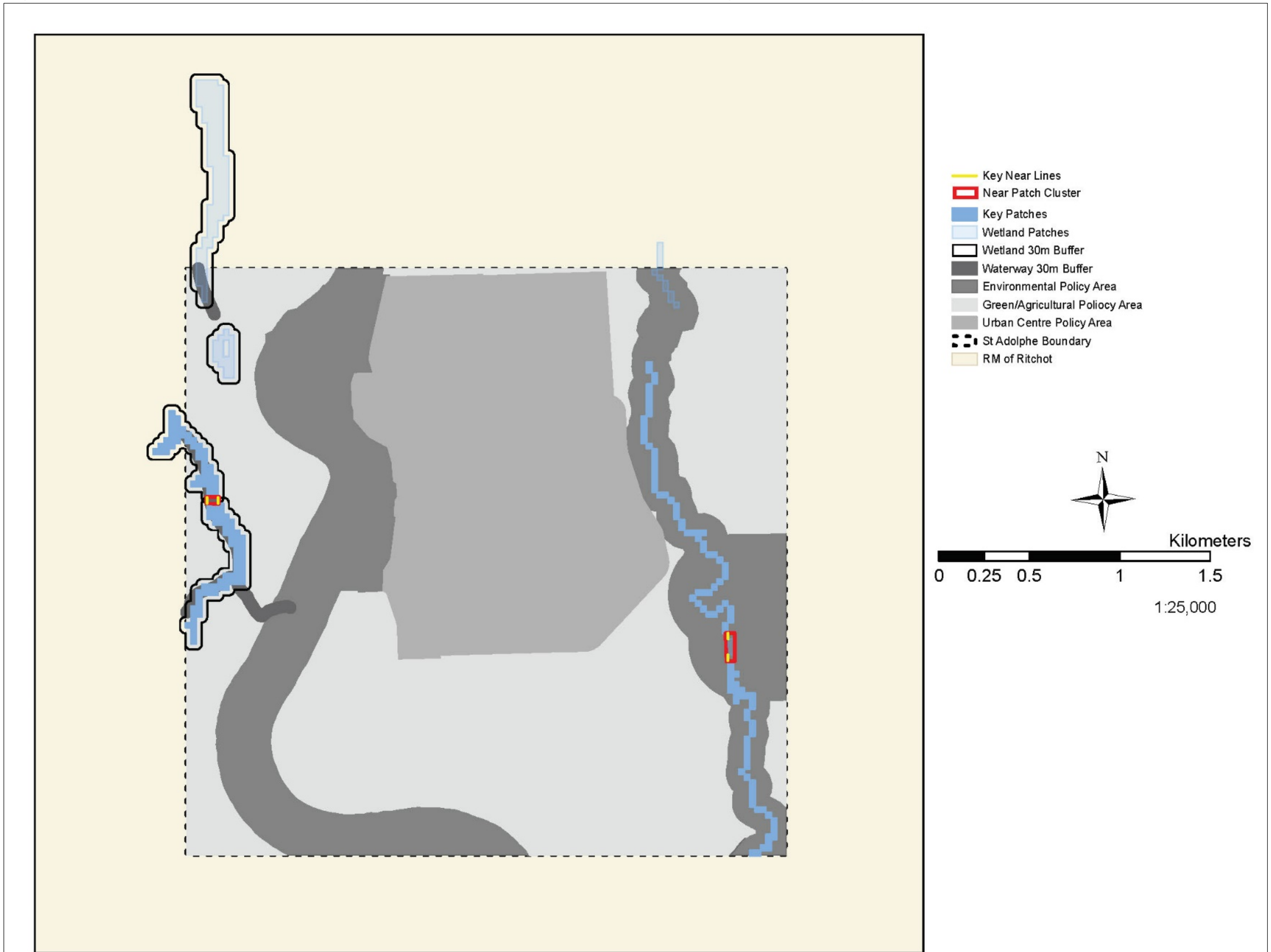
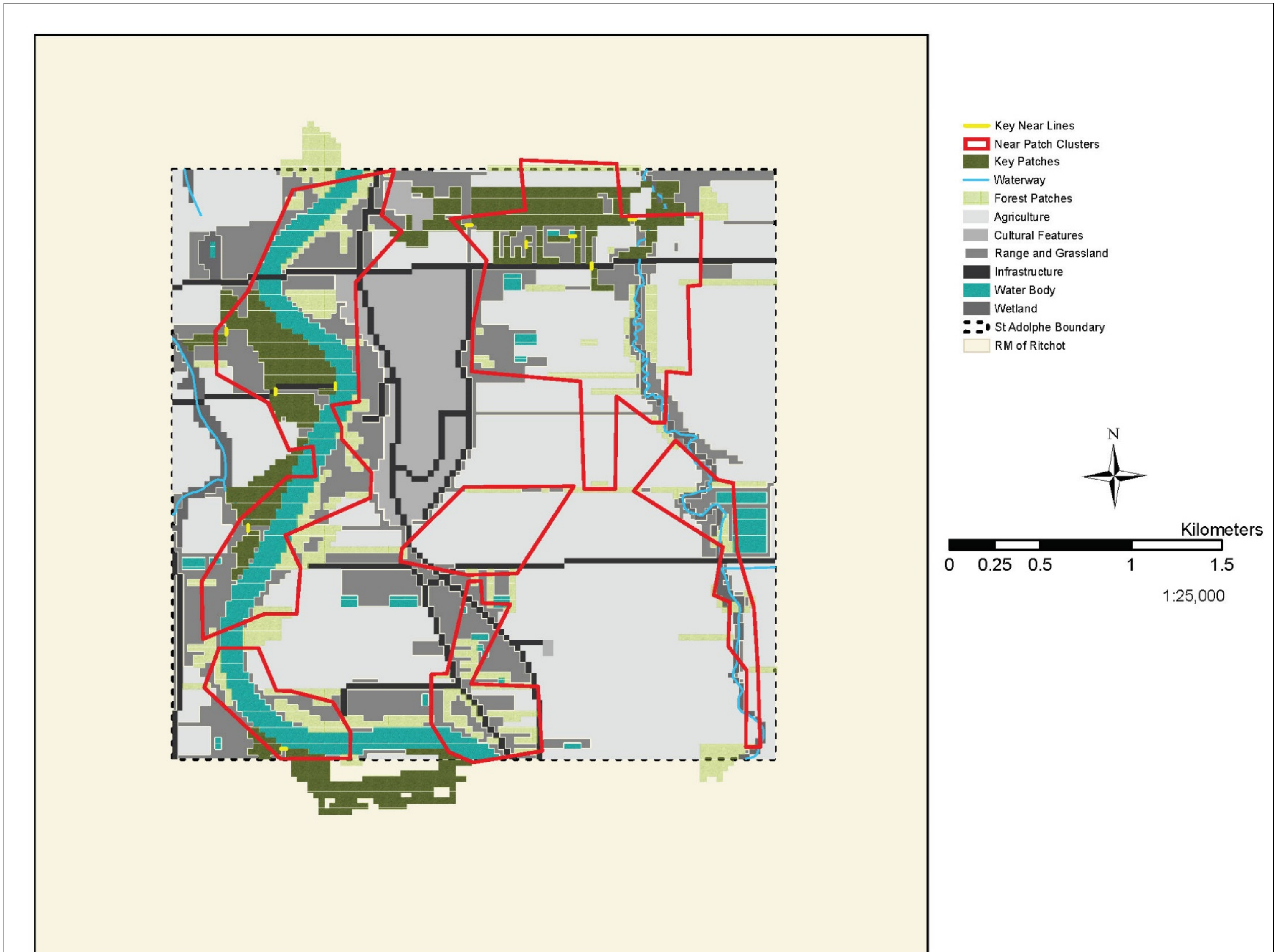


Figure 4.15 **Wetland Land Cover Type: Patch Clusters and Land Designation Policy Areas**



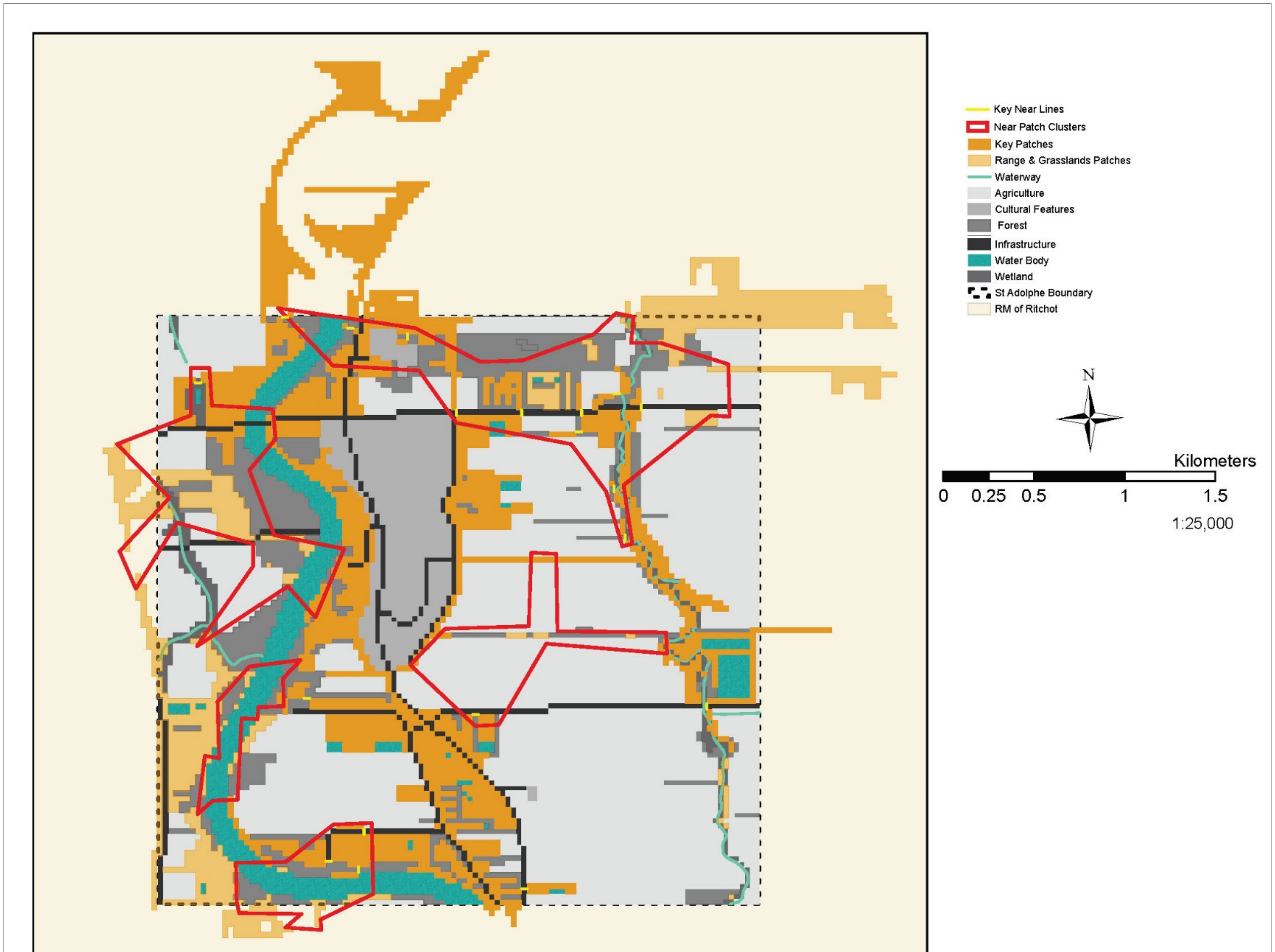
Source: Province of Manitoba, 2013b; Province of Manitoba, 2016; Province of Manitoba, 2018

Figure 4.16 **Forest Land Cover Type: Patch Clusters and Other Land Cover Types**



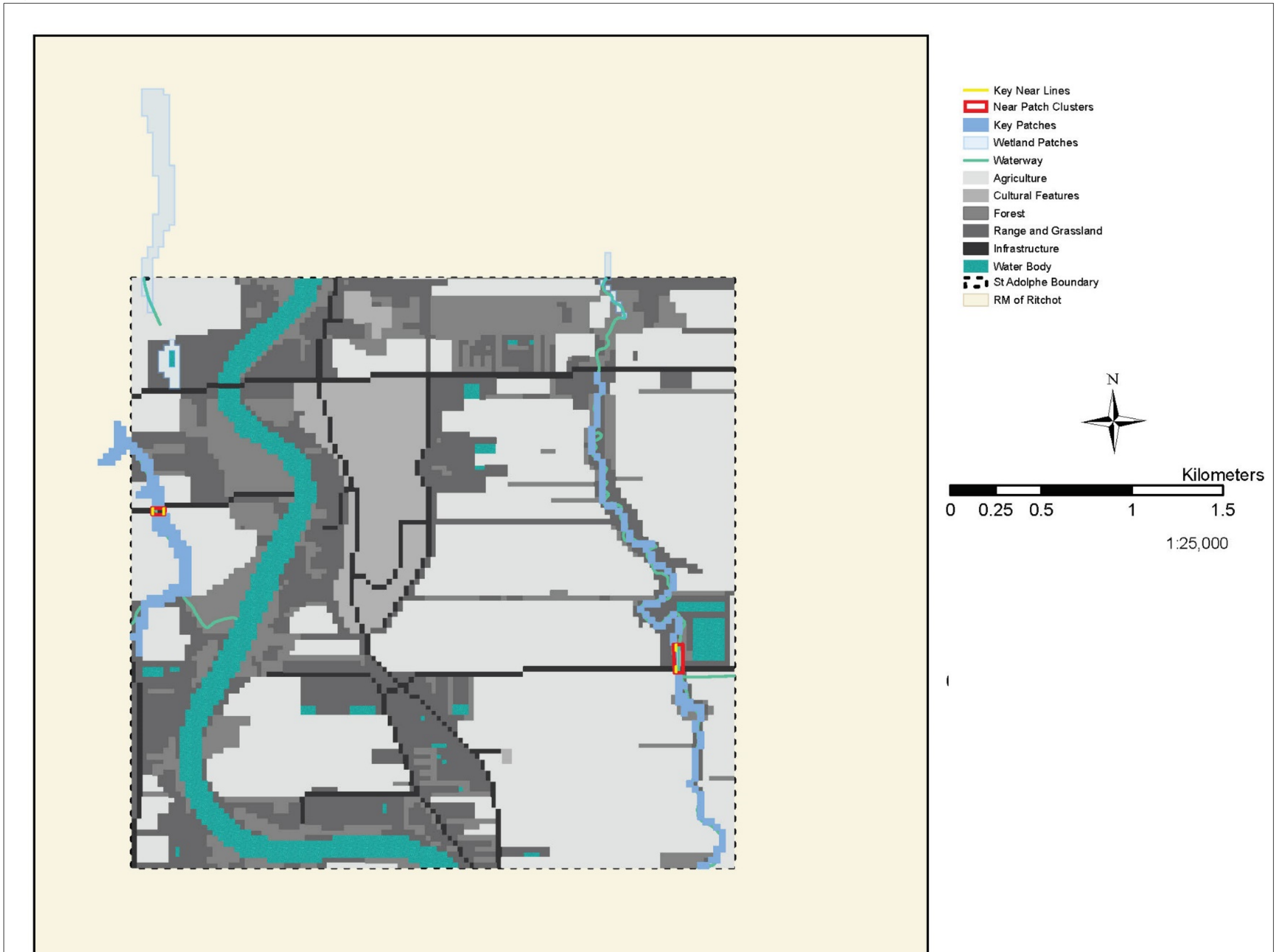
Source: Province of Manitoba, 2004; Province of Manitoba, 2013b; Province of Manitoba, 2018

Figure 4.17 **Range and Grasslands Land Cover Type: Patch Clusters and Other Land Cover Types**



Source: Province of Manitoba, 2004; Province of Manitoba, 2013b; Province of Manitoba, 2018

Figure 4.18 **Wetland Land Cover Type: Patch Clusters and Other Land Cover Types**

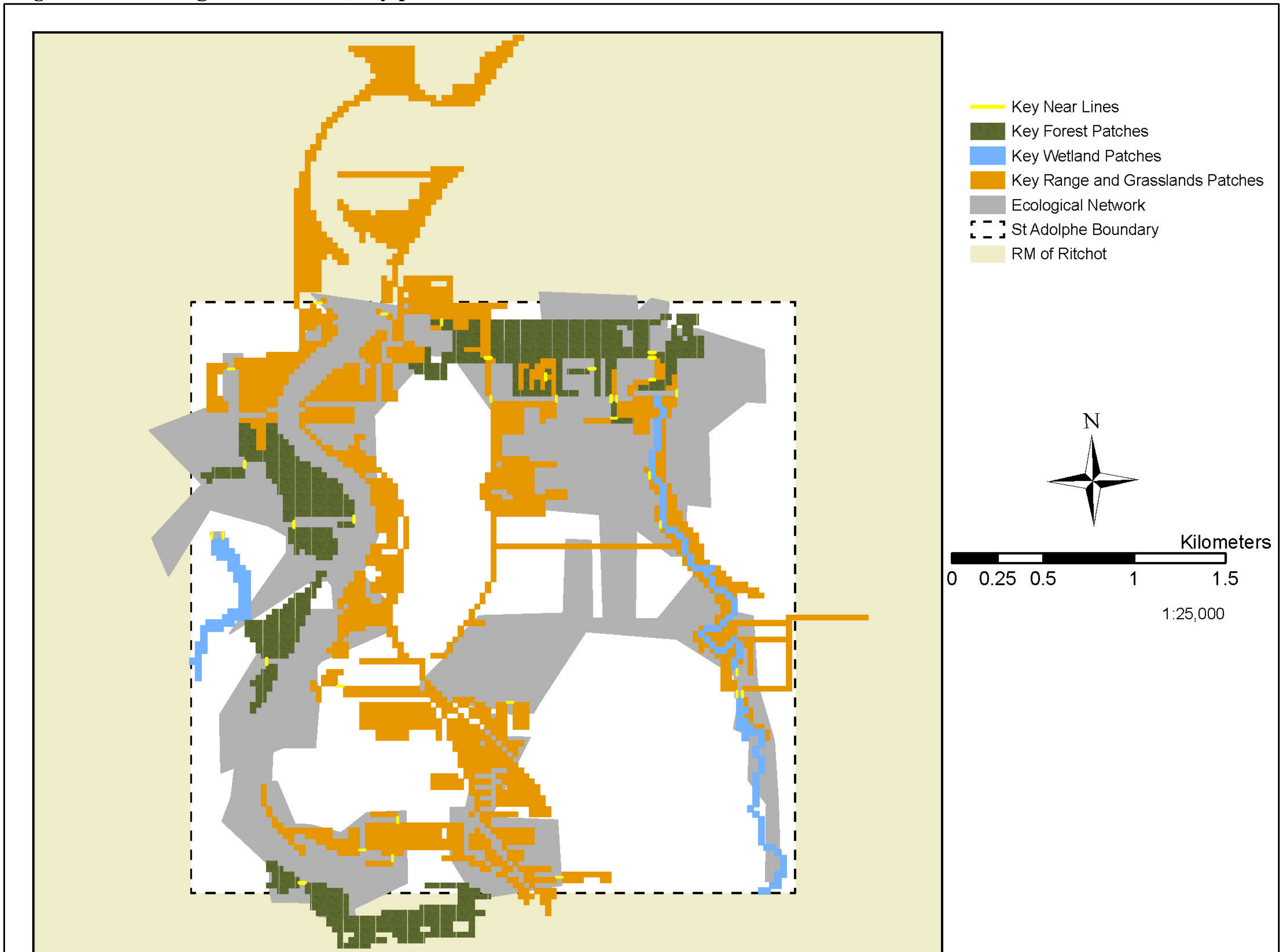


Source: Province of Manitoba, 2004; Province of Manitoba, 2013b; Province of Manitoba, 2018

produced provide insight as to what land cover type is located between these key patches. This can serve to highlight potential barriers to enhancing connectivity. Figure 4.16 demonstrates that two land cover type are found between key *Forest* patches and near lines: *Range and Grasslands* and *Infrastructure*. Figure 4.17 demonstrates that three land cover type are found between key *Range and Grassland* patches and near lines: *Forests, Infrastructure*, and *Wetlands*. Figure 4.18 demonstrates that two land cover type are found between key *Wetland* patches and near lines: *Forests* and *Infrastructure*. The maps produced can also identify what other land cover types are located between lower PROX value patches. Figure 4.16, Figure 4.17 and Figure 4.18 demonstrated that all land cover types are found between like patches within a cluster depending on where the cluster is located in the sample site.

The final step of the Prognosis planning phase was to build a map that identified the natural ecosystem ecological network of the sample site, its key patches for conservation and key "near line" areas for restoration; see Figure 4.19. The map highlights the shape and spatial arrangement of the defined ecological network as well as identifies the shape and arrangement of key patches and "near lines" as it relates to the ecological network. Figure 4.19 demonstrates that there is some overlap in where key *Wetland* and *Range and Grassland* patches are located, as well as where key *Forest* and *Range and Grassland* patches are located. Figure 4.19 also demonstrates that while the majority of key patches are found within the defined area of the ecological network, some patches are not entirely found within this defined area. As well, Figure 4.19 demonstrates that areas identified as key "near lines" are all found within the defined ecological network.

Figure 4.19 **Ecological Network, key patches and "near lines"**



Source: Province of Manitoba, 2013b; Province of Manitoba, 2013c; Province of Manitoba, 2018

4.2 Analysis

The following section is organized in five sub-sections. The first subsection presents the analysis from the precedent analysis. The analysis from the Focus, Analysis, Diagnosis, and Prognosis Planning Phases are each presented in the following four sub-sections.

4.2.1. Precedent Review Analysis

The following section discusses factors from the precedent review as summarizes in three themes: Defining the network; Organizing the landscape; and Planning and Policy.

Defining the network:

To effectively protect and enhance the green network, each of the three precedents reviewed emphasized the need to first define the network and its components. Although each took a different approach to doing this, all considered green spaces or open spaces as the basis of their networks. For the City of Edmonton and the City of Ottawa this meant parks and greenspaces, whereas for the HRM this meant a broader definition that included land cover type associated other human uses like agriculture and cultural features in addition to parks and greenspaces. All plans varied in how they defined these spaces, but each broadly separated the network into categories reflecting ecology and human-based green/open spaces. Again, these broad categories reflected the scope of the plan and the elements of importance to the municipality. Ottawa's Greenspace Master Plan simply separated components into their human and ecological dimensions, whereas plans from the HRM and Edmonton went further by adding a level of functional classification to their categories. The addition of this functional classification provided plans an ability to further classify components into structures relevant to the local context and gain further understanding of the spaces that compose the network. Furthermore, by evaluation spaces as they relate to the ecological and human functional value they provide, the HRM and Edmonton plans attempt to address the multifunctionality and interconnectedness of spaces. In defining the ecological network in the RM of Ritchot, it would be important to recognize that spaces can perform both ecological and human functions, and although broadly separated to ease their categorization, they should be considered as a functional unit. As such, when defining the ecological network in the RM of Ritchot focus can be directed toward open spaces considered as more natural lands but the human components that may contribute to ecological function should not be excluded.

As mentioned, plans reviewed each took a different approach to defining green/open spaces. Each applied a distinct definition that while sharing similarities, was reflective of the local context and the values deemed important to the area. Determining what to consider in the definition of open/green space relied on a combination of research, local context analysis, and public consultation. In determining what constitutes the ecological network in the RM of Ritchot, the precedents reveal the need to consult various sources of information. All plans relied on existing data from sources like municipal plans, strategies, and land use by-laws, regional plans and policy, and provincial plans, acts, and strategies. In many instances, datasets were already available from different sources but had not been combined and analyzed in the way that green network planning introduced. Although some primary data collection was required to create particular datasets, the plans highlighted that undertaking green/open space planning is possible with existing data sources. What this brings to the planning process in the RM of Ritchot is an ability to limit capacity needs associated with primary data collection while still maintaining an ability to integrate ecology and science within the planning process.

In conjunction with research and analysis, the plans identified the need for public consultation in network planning. By consulting with the public and stakeholders, plans were able to better focus on the community's priorities, identify opportunities and barriers to the use of open/green spaces by residents, determine their demand for use, and define their vision of a green network. Although each plan largely based the definition of the ecological network on ecological principles and scientific methodology, public consultation was key to defining the human components of the network as it clarified where planners should direct their efforts in collecting and analyzing human-based network component data. Public consultation did however inform planners on the ecological network by clarifying what functions should be evaluated, as they reflected not only ecological functions based on science but landscape functions important to residents. This was especially evident in the Edmonton and HRM plans as they categorized green/open spaces based on landscape function and assigned functional scores to spaces. In these plans, through public consultation the functions deemed important to the human-based network components were determined and were used to evaluate the ecological network. In this way, providing a tool to evaluate the ecological network from a human function perspective

Organizing the landscape:

By defining what constituted green/open spaces, precedents reviewed were able to identify the network. As these spaces were considered the foundation of the physical landscape, identifying the green network provided planners with an opportunity to guide the organization of land use in the municipality. All plans incorporated the principles of landscape ecology in their definition of open/green space types, helping to define the role network structures played in the landscape. Understanding these roles assisted in identifying their functional role in the landscape, which served as the basis for their functional evaluation. As each plan included some form of open/green space evaluation based on level of function provided, planners were provided with a way to identify locations in the landscape key to the function of the network and identify gaps.

As such, planners were provided with a picture of the network on a large scale, regional scale in the case of Ottawa and HRM and whole municipality for Edmonton, and an opportunity to identify gaps in the overall network. This provided an ability for planners to organize the landscape by focusing on gaps and address them at the smaller scale (e.g. parcel, urban centre vs. rural). In this way, land use organization was informed by not only its role in the larger landscape network but also reflected its use at a smaller scale.

Furthermore, by providing open/green spaces a score/rank based on function planners were provided an opportunity to prioritize efforts to areas of high functional importance. This provided plans with a way organize the landscape by identifying areas important to network protection and enhancement and areas better suited for growth and development. As growth is a key factor in planning for the RM of Ritchot, determining where to direct growth and development and where to protect and enhance the ecological network could be of great benefit. Determining a way to score/rank open/green spaces could direct planners on where to increase connectivity to enhance landscape function. By doing so, planners could highlight key functional areas in the ecological network and use this to inform public and stakeholder consultation. In this way, land use could be organized to reflect an ecological network that considers ecological principles, network function, and public priorities.

Land Use Planning and Policy:

The reviewed precedents revealed that to address ecological network protection in the municipal planning process care must be taken to ensure green network plans align with priorities and key strategies like plans, policies, and by-laws. Consideration to the various levels of governance will be required to ensure a comprehensive understanding of municipal, regional, and provincial strategic direction. By doing so, green network plans can inform and support new and existing planning strategies and the organization of land use. In addition to this, as green network plans consider the broader policy framework, they assist in addressing regional and provincial planning priorities. Each plan reviewed was undertaken because of a directive from a broader strategic plan that instructed the civil service to develop a vision and plan for green/open spaces. As such, green space network plans reflected a number of governance levels, where policy directives focused on a range scales from small municipal actions to broader regional ones.

In this way, the green network plan becomes a frame of reference of the physical landscape in land use planning and decision making. Each plan reviewed had examples of plans they supported, clearly identifying the links between the network plan and broader municipal planning priorities. Although each subsidiary plan had specific considerations, they used the green network plans as their foundation. As the green network plans were based on datasets from multiple sources that not only included technical descriptions and analysis but public priorities, subsidiary plans reflected the priorities of residents and were grounded in science. In this way they served as a tool for planners and decision makers to make evidence-based decisions that reflected a number of municipal and scientific parameters and considerations. These served as evidence for the RM of Ritchot as to how multiple municipal planning priorities can be integrated with objectives relating to green space planning, taking these priorities beyond only ecological ones and addressing social and economic issues in turn. By taking this approach, the RM of Ritchot's municipal planning can be broadened to consider the multifunctionality of landscapes and their ability to provide numerous services beneficial to the environment and human well-being. In this way, it can go beyond simply protecting and enhancing the ecological network and focus on protecting and enhancing all network components.

4.2.2. Analysis: Focus and Analysis Planning Phases

The Focus and Analysis planning phases were focused on establishing a land cover type classification system, building an associated base map, and quantifying existing land cover type composition. Building on the results from the Focus planning phase, the Analysis planning phase utilized a number of landscape metrics outlined in the Sustainable Land Planning Framework (SLPF) to quantify existing land cover type composition. The following section provides a summary analysis of these results.

The classification system generated in the Focus planning phase resulted in seven land cover type classes (Figure 4.2) that when applied to equation one resulted in a Patch Richness (PR) value of seven. Two factors are important to consider when interpreting PR: historical PR and the existing greater regional PR. Comparison of PR to historical PR provided insight into the land transformation process over time and associated changes in PR – see *Section 4.1.3 Patch Richness*. While not precise, historical PR values coarsely demonstrate that over time the sample site's PR value has incrementally increased, suggesting greater diversity of land cover types and greater heterogeneity across the landscape. To identify if this increase in PR over time implies an increase in biodiversity, it important to consider the composition of land cover types added through time as biodiversity is highly dependent upon the composition of patch types (Leitao, et al. 2006, p. 65). Then, PR must be evaluated in association with an explicit listing of land cover types. When a land cover type listing associated with historical PR values is considered, it demonstrates that prior to 1900 no human components were included in the listings whereas the maps from 1930 onwards included various human components (i.e. roads, settlements, agriculture). A higher presence of human components coincides with the time periods of increased settlement in the RM of Ritchot and the modification of the landscape discussed in

Chapter 2. Therefore, while PR has increased and implied a more diverse, heterogeneous landscape over time, this increase in land cover type diversity and heterogeneity is the result of more human-influenced land cover types created during land transformation. This suggests that natural lands were lost and fragmented as the landscape was modified and PR increased, suggesting a loss of biodiversity associated with natural lands lost and fragmented.

Comparison of PR to the greater landscape PR (i.e. RPR) provided insight into the level of diversity and heterogeneity present in the study area as compared to the greater region at the same moment in time. This comparison attempts to determine what would be the possible maximum diversity of land cover types in the sample should all listed land cover types in the region be found in the sample site (Leitao, et al. 2006, p. 67). As discussed, the classification system generated in the Focus planning phase resulted in seven land cover type classes, a decrease from the seventeen land cover types included in the original land cover type dataset (Figure 4.2). When applied to equation one, this resulted in a PR value of seven and an RPR value of seventeen. When compared, the values propose that the sample site is less diverse and heterogeneous than the greater region. As the area is less diverse than the greater region, the PR and RPR values suggest that less biological diversity is supported in the sample size as compared to the greater region. While land cover types listing for both the sample site and the greater region include human-influenced components, the greater region listing includes a more varied composition of natural land ecosystems. This suggests that the greater region has more variety of physical and ecological conditions that support greater diversity of natural land cover types.

While historical land cover types were not quantified by using methods outlined in the SLPF, historical photographs were used to provide insight into past conditions. Figure A-1 and Figure A-2 illustrate land cover types present in the RM of Ritchot prior to the year 1900 and suggest a sample site PR value of one to four. Figure A-3 illustrates land cover types present in the RM of Ritchot from 1930 and suggest a PR value of two to four. Figure A-4 and Figure A-5 illustrate land cover types present in the RM of Ritchot from 1950 and 1969 respectively and suggest a PR value of four to five. Finally, Figure A-6 illustrates land cover types in the RM of Ritchot from 1999 and suggests a PR value of six.

While comparison of PR to the historical and greater region situation provides more context to the discussion of diversity in the sample site, it does not provide insight into the distribution of land cover types in the sample site. Understanding distribution of land cover types enables for better understanding of surface area, a key component of landscape structure, thereby providing a critical quantitative description of landscape composition and a better understanding of its implications for landscape function (Leitao, et al., 2006, p. 66). Class Area Proportion (CAP) facilitates this through its evaluation of abundance of land cover types in the landscape as it relates to the percent of total area covered. Table 4.1 reveals that the land cover type *Agriculture* occupied the greatest area proportion of the landscape, and the patch type *Wetland* occupied the least area proportion of the landscape. All land cover types with the exception of the *Agriculture* land cover type occupied an area proportion between two and twenty-two percent. Natural land PLAND values can be compared to guidelines relating to percent area cover (Table 2.2) to determine how values measure to optimal values that promote protect biological materials and ecological structures and characteristics as well as enhance diversity. Table 4.6 demonstrates how the *Wetland* and *Forest* land cover types PLAND values fall below the optimal value. This implies that to meet optimal values, all existing wetlands and forest should be protected and that restoration will be required to grow area cover. Currently, Environment Canada does not offer a numerical optimal value guideline for grasslands but emphasizes the need to maintain native grassland ranges. Chapter 2 clarified how grassland prairie covered the RM of Ritchot, with the exception of wetter areas that were dominated by river bottom forest and wetlands. Then, generally protecting and restoring grasslands in these areas can help support an optimal cover area in the absence of a numerical optimal value.

Table 4.6 **Natural Land Cover Type PLAND and Optimal Value Comparison**

Natural Land Cover Type	PLAND Value (%)	Optimal Value (%)
Wetland	2.05	6.00
Forest	12.86	30.00
Range and Grasslands	21.32	No numerical value available

While historical CAP values were not determined in this research, assumptions can be made as to historical CAP values based on the literature review and determined historical PR values, and provide some historical context to CAP. The Chapter 2 Literature Review identified how much of the original landscape had extensive tree belts, most often along waterways, numerous ephemeral and perennial wetlands, and an extensive land cover of Tall Grass and Mixed Grass Prairie. While no exact CAP value is available, one can assume that without the pronounced presence of settlements and associated roadways that these land cover types dominated the landscape. Historical PR from pre-1900, as per historical maps, would support this as it implies a low number of land cover types (i.e. PR = one to four) that most likely resembled the pre-land conversion state. By 1999, PR had increased to six and included a number of land cover types that reflected human land uses (i.e. agriculture, settlements, roads). This suggest that the increase in PR as a result of settlement reduced the dominance of natural land ecosystems, thereby changing CAP values to values that more closely reflect similar values as today. Then, it can be assumed that the landscape was converted from a landscape with high natural ecosystem

CAP values to a landscape with a reduced presence of natural ecosystems and more dominated by human-based landscape components similar to what is observed in the sample site today. This suggest a loss and fragmentation of natural lands, which likely resulted in an associated loss of biodiversity and ecological function.

CAP also enabled the identification of the matrix, a key ecological structure that exerts influence over biotic components and function, by determining if a land cover type dominated area distribution or not. Although the land cover type *Agriculture* constitutes forty-five percent of the landscape surface area of the sample site, a matrix does not exist because it does not comprise more than fifty percent of the landscape, the typical measurement used to define a matrix, and therefore does not overtly dominate the landscape (Leitao et al., 2006, p. 75). However, its fairly large CAP value suggests a strong influence on ecological structure and characteristics. Introduction of agriculture modified the landscape and replaced former land cover types that may have been historically natural lands. The modification of drainage patters, soil, and vegetative cover completed to accommodate agriculture has changed the ecological structure and characteristics of the landscape and decreased the biodiversity associated with historic natural lands. The *Range and Grasslands* and *Forest* land cover types occupy approximately twenty-one and thirteen percent respectively of the landscape. Together with *Agriculture*, these three land cover types occupy over eighty-one percent of the sample site's surface area. Although *Range and Grasslands* and *Forest* land cover types are not co-dominant land cover types, they likely exert positive influence on the biological diversity and ecological function of the landscape. They do this by reducing the negative ecological effects associated with a greater presence of the *Agriculture* land cover type like land cover and soil manipulation, monocultural temporary vegetative communities, and pesticide application. As such, *Range and*

Grasslands and *Forest* may play an important role in supporting biological diversity and ecological function in the area.

CAP also enables the identification of land cover types less represented in the landscape. Four of the land cover type listings had PLAND values of less than seven percent: *Cultural Features, Infrastructure, Waterbodies,* and *Wetlands* (Table 4.1). The relatively low *Cultural Features* and *Infrastructure* PLAND values suggest that urban land uses do not yet dominate the landscape and may not be exerting a substantial influence on biological diversity and ecological function. CAP results also identified that the land cover type *Wetland* is poorly represented and relatively rare in the landscape. Considering this land cover type was one of the few historical land cover types occupying the sample site only a century ago, there has been a substantial loss of wetlands in the sample site over the last century and likely a loss of associated biodiversity and ecological function. Finally, while the *Waterbodies* land cover type includes all open water (i.e. lakes, rivers, streams, ponds and lagoons – see Appendix C), Figure 4.3 demonstrates how rivers and streams likely compose the majority of the land cover type surface area. The land cover type ArcGIS generated feature attributes confirm this; rivers and streams in the sample site occupied over eighty-two percent of the *Waterbodies* land cover type surface area. Chapter 2 Literature Review identified rivers as a significant landscape component, where they have a strong relationship with the surrounding landscape and play a key role in terrestrial natural land ecological process and functions. As such, while the *Waterbodies* PLAND value is slightly below seven percent, this land cover type likely still exerts strong pressures on the landscape mosaic, its land cover type patches and corridors, their functions, and subsequently biodiversity and ecosystem services.

When CAP values are sorted to compare the area distribution of natural land ecosystem patches (i.e. *Forest, Range and Grasslands*, *Waterbodies, and Wetland)* versus human-influenced patches (i.e. *Agriculture, Cultural Features*, and *Infrastructure*), CAP values identify that human-influenced components occupy more surface area than natural ecosystems, with combined PLAND values of fifty seven percent and forty three percent respectively. The listings used to classify land cover types help distinguish two types of human-influenced components: urban (i.e. *Cultural Features* and *Infrastructure*) and agriculture (i.e. *Agriculture*). When the *Cultural Features* and *Infrastructure* land cover types are combined, their combined PLAND value becomes approximately ten percent, thereby increasing their potential to influence surrounding biological diversity and ecological function. While urban and agriculture land cover types are both human-influenced components, they have different effects on biodiversity and ecosystem services. Due to the large *Agriculture* land cover type PLAND value, *Agriculture* likely has more influence on surrounding natural ecosystems, however, as urban features often increase together, urban land cover types could increasingly become an influencing land cover types should urban growth occur. For the time being, CAP demonstrates that the sample site retains the historical rural agricultural character established in the last century but maintains a fairly strong presence of natural land ecosystems with the exception of the wetland land cover type.

The results of both the PR and CAP values have enabled assumptions to be made regarding the diversity and heterogeneity of the sample site; however, both diversity and heterogeneity can be quantified through the use of the Shannon's Index to confirm assumptions. Table 4.2 identifies the sample site's Shannon's Diversity Index value as 2.18, a relatively low number when one considers that the minimum possible value equals zero with an unlimited maximum. This indicates that the sample site is relatively not very diverse, where when landscape patches are sampled at random patches are likely to be the same. However, without comparing the calculated Shannon's Diversity Index to a similar calculated value for another landscape, the researcher is unable to confirm whether this value is in fact a low value. Table 4.2 also identifies the landscape's Shannon's Evenness Index value as 0.78, a fairly high number when one considers that the minimum possible value equals zero and the maximum possible value equals one. This indicates that patches are fairly evenly distributed and not dominated by one patch type, and therefore fairly heterogeneous. The sample site's CAP value supports this conclusion as it demonstrated that land cover type surface area was not dominated by one land cover type, but rather distributed in a somewhat evenly manner. So, while the sample site is not overly diverse it is fairly heterogeneous even though there are not a high number of land cover types competing for area.

While the PR, CAP and Shannon's Indices landscape metrics are useful in measuring landscape composition, they do not reveal any information as to the spatial character of the sample site or the configuration of its landscape mosaic. These landscape metrics may provide key information as to the composition and distribution of existing ecosystems, however, they do not provide information as to how ecosystems are spatially arranged (e.g. Where are they located?), what their spatial character is (e.g. What is configuration in the landscape mosaic?), and how they organized in the landscape (e.g. Are they aggregated or isolated? How connected are they?). Therefore, to fully understand the landscape and support evidence-based land use planning recommendations that reduce natural land loss and fragmentation to protect associated biodiversity and the continued the delivery of ecosystem services, it is necessary to also consider the spatial configuration of land cover types. In this way, compositional landscape metrics can compliment configurational landscape metrics to comprehensively quantify the landscape and build a complete picture of the landscape that better informs the definition of an ecological network and identifies opportunities for connectivity.

4.2.3. Analysis: Diagnosis and Prognosis Planning Phases

The Diagnosis and Prognosis Planning Phases were focused on quantifying land cover type configuration, identifying the landscape mosaic and defining an ecological network, assessing isolation and fragmentation and identifying opportunities for connectivity, and developing a visual tool to help communicate the ecological network. Building on the result from the Focus and Analysis planning phases, the Diagnosis planning phase utilized a number of landscape metrics outlined in the SLPF to quantify land cover configuration. The Prognosis planning phase compiled the collected information to define the ecological network and identify opportunities for connectivity in the sample site. The following section provides a summary analysis of these results.

Spatial character of the sample site can be identified by defining the components of the landscape mosaic (i.e. patches, corridor, and matrix) through the use of the sample site's base map and CAP values. As discussed in *Section 5.1.1*, CAP values identify that no matrix is present in the landscape. Then, the land cover types in the sample site landscape mosaic take on the structural form of either patch or corridor. With the use of the base map, spatial character can be further identified by clarifying landscape structures by recognizing whether land cover types take on a linear form (i.e. corridor) or non-linear form (i.e. patch). When the base map is reviewed, it is observed that the two land cover types exhibit a linear form: *Infrastructure* and *Waterbodies*; as such they are considered corridors. The land cover type classification listing describes *Infrastructure* as: secondary roads, trails, cut survey lines, right-of-ways, railway lines and transmission lines; human-influenced components that Forman (1995) interprets as corridors as they typically exhibit linear structure and nearly all have strong transport or conduit function that facilitates flows between nodes (p. 160). As discussed in *Section 4.1.1*, the land cover type classification listing describes *Waterbodies* as: all open water - lakes, rivers, streams, ponds and lagoons. While lakes, ponds, and lagoons likely take on a more non-linear form, rivers and streams are linear structures. *Section 4.1.1* identified that rivers and streams in the sample site occupied over eighty-two percent of the *Waterbodies* land cover type surface area. While the researcher recognizes that a limited proportion of the *Waterbodies* land cover type structures exhibit a non-linear form, for the purpose of subsequent landscape metric measurements the researcher considered the *Waterbodies* land cover type as a linear structure. The base map also identifies that the remaining land cover types (i.e. *Agriculture, Cultural Features, Range and Grasslands*, *Forest, and Wetland)* exhibit non-linear structures, and as such are considered patches.

While the base map and PR and CAP values identify the structural forms of land cover types in the landscape mosaic and their proportional area, they do not clarify spatial characteristics like land cover type patch contiguity or subdivision, patch near distance or dispersal, and patch size. As fragmentation divides large contiguous patches into increasingly smaller patches (Leitao, et al. 2006, p. 77), understanding these key configurational factors can support the identification of the ecological network and opportunities for connectivity. To clarify whether patches are contiguous or subdivided, Patch Number (PN) values can be referred to. Table 4.3 identifies that the sample site landscape had a total of one hundred and forty-nine patches present. The *Forest* land cover type had the greatest number of patches with sixty-eight and the land cover type *Cultural Features* had the least with three patches; the remaining land cover types had PN values between eight and forty-seven patches (Table 4.3). On a per unit area basis, the *Forest* land cover type had the greatest Patch Density (PD) at 6.33 patches per hectare, whereas the land cover type *Cultural Features* had the least at 0.27 patches per hectare (Table 4.3). These values suggest that the *Forest* land cover type is the most subdivided patch type in the landscape and that the *Cultural Features* land cover type is least subdivided.

Examining PN values in combination with CAP values can help quantify if suggested observations are true by further revealing patch spatial characteristics as they relate to patch contiguity, subdivision, and size. Landscape metrics identify *Forest* and *Range and Grassland* land cover type PN values as sixty-eight patches and forty-seven patches respectively, suggesting that both land cover type patches are relatively not aggregated. Comparison of *Forest* PN values (Table 4.3) with *Forest* CAP values (Table 4.1) reveals that a moderately low surface area supports the greatest number of patches, as compared to other land cover type PN values, suggesting that patches are not only fairly disaggregate but fairly small. When this analysis is completed on *Range and Grasslands* patches, it is revealed that a larger surface area occupies the relatively high PN value, suggesting that patches may be disaggregated like *Forest* patches, but larger than forests patches. The analysis offers different observations when completed on the remaining land cover types. When *Agriculture* PN values (Table 4.3) are compared to its CAP values (Table 4.1),it is revealed that the greatest land cover type CAP value supports a relatively lower PN value as compared to *Forest* and *Range and Grasslands*, suggesting that patches are more aggregated and relatively larger. The *Wetland* land cover type analysis reveals that its PN value is relatively low and equals roughly a third of the *Agriculture* PN value (Table 4.3), suggesting that Wetland patches could proportionally equal roughly a third of the size of *Agriculture* patches. However, the *Wetland* CAP value is the smallest in the landscape and substantially less than the *Agriculture* CAP value, suggesting that the *Wetland* land cover type patches are relatively small but does not offer any suggestion as to whether patches are aggregated or not. Finally, when this comparison is completed on *Cultural Features* patches, it is revealed that a small surface area supports a small PN value, suggesting that patches are smaller and, like the *Wetland* land cover type, not offering a suggestion as to whether patches are aggregated or not. To confirm these assumptions and answer gaps, this analysis must be completed in conjunction with size and proximity landscape metrics.

While the PN and PD landscape metrics clarify the patch subdivision aspect of fragmentation, these metrics can only provide assumptions as to patch size. To clarify patch size AREA_MN can be referred to. Table 4.4 identifies that the *Agriculture* land cover type had the largest average patch size and the land cover type *Forest* had the smallest average patch size. Table 4.4 also identifies that the natural land ecosystem land cover types (i.e. *Forest, Range and Grasslands*, and *Wetlands*) in the sample site have substantially lower AREA_MN as compared to the human-influenced land cover types (i.e. *Agriculture* and *Cultural Features*). These values demonstrate that on average human-influenced land cover type patches are larger than patches of natural land ecosystems, and likely have a greater influence on patch dynamics on account of their size. However, to fully comprehend the effect of patches in the landscape it is necessary to understand patch size in relation to subdivision and contiguity.

As the AREA_MN value is dependent on the PN value, evaluating AREA_MN values in relation to PN values can help confirm if prior assumptions related to the aggregation of patches are true and help answer gaps as they relate to patch subdivision. Comparison of *Forest* AREA_MN values (Table 4.4) and *Forest* PN values (Table 4.3) reveals that the land cover type with the smallest average patch size also has the largest number of patches, indicating that the sample site landscape has many relatively small *Forest* patches. This demonstrates that *Forest* patches are fairly disaggregated and that the forest network is fragmented. When the analysis is completed for the *Range and Grassland* land cover type, similar results emerge. Comparison of *Range and Grassland* AREA_MN values (Table 4.4) and *Range and Grassland* PN values (Table 4.3) reveals that a land cover type with a fairly small average patch size, as compared to human-influenced land cover types, also has a fairly large number of patches, indicating that the landscape has many relatively small *Range and Grassland* patches. Like *Forest* patches, this suggest that *Range and Grassland* patches are fairly disaggregated and that the range and grassland network is fragmented. When *Agriculture* AREA_MN values (Table 4.4) are compared to its PN values (Table 4.3), it is revealed that the land cover type with the largest average patch size has a moderately low PN value as compared to *Forest* and *Range and Grassland.* This indicates that the landscape has less *Agriculture* patches, but that they are larger in size suggesting that patches are more aggregated, and the agriculture network is less fragmented. The *Wetland* land cover type analysis reveals that the land cover type has fairly small patches (Table 4.4) and fairly low number of them (Table 4.3). This suggest that while *Wetland* patches are smaller, they are more aggregated and the network less fragmented as compared to *Forest* and *Range and Grassland* networks. Finally, the *Cultural Features* analysis reveals that the land cover type has fairly large patches (Table 4.4) but that there are a low number of them in the landscape (Table 4.3). This suggests that while the *Cultural Features* patches are larger on average, they are more aggregated, and that the cultural feature network less fragmented.

While AREA_MN provides valuable information to compare land cover type patch sizes and evaluate against PN values, it does not provide information of the distribution of patch sizes within land cover type classes. Sophisticated statistical measures can address this issues, however, Leitao, et al. (2006) suggest that this issue can also be addressed in a simplified manner by a scatter plot of patch sizes as this will enable a rudimentary identification of land cover type patch size distribution and provide valuable insights into the sample site's patches (p. 91). Patch size distribution scatter plots (Figure 4.20, Figure 4.21, Figure 4.22, Figure 4.23, Figure 4.24) demonstrate that all land cover type AREA_MN values, with the exception of the *Forest* land cover type, are influenced by an outliner patch.

These discrete outlier patches are typically much larger in size than most other patches of similar land cover type, where outlier patch surface areas are approximately double the size of the next largest patch. These outlier values likely have an effect on AREA_MN values. Table 4.7 lists patch size lower and upper limit values and outlier values as demonstrated in the scatter plots. Figure 4.20, Figure 4.21, Figure 4.22, Figure 4.23, and Figure 4.24 demonstrate that when outliers are removed the distribution of patch sizes within land cover type classes display less variability in patch size and generally fall within a fairly evenly distributed patch size range. The range of patch size distribution demonstrated in Table 4.7 shows that *Forest* and *Range and Grassland* land cover types have their smallest patches at the lowest limit patch size possible in the sample set, whereas the smallest *Agriculture, Cultural Features*, and *Wetland* land cover types patches are considerably bigger. However, when upper limit patch sizes are considered *Forest* and *Range and Grassland* patches are considerably larger than *Cultural Features* and *Wetland* patches. This suggests that *Cultural Features* and *Wetland* patches have a narrower range of distribution of patch sizes as compared to *Forest* and *Range and Grasslands* patches who have a greater distribution of patch sizes. While patch size ranges differ between land cover types, this patch size distribution suggests that fragmentation processes have affected patches in similar way within sample site landscape and created a fairly even distribution of patch sizes across the land cover type classes. However, without more sophisticated statistical analysis, trends and correlations can not be assessed nor can their significance be evaluated; this was not completed as part of this practicum's research.

Figure 4.20 **Agriculture Land Cover Type Patch Size Distribution**

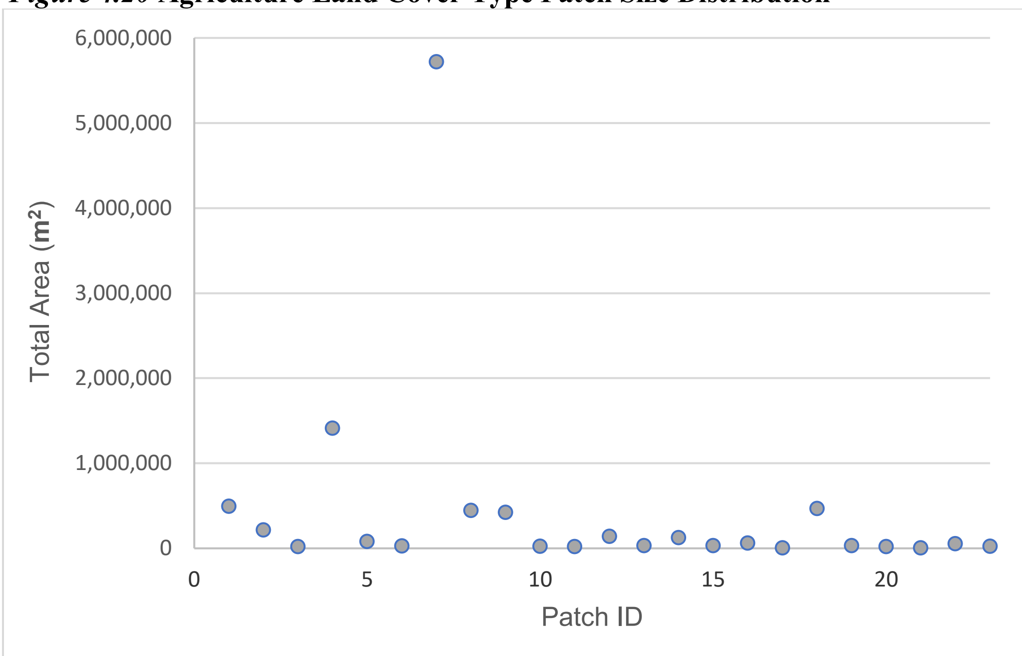


Figure 4.21 **Cultural Features Land Cover Type Patch Size Distribution**

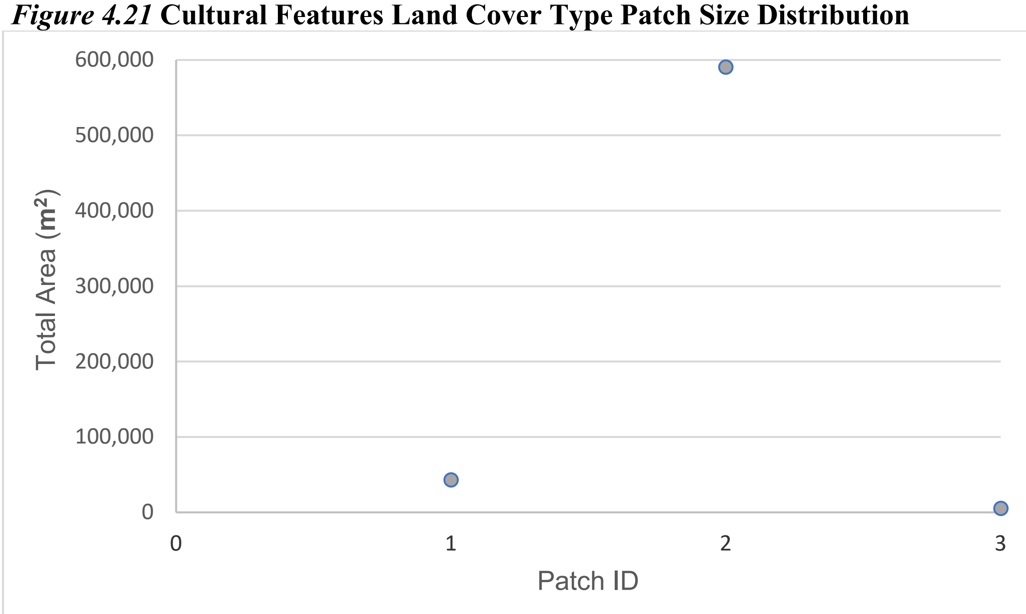


Figure 4.22 **Forest Land Cover Type Patch Size Distribution**

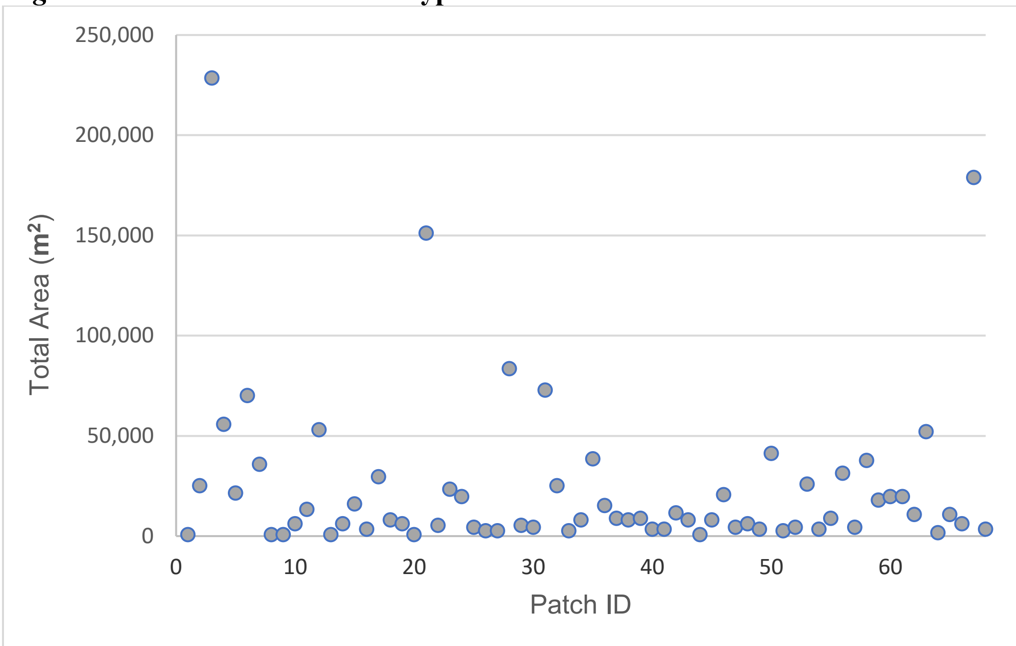


Figure 4.23 **Range and Grasslands Land Cover Type Patch Size Distribution**

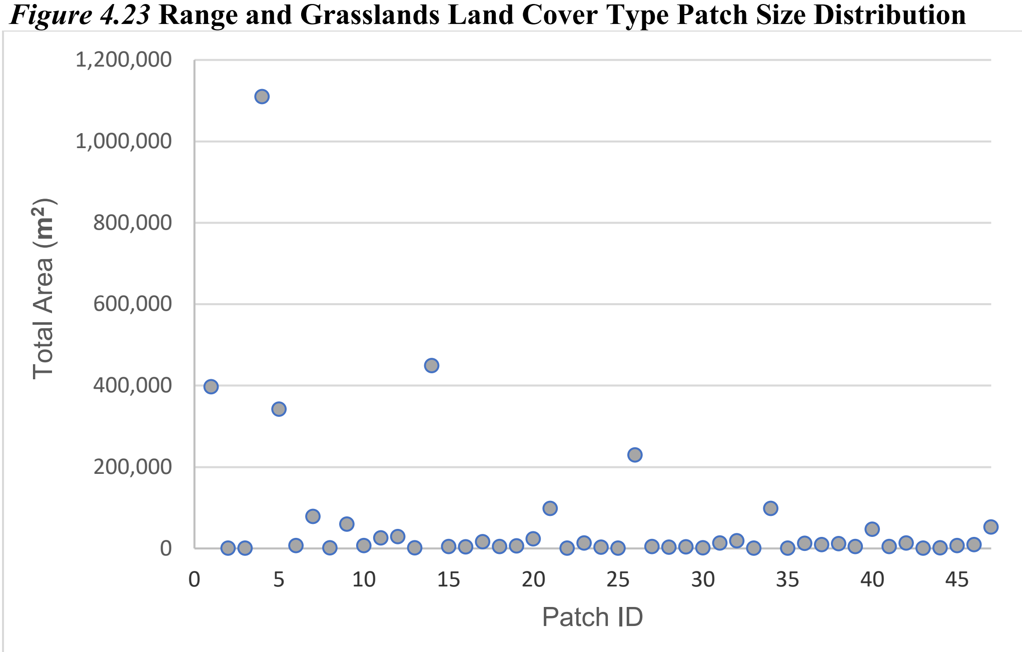


Figure 4.24 **Wetlands Land Cover Type Patch Size Distribution**

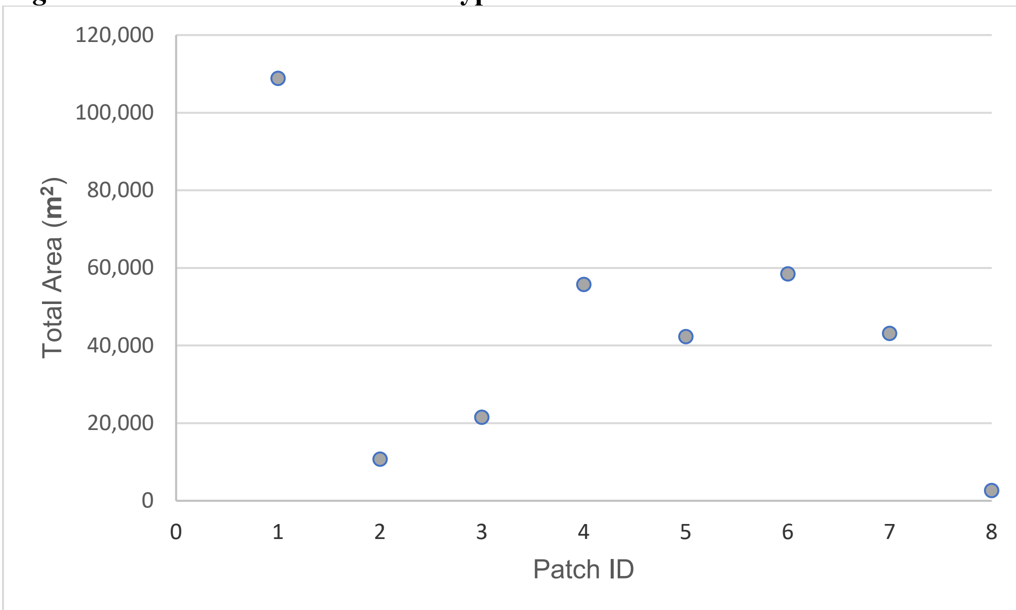


Table 4.7 **St Adolphe Sample Site Patch Size Limits and Outliers**

Land Cover Type	**Lower limit patch size (m^2)**	**Upper limit patch size (m^2)**	**Outlier (m^2)**
Agriculture	8,100	1,415,700	5,723,100
Cultural Features	5,400	43,200	590,400
Forest	900	228,600	N/A
Range and Grassland	900	449,100	1,109,700
Wetland	2,700	58,500	108,900

Figures 4.22, 4.23, and 4.24 can also be used to evaluate patch size to criteria set by guidelines for optimal natural ecosystem patch type size as listed in Table 2.2. Table 4.8 clarifies optimal patch size as per guidelines, the number of patches at or above the guidelines, and the largest patch size for each natural ecosystem land cover type. The results demonstrate how zero *Forest* patches meet the set guidelines for optimal patch size, where the largest patch in the sample site is approximately ten times smaller than optimal size. This would support the need to conserve at minimum the largest *Forest* patch in the sample site. The result also demonstrate that

one *Range and Grasslands* patch meets the set guidelines for optimal patch size. This would support the prioritization to conserve the large *Range and Grassland* patch to support and maintain associated biodiversity and ecological structures and characteristics. As the guidelines set aim to conserve a variety of wetland sizes, effort should be to maintain a range of wetlands of varying sizes especially those that contribute to landscape heterogeneity including the largest patch.

***Table 4.8*. St Adolphe Sample Site Patch Sizes in comparison to Guidelines**

Natural Ecosystem Land Cover Type	Optimal Patch Size Guideline	Number of Patches at or Above Guidelines Size	Largest Patch Size (hectares)
Forest	200 hectares	0	22.86
Range and Grasslands	100 hectares	1	110.97
Wetland	Various	0	10.89

Although PN, PD, and AREA_MN help quantify patch subdivision and size, they do not fully clarify issues of patch contiguity. To understand this element of landscape configuration and clarify gaps as they relate to patch isolation and fragmentation, the Proximity (PROX) landscape metric can be referred to. By analysing PROX values, the spatial distribution of specific patches across the landscape can be quantified, thereby allowing for better understanding of how patches are distributed across the landscape in relation to one and another and relative to a focal patch (Leitao, et al., 2006, p.146). In this way, PROX considers both patch number and patch area within its calculation and integrates key patch spatial characteristics within one analysis. As a unitless measure of patch isolation, PROX values allow the comparison of spatial configuration between patches in the landscape. Table 4.5 identifies that the *Agriculture* land cover type had the largest average PROX_MN value and the land cover type *Cultural Features* had the smallest PROX_MN value. Table 4.5 identifies that *Agriculture* and

Range and Grassland land cover types have much larger PROX values than *Cultural Features, Forest*, and *Wetland* land cover types. Comparing land cover type PROX values in relation to PN and patch area values can provide some context to these PROX values.

When the *Agriculture* land cover type is compared to the *Forest* land cover type, it becomes evident that PROX values are affected by the clear distinctions between land cover type CAP, PN, and surface area values. The *Agriculture* land cover type has fewer patches (Table 4.3) but patches are much larger on average than those of *Forest* land cover type patches (Table 4.4), suggesting that the *Forest* land cover type has been more fragmented over time and converted into smaller patches as a result. As a result, the sample site contains larger neighbour *Agriculture* patches, some much larger (Figure 4.20), which results in substantially larger PROX values. On the other hand, the sample site contains many small neighbour *Forest* patches (Figure 4.22), that when combined with its relatively small total surface area occupied (Table 4.1) results in smaller PROX values. These conclusions support prior assumptions that *Agriculture* patches form a fairly connected network of aggregated, large patches, whereas *Forest* patches form a fairly fragmented network of disaggregated, small patches.

When the *Agriculture* land cover type is compared to the *Range and Grassland* land cover type a similar pattern emerges. While the *Range and Grassland* land cover type has fewer patches than the *Forest* land cover type, there are more *Range and Grassland* patches than the *Agriculture* land cover type (Table 4.3), where on average *Agriculture* patches are larger than the *Range and Grassland* patches (Table 4.4). This suggest that the *Range and Grassland* land cover type has been more fragmented over time and converted into smaller patches as a result, ensuing in small neighbour patches and resulting in smaller PROX values as compared to *Agriculture* patches. When *Forest* and *Range and Grassland* land cover types are compared it becomes evident that the *Range and Grassland* land cover type has fewer patches than the *Forest* land cover type (Table 4.3), suggesting that the *Forest* land cover type has been more fragmented than the *Range and Grassland* land cover type and more converted into smaller patches. As a result, the sample site contains larger neighbouring *Range and Grassland* patches as compared to *Forest* patches, which results in a larger PROX values. Again, these conclusions support prior assumptions that *Range and Grassland* patches form a fairly fragmented network of disaggregated, small patches as compared to the *Agriculture* patch network, but that the network is formed of larger, more aggregated patches than the *Forest* patch network.

When the *Wetland* land cover type is compared to other land cover types a different pattern emerges. Table 4.3 identifies that there are few *Wetland* patches in the sample site and that patches are of moderate size as compared to other land cover type patches (Table 4.4). Consequently, this should result in larger PROX values, however, because of the small total area occupied by *Wetland* patches (Table 4.1) smaller PROX values are the result. This suggest that while *Wetland* patches are smaller, they are more aggregated and the network less fragmented as compared to *Forest* and *Range and Grassland* patch networks but less aggregated and more fragmented as compared to the Agriculture patch network. This supports the prior assumption that *Wetland* patches form a different type of network than *Agriculture*, *Forest*, and *Range and Grassland* patches, one that is formed of aggregated, small patches.

Finally, when the *Cultural Feature* land cover type is compared to other land cover types a distinct pattern emerges but one that more closely resembles *Wetland* patches. Table 4.3 identifies that there are a low number of *Cultural Features* patches in the sample site and that patches are of moderate size as compared to other land cover types. Like *Wetland* patches this should result in larger PROX values, but again like *Wetland* patches, the small total area occupied by *Cultural Features* patches (Table 4.1) effects PROX measurements and results in smaller PROX values. This suggest that while *Cultural Features* patches are relatively smaller, they are more aggregated and the network less fragmented as compared to *Forest* and *Range and Grassland* patch networks but less aggregated and more fragmented as compared to the *Agriculture* patch network.

While PROX allows for comparative spatial configuration analysis between land cover types, it also enables spatial configuration patterns to emerge within land cover types classes. These patterns can support the identification of key patches as well as opportunities to better connect the landscape. To identify such factors, PROX value distribution can be referred to. When the *Range and Grassland* land cover type patch PROX value distribution is analyzed Figure 4.7 demonstrates that four broad classes of PROX values emerge: 1) >1200; 2) 600 – 1200; 3) 400 – 600; 4) <400. While PROX value classes are all composed of a number of patches each with a varying frequency of neighbour patches within a 500m buffer, all are similar in that composite patch PROX values are generally composed of one to two patches of high PROX value neighbour patches and several neighbour patches of low PROX value. This trend appears in all PROX value classes. As well, patches with PROX values in classes above 400 all share the similar characteristic that high PROX value patches share common high PROX value neighbour patches. For example, nine patches have PROX values that fall within the >1200 class (Figure 4.7). While a differing number of neighbour patches ranging from one to twenty-three contribute to PROX values, one high PROX value neighbour patch is common among all patches. This trend is demonstrated in all PROX value classes above 400 (Table 4.9, Table 4.10, Table 4.11). Whereas, PROX values within the <400 PROX value class do not generally share a common high PROX value neighbour patch, where there is a greater range of neighbour patches

PROX values. This indicates that the patches within PROX values classes above the 400 are clustered around a common neighbour patch that is fairly large and located relatively near to focal patches at a common distance, while patches with PROX values below 400 have smaller neighbour patches that are located relatively further away from the focal patch and less clustered together.

Table 4.9 **Range and Grassland Patch PROX Value Class >1200**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High Value PROX Neighbour Object ID/PROX value
2	1242	4	4/1233
8	1235	4	4/1233
14	1312	23	4/1233
31	1236	4	4/1233
36	1266	6	4/1233
39	1240	6	4/1233
40	1269	11	4/1233
41	1262	8	4/1233
42	1233	1	4/1233

Table 4.10. **Range and Grassland Patch PROX Value Class 600-1200**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High Value PROX Neighbour Object ID/PROX value
4	675	27	14/499
11	608	8	14/499

Table 4.11. **Range and Grassland Patch PROX Value Class 400-600**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High Value PROX Neighbour Object ID/PROX value
3	454	3	1/441
10	513	12	14/499
15	513	11	14/499
16	518	12	14/499
18	503	10	14/499
20	451	4	1/441
22	499	9	14/499
24	499	2	14/499
37	512	2	14/499

While *Forest* land cover type patch PROX values are lower than those of the *Range and Grassland* land cover type patch PROX values, their distribution demonstrates a similar pattern to the *Range and Grassland* land cover type. Figure 4.6 demonstrates that three broad classes of PROX values emerge: 1) >250; 2) 100 – 250; 3) <100. Again, PROX value classes are all composed of a number of patches each with a varying frequency of neighbour patches within a 500m buffer, but all are similar in that composite patch PROX values are generally composed of one to two patches of high PROX value neighbour patches and several neighbour patches of low PROX value. This trend appears in all PROX value classes. Like the *Range and Grassland* land cover type patches, *Forest* patches above a certain value, in this case patches with PROX values above 250, share the similar characteristic that high PROX value patches share common high PROX value neighbour patches. For example, five patches have PROX values that fall within the >250 class (Figure 4.6). While a differing number of neighbour patches ranging from eight to thirteen contribute to patch PROX values, one neighbour high PROX value patch is common among all patches (Table 4.12). However, patches with PROX values below 250 may not share a common high PROX value neighbour patch, where there is a greater range of neighbour patches PROX values.

Table 4.12 **Forest Patch PROX Value Class >250**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High PROX Value Neighbour Object ID/PROX value
4	257	11	3/254
12	265	13	3/254
13	256	8	3/254
16	256	10	3/254
19	260	12	3/254

In the 100-250 PROX value class some patches share common high PROX value neighbour patches (Table 4.13), whereas patches found within the <100 PROX value class do not generally share a high PROX value neighbour patch. This indicates that the patches within the PROX value class > 250 are clustered around a common neighbour patch that is fairly large and located relatively near to focal patches at a common distance. It also indicates that patches with PROX values within the 100-250 class may be clustered around common neighbour patches that are fairly large but that are located at various further distances from focal patches, while patches within the PROX value class of <100 have smaller neighbour patches that are located relatively further away from the focal patch and less clustered together.

***Table 4.13*. Forest Patch PROX Value Class 100-250**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High PROX Value Neighbour Object ID/PROX value
3	141	16	4/62 & 12/59
11	170	5	21/168
33	216	7	21/168
35	198	11	21/168
46	100	6	28/93
61	206	7	67/199

The *Wetland* land cover type patch PROX values are lower than those of both the *Range and Grassland* and *Forest* land cover types patch PROX values, but their patch PROX value distribution demonstrates a somewhat similar pattern. Figure 4.8 demonstrates that three broad classes of PROX values emerge: 1) >100; 2) 40-60; 3) <40. Wetland PROX value classes are all composed of a number of patches with a frequency of one to three neighbouring patches within a 500m buffer. Because of the low number of neighbour patch PROX values associated with focal patches, patch PROX values are generally composed of a single high PROX value neighbour patch and one or two low PROX value patches. Unlike the *Range and Grassland* and *Forest* land cover type patches, *Wetland* patches do not share common high PROX value neighbour patches in any of the patch PROX value classes (Table 4.14). For example, two patches have PROX values that fall within the 40-100 class (Figure 4.8). Each patch has a low number of neighbour patches ranging from one to two that contribute to patch PROX values, and both have different high PROX value neighbour patches (Table 4.14).This indicates that the patches within PROX value classes of >100 and 40-100 may be clustered with a low number of neighbour patches that are relatively large and located relatively near to the focal patch at a common distance. It also indicates that patches with PROX values of <40 have smaller neighbouring patches that are located relatively further away from the focal patch.

Table 4.14 **Wetland Patch PROX Value Classes >100 and 40-60**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High PROX Value Neighbour Object ID/PROX value
8	110	2	4/62 & 7/48
5	65	2	6/65
6	47	1	5/47

The *Agriculture* land cover type also exhibit similar PROX value distribution patterns, however PROX values are larger than natural ecosystem-based land cover type PROX values. Figure 4.4 demonstrates that three broad classes of PROX values emerge: 1) >6000; 2) 500-2000; 3) <500. PROX value classes are all composed of a number of patches each with a varying frequency of neighbouring patches within a 500m buffer, but all are similar in that composite patch PROX values are generally composed of one to two patches of high PROX value neighbouring patches and several neighbouring patches of low PROX value. This trend appears in all PROX value classes. Like the natural ecosystem land cover type patches, high PROX value *Agriculture* patches (i.e. >6000) share a common high PROX value neighbour patch. For example, three patches have PROX values that fall within the >6000 class (Figure 4.4).While the number of neighbour patches that contribute to patch PROX values is different between patches, either three or four, one neighbour high PROX value patch is common among all patches (Table 4.15). However, patches with PROX values below 2000 may not share a common high PROX value neighbour patch, where there is a greater range of neighbour patches PROX values. In the 500-2000 PROX value class some patches share common high PROX value neighbour patches (Table 4.16), whereas patches found within the <500 PROX value class do not generally share a high PROX value neighbour patch. This indicates that the patches within the PROX value class >6000 are clustered around a common neighbour patch that is fairly large and located relatively near to focal patches at a common distance. It also indicates that patches with PROX values within the 500-2000 class may be clustered around common neighbour patches that are fairly large but that are located at various further distances from focal patches, while patches within the PROX value class of <500 have smaller neighbour patches that are located relatively further away from the focal patch and less clustered together.

Table 4.15 **Agriculture Patch PROX Value Class >6000**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High PROX Value Neighbour Object ID/PROX value
2	6364	3	7/6359
8	6830	4	7/6359
21	6363	3	7/6359

Table 4.16 **Agriculture Patch PROX Value Class 500-2000**

Patch Object ID	Composite PROX Value	Number of Neighbouring Patches	High PROX Value Neighbour Object ID/PROX value
1	1312	7	7/1272
6	982	5	1/550 & 7/397
7	937	11	2/242 & 8/496
9	1022	7	7/489 & 8/496
10	546	6	9/471
19	1664	5	7/1590

Finally, when *Cultural Features* PROX value distribution is evaluated a different pattern emerges. Figure 4.5 demonstrates that the *Cultural Features* land cover type only has three patches in the landscape and that no distinct PROX value classes emerge. Figure 4.5 also demonstrates that one patch has a PROX value of zero; this indicates that the patch does not have any neighbour patches within the 500m buffer. PROX values for the remaining patches indicate that patches are clustered relatively near to each other and that one patch is larger than the other.

The PROX analysis allowed for land cover type spatial patterns to emerge by identifying the discrete patch network for each natural ecosystem land cover type and enabled the recognition of "near lines" (Appendix F) that enabled the identification of patch clusters Figure 4.9, Figure 4.10, Figure 4.11). When analyzed, it becomes apparent that there are clusters of "near lines" present within each natural ecosystem land cover type where clusters represent a conglomeration of near lines that are denser than in other areas in the sample site. When these clusters of near lines are isolated, distinct cluster shapes become apparent providing insight into the spatial character of the landscape (Figure 4.9, Figure 4.10, Figure 4.11). The influence of PN values on clusters becomes apparent when clusters are compared across natural ecosystem land cover types. The *Forest* and *Range and Grasslands* land cover types have relatively high PN values (Table 4.3) whereas the *Wetland* land cover type has a relatively low PN value (Table 4.3); clusters reflect this as the *Forest* and *Range and Grasslands* clusters have many more "near lines" as compared to the *Wetland* clusters. Then, PN values influence how many clusters form in the landscape where the more patches present in the landscape resulted in more clusters. The PROX analysis also identified high PROX value patches (Tables 4.10 to 4.17). Interpretation of PROX calculations reveals two key points: 1) Common high PROX value neighbour patches, and 2) High PROX value patches are often connected to common high PROX value patches. This suggests that common high PROX value neighbour patches have influence on landscape dynamics on account of their size and their proximity to focal patches, especially high PROX value focal patches.

These results suggest that conservation efforts could be focused on the common high PROX value patches as well as the high value focal patches. Connectivity efforts could be focused towards areas identified by the “near lines” between them. Together, the identified patches and “near lines” can be considered as key to conservation and restoration. When highlighted on maps, all key patches and “near lines” fall within identified clusters with the exception of one *Range and Grassland* patch and associated “near line” (Figure 4.9, Figure 4.10, Figure 4.11). While not considered key patches and “near lines”, several low PROX value patches are also found within clusters. In terms of the *Forest* land cover type patch network, three clusters do not contain any key patches and “near lines”, whereas all *Range and Grassland* and *Wetland* clusters have a mixture of key and non-key patches and “near lines”. The maps produced present a way to visualize these results and identify the discrete patch cluster patterns that could serve as the basis for planning an ecological network in the sample site.

Following this logic, the identified clusters were used to define the ecological network of the St Adolphe sample site. When discrete patch clusters are joined a distinct shape and arrangement of an ecological network emerges (Figure 4.19) and a way is provided to visualize where to focus conservation and restoration of the ecological network. When key patches and “near lines” of the ecological network are identified (Figure 4.19) a way is provided to visualize where to prioritize conservation and restoration as it relates to areas of most value to supporting biodiversity and maintaining ecological structure and characteristics.

However, planning for the ecological network requires an understanding of the land use policy framework context and other land cover types in relation to patch networks as they may present opportunities and barriers to conserving patches and enhancing their connectivity. When patch clusters are analyzed in relation to policy areas and waterway and wetland buffer layer areas (Figure 4.12) several observations can be made. In terms of the *Forest* land cover type patch network, much of the clusters and key patches and "near lines" occupy space within either Environmental Policy Areas or within a waterway and wetland buffer layer area. This is also true for the *Wetland* land cover type patch network, and while true for the *Range and Grassland* land cover type patch network it is to a lesser degree. When not occupying space in either the Environmental Policy Areas or within a waterway and wetland buffer layer area, *Forest* patches and clusters are largely found in the Urban Centre Policy Area and to a lesser degree in the Green/Agricultural Policy Area (Figure 4.13). Whereas when not occupying space in either the Environmental Policy Areas or within a waterway and wetland buffer layer area, *Range and Grassland* patches and clusters are largely found Green/Agricultural Policy Area and to a lesser degree in the Urban Centre Policy Area (Figure 4.14). The *Wetland* land cover type patches and clusters are all found within either the Environmental Policy Areas or within a waterway and wetland buffer layer area (Figure 4.15). These findings provide the land use policy context required to better understand how existing land use designation policy areas could support conservation of key patches and enhance connectivity through the preservation and restoration of natural ecosystems in areas identified as key patches and key "near lines".

Another key land use policy to consider in understanding the planning context is the Designated Flood Area Regulation as it identifies the RM of Ritchot within the Red River Designated Flood Area. The Water Resources Administration Act "prohibits the building, construction, erection of any building structure or erection other than a fence as well as prohibits the alteration or change of land within a Designated Flood Area" (Province of Manitoba, 2018a, p. 25). However, the Designated Flood Area Regulation provides the floodproofing criteria that enables construction and relocation of structures to occur if in compliance to three provisions: 1) located within a designated dyking system; 2) on a site elevated above the stipulated flood protection level; and 3) within a dyke constructed to listed standards (Province of Manitoba, 2002, p. 3). As such, development is restricted in the municipality. This provides the policy context that could support an opportunity to conserve natural land as by requiring development occur in areas with existing flood protection development can be focused toward existing settlement with appropriate flood protection and away from natural lands. In the sample site, this would mean focusing development within existing settlement, illustrated by the *Cultural Features* land cover type, as it has existing flood protection. In addition, the requirement to construct a dyke to listed standards may potentially be seen as an additional burden and risk that may deter development, which could further support the conservation of natural lands. Furthermore, if natural lands can be found to provide flood mitigating ecosystem services, the policy context may potentially restrict their conversion to land uses that reduce the landscape capacity to provide flood protection. This would require further understanding of the abiotic biophysical characteristics to determine the capacity of the landscape to mitigate flooding, however, conserving natural ecosystem types that support flood mitigation (see Table 2.1) could protect the biotic elements that support these functions.

Other land cover types may also play an important role in either facilitating or creating a barrier to planning an ecological network. When patch networks are analyzed in relation to other land cover types several observations can be made. Figure 4.16, Figure 4.17, and Figure 4.18 demonstrate that many of the *Forest, Range and Grassland*, and *Wetland* clusters form shapes that either follow the form of waterways or have waterways that intersect the cluster; this may present a physical barrier to connecting patches. However, the location of cluster shapes may also reflect other biophysical characteristics that form ecological structures and characteristics, and as such these physical barriers may be an essential character of the ecosystem cluster. However, the researcher recognizes that to fully understand what influences the formation of clusters will also require a closer investigation of abiotic biophysical characteristics that shape the landscape and impact the establishment of land cover types. This will support a better understanding of the degree other land cover types either facilitate or create a barrier to ecosystem cluster integrity and ecological network connectivity.

Another common physical barrier observed in Figure 4.16, Figure 4.17, and Figure 4.18 is the *Infrastructure* land cover type, where on several occasions this land cover type was found in areas of the *Forest, Range and Grasslands*, and *Wetland* patch networks identified as a key "near lines". Other natural ecosystem land cover types were also often found to be the land cover type intersecting like patch types. For example, *Forest* and *Range and Grassland* are patches regularly found in near proximity to each other and are often the patch type impeding like patch type connectivity (Figure 4.16, Figure .17, and Figure 4.18); this is less so with the *Wetland* land cover type patches. While the *Agriculture* land cover type is also found in several *Forest* and *Range and Grassland* clusters, it less pronounced than other land cover types. However, when present it often occupies a large portion of the cluster. Finally, Figure 4.16, Figure 4.17, and Figure 4.18 demonstrate that the *Cultural Features* land cover type has a limited presence in clusters where it is most present in the *Range and Grassland* clusters. These findings suggest that the location of the cluster has an effect on what other land cover types are present. In clusters that form near waterways or have waterways that intersect it, often other natural ecosystem land cover types will most often occupy the cluster, whereas clusters that form away from waterways are generally more occupied with human-based land cover types. These findings provide the context required to better understand how other existing land cover types may create barriers to enhancing connectivity of like patch types and offer insight into how other land cover types interact with like patch networks.

4.3 Summary

The research completed as part of this chapter attempted to interpret what calculated landscape metrics revealed about the St Adolphe sample site's land cover type landscape composition and configuration. The chapter outlined quantitative findings based on eleven calculations adapted from six landscape metrics included in the Sustainable Land Planning Framework and generated associated ArcGIS maps to visually communicate results. The chapter provided an analysis of these findings and identified the sample site's landscape composition and configuration. The chapter identified landscape composition in terms of Patch Richness, Class Area Proportion, and Shannon's Index landscape metrics. This revealed what land cover types composed the landscape, the proportional area they occupied, quantified land cover type diversity and evenness, and clarified if there was the presence of a landscape matrix. The chapter clarified the spatial arrangement, spatial character, and organization of the landscape by its analysis and interpretation of landscape configuration results obtained through the Patch Number and Density, Mean Patch Area, and Proximity landscape metrics. This revealed the components of the landscape mosaic, where land cover types were located in the sample site, their configuration, whether patches were aggregated or isolated, and provided insight into their contiguity. In this way, the chapter defined the ecological network in the context of the network of natural ecosystem patches, their association to other natural ecosystem land cover types as well as human-based land cover types and clarified their relationship to the planning context present. Finally, the chapter provided information to clarify areas ideal for natural ecosystem conservation and restoration that can enhance patch connectivity, support biodiversity and maintain ecological structure and characteristics by identifying patch clusters, and key patches and “near lines”. The next chapter discusses these results in attempt to synthesize findings.

Chapter 5: Synthesis

This chapter presents the synthesis of the research discussed in the Chapter 2 Literature Review and Chapter 4 Results and Analysis. The findings discussed in this chapter can be distilled into three broad themes that follow research questions:

- Classifying and Quantifying Landscape Composition and Configuration;
- Defining the Ecological Network and Identifying Opportunities for Connectivity; and
- Utility to the RM of Ritchot and Winnipeg Metropolitan Region.

The chapter will present the synthesis of research according to these three themes.

5.1 Classifying and Quantifying Landscape Composition and Configuration

5.1.1 Classification of Land Cover Types

A key objective of this practicum was to develop a tool to better communicate ecological network planning to planners and decision-makers. The literature review revealed that one of the goals of ecological network planning is to illustrate the ecological network to visually communicate how to protect and restore important landscape structures and functions. Quantifying landscape composition and configuration are key to this process as it enables insight into the current landscape structures and their spatial patterns. However, prior to quantifying landscape composition and configuration, developing an appropriate classification system is critical. The research revealed that while the researcher is free to apply the classification system of their choosing, quantification of landscape composition and configuration is sensitive to the classification system used. The research completed suggests three key explanations for this.

First, classification systems reflect the goals and objectives of the desired ecological network. the wide range of contexts, spatial scales, species and processes that can be considered in defining landscape components inherently makes ecological network planning a complex exercise (Firehock, 2015; Benedict, et al., 2006). Furthermore, the inclusion of ecological network planning into the land use planning process has created a need to include the human dimension and a multifunctional land use perspective, further complicating the definition of landscape components. Then, clear explicit goals and objectives can clarify the focus of the ecological network and allows for key landscape components to emerge (Leitao, et al., 2006). The literature review clarified that ecological network planning is generally focused on conserving natural lands and better linking them to form a cohesive network. Then, by identifying the landscape components of importance clarification of the landscape structures and functions is possible. This enables a better understanding of the natural lands that the ecological network wishes to conserve and better link as well as provides the necessary context required to classify landscape components that will support their appropriate quantification.

The ecological network plans and strategy reviewed in the precedent review reflected this understanding as their classification systems were based on their respective goals and objectives. While the plans and strategy had the goal to form cohesive networks of natural lands, the distinct objectives set reflected the local context, spatial scale, species and processes of concern. This allowed for the identification of important landscape components and for individual perspectives to emerge in classification systems. For example, the Ottawa plan focused their ecological network on green spaces that serve one of two purpose: to either provide recreation and leisure activities or preserve natural areas and environmental systems, whereas the Edmonton strategy and HRM plan included more nuanced multifunctional objectives by focusing on open/green spaces that either provided an ecological or a cultural purpose, where cultural took on several meanings like community shaping, outdoor recreation, working landscapes and wellness. This resulted in the identification of landscape ecological and human components relevant to desired objectives and the development of classification systems that reflected distinct objectives. In this way, the subsequent quantification of ecological network composition and configuration reflected a classification system based on desired goals and objectives.

Furthermore, landscape ecology explains how identifying ecosystems to conserve and better link relies on understanding the biophysical characteristics of a landscape as this clarifies how landscape composition and configuration are established (Lovett, et al., 2005; Forman, 1995; Leitao et al., 2006). This practicum had an objective to define an ecological network that reduces biodiversity loss and supports the continued provision of ecosystem services. While the research acknowledged the influence of both biotic and abiotic biophysical characteristics of the landscape on biodiversity and ecosystem services, this practicum focused on defining the ecological network as it relates to the biotic characteristics of ecosystems. Chapter 4 demonstrated how this objective influenced the classification established and resulted in a classification system that focused on the biotic biophysical characteristic of land cover type. Had the practicum had an objective for the ecological network to achieve, as for example enhancing a specific ecosystem service like water management or climate regulation, greater understanding of abiotic biophysical characteristics would likely have been required. This would have resulted in a different classification system applied as the quantification of landscape composition and configuration would need to reflect relevant abiotic biophysical characteristics.

Second, classification systems reflect the referenced dataset. The research demonstrated that a key component to planning an ecological network involves understanding the relationship between ecosystems and their spatial patterns and characteristics. To address this, ecological network planning relies on mapping instruments like GIS and associated datasets to identify and illustrate landscape components and biophysical characteristics of concern. In doing so, elements of the physical environment are clarified, and ecological network information is generated that can support the planning process involved in creating and amending the comprehensive community plan. While it is suggested that maps generated should use the most current datasets available and analysts should avoid compiling datasets and creating hybrid data (Benedict, et al., 2006), Chapter 4 demonstrated that this may be unavoidable unless the analyst has access to a wide range of current data sources or a capacity to produce primary data. This practicum did not have the capacity to generate primary data. As a result, this research relied on publicly accessible data to generate the baseline maps and feature attributes needed to support the classification of landscape components. This resulted in a classification system reliant on outdated datasets which may have inherently produced quantitative results that no longer represent the current state of the landscape. The capacity and knowledge required to generate current datasets may not be available in WMR municipalities like the RM of Ritchot and may affect their ability to address emerging issue like biodiversity loss and climate change. Then, finding ways to access more current and complete datasets could help ensure maps generated and subsequently classification systems developed better reflect the current state of the landscape and enable more accurate quantification of landscape composition and configuration.

Third, classification systems reflect the distinctions made by the analyst. To ensure proper interpretation of produced maps and associated attributes, classification systems should be expressed at a similar resolution, include all landscape components relevant to the set goals and objectives, and use explicit criteria to interpret categories (Leitao, et al., 2006, p. 55). While a classification system may rely upon the datasets available, how datasets are interpreted and distinguished is dependent on the analyst and can have impacts on quantitative results generated; this was demonstrated in quantitative mapping analysis undertaken. The land cover type dataset used in the research included a total of 17 land cover types, however, the land cover types included in the analysis were refined to only those present in the RM of Ritchot and subsequently the sample site of St Adolphe. In doing this, land cover types not included in the sample site were excluded. This distinction inherently expressed a particular hierarchal scale, where the research focused on a site level scale rather than the greater region. Furthermore, to avoid differences of interpretation and ensure consistency among land cover type classifications, the researcher joined similar land cover type sub classes together to form a larger class. This explicit classification criteria affected the number of land cover type categories created and had an impact on quantitative results. For example, Chapter 4 demonstrated how the calculated Patch Richness (PR) value equaled 7, however, had sub classes not been joined this value would have increased to 9. By including only land cover types found in the sample site and by joining sub classes of land cover types, explicit distinctions were made that influenced how the classification system was expressed thereby having an effect on all subsequent landscape metric measurements. The difficulty in this lies in ensuring the distinctions made to the classification system continue to support a landscape evaluation that provides an accurate representation of the landscape.

In general, defining an appropriate classification system is a critical step to understanding landscape composition and configuration. Without considering all the factors that influence how a classification system is expressed can lead to a misrepresentation of landscape components and affect how the current state of landscape composition and configuration is quantified.

5.1.2 Quantification of Landscape Composition and Configuration

Before the ecological network can be defined and opportunities for connectivity identified, getting an understanding of the landscape's composition and configuration is critical.

Landscape ecology principles explored in the literature review demonstrated the increasing interest in enhancing functional connectivity as a way to address the need to conserve ecosystem services. Then, to develop an ecological network that facilitates functional connectivity attention must be paid to not only the composition of landscape structures but also to the configuration of structures as they both independently and interactively affect the level of function expressed by ecological processes and subsequently the ecosystem system delivered (Leitao et al., 2006). Reducing biodiversity loss through conservation of ecosystems and their restoration in areas that enhance functional connectivity can facilitate this. However, this requires a better understanding of the spatial composition of landscape structures as it identifies the landscape mosaic and clarifies spatial heterogeneity and configuration, key elements to understanding the interactions between landscape components and incorporating connectivity. Landscape metrics that evaluate the type, area, size, location and proximity of landscape structures were identified as a way to enable this better understanding as they provide insight into assemblages of biological landscape structures, their current state in the landscape, and the effects spatial patterns have on ecological processes. This clarifies spatial heterogeneity and configuration and facilitates the identification of areas ideal for conservation and restoration of connectivity.

Reducing the confusion surrounding the selection and interpretation of landscape metrics is key to ensuring landscape composition and configuration quantify the landscape in a manner relevant to the determined goals and objectives. The Sustainable Land Planning Framework (SLPF) provided the guidance needed to select appropriate landscape metrics that enabled the evaluation of factors identified as critical to quantifying landscape composition – Patch Richness, Class Area Proportion and Shannon's Index – and configuration – Patch Number and Density, Mean Patch Size, and Proximity. By providing an understanding of the concepts behind landscape metrics, how to calculate them, and their utility and limitations, the SLPF simplifies the selection of landscape metrics and facilitates the integration of ecosystem and biodiversity expertise into the planning process. However, a limitation of the SLPF is that it did not provide guidance as to how patches should be defined. Because the land cover type shape files used in this research did not aggregate contiguous polygons of the same land cover type, this practicum considered patches as aggregate polygons of similar land cover type found within a 1m buffer. While this accommodated data collection and interpretation at a sample site scale, this is a limitation for the municipal and regional scales as this buffer may not be an accurate reflection of patches at higher scales. Furthermore, should this buffer be maintained for higher scales a complex data collection and interpretation process would likely result. Then, better alignment between how patches are defined, and the scale of analysis would allow for the quantitative mapping analysis to be more robust and optimized for the appropriate scale.

Another limitation of the SLPF did not offer instructions on how to acquire the data needed to apply to landscape metrics beyond specifying that data is acquired through digital mapping analysis. Chapter 4 demonstrated how reliant the SLPF is on digital mapping analysis, as all landscape metrics relied on quantitative data generated from spatial analysis completed with the ArcGIS digital mapping program. The ArcGIS program facilitated the collection of data needed to quantify the landscape and evaluate ecosystem type, area, size, location and proximity, which enabled the true representation of the landscape mosaic form and its patterns to emerge. However, this could be problematic for municipalities who lack digital mapping analysis knowledge and capacity as quantifying landscape composition and configuration would be substantially more difficult and complex without the use of sophisticated spatial analysis tools like ArcGIS. Furthermore, should a similar exercise be completed on a higher hierarchal scale, as for example the entire municipality or at the regional scale, there would be a substantial increase in data generated which would prove to be much more difficult and complex to manage and analyze, if not impossible, without the use of tools like ArcGIS.

Although mapping analysis can be problematic for the reason discussed above, should a municipality be able to generate the necessary data, the SLPF provided a simple and easy way to build a comprehensive picture of the landscape's composition and spatial patterns at a particular moment in time. This provided a method to quantify landscape composition and configuration at different time periods and allowed for a series of maps to be developed that could be used to evaluate and visually represent land transformation through time (Leitao, et al., 2006, p. 49). However, two limitations were presented with the quantitative mapping analysis. First, the mapping analysis was completed on a sample site and therefore does not reflect the ecological network present in the municipality. This map produced identified the presence of a riverscape and reflected the low-lying ecosystems present in the municipality and did not reflect the upland ecosystems. As such, should the quantitative analysis be completed on the entirety of the municipality composition and configuration would be different and reflect different landscape dynamics.

Second, the quantitative mapping analysis was unable to quantify historical land cover type change. The research used historical maps to assess land transformation through time. However, because historical maps generally do not share the same goals and objectives to identify ecosystems to conserve and restore connectivity, the distinct classification system applied, scale represented, and context will likely not reflect the similar conditions reflected if maps were all constructed based on a similar classification system, scale and SLPF evaluation criteria. This impacts the ability of the analyst to quantify landscape composition and configuration of historical maps, and therefore impacts the ability to assess land transformation through time. While the research used historical maps to quantify the landscape, this was limited to the Patch Richness (PR) landscape metric as this metric did not rely on spatial data to quantify its value. Furthermore, the historical PR values determined in the research are limited in their comparison as the historical maps did not share similar classification systems, scale, and context. While the comparative analysis provided some broad historical land transformation context on ecosystem type and location, it failed to provide historical context on ecosystem area, size, and proximity. Without quantifying these key criteria, an accurate depiction of landscape composition and configuration change through time is not possible. This may require that environmental reconstruction techniques like electronic capture (i.e. digitizing) and interpretation of coverage extent be employed with programs like ArcGIS to create a visualization of historical context (Hanuta, 2001). However, in the absence of such ability, land use planners may need to rely on historical maps to make broad level assumptions that can inform decisions on where to conserve ecosystem and restore their connectivity.

5.2 Defining the Ecological Network and Identifying Opportunities for Connectivity

Since biodiversity loss and climate change are increasingly creating vulnerabilities for communities, ecological network planning has emerged as a way to maintain ecologically beneficial spatial arrangements of land cover types that support biological diversity and ecological function (Sauchyn & Kulshreshtha, 2008; Leitao et al., 2006, p.xvii). The literature review revealed how a pattern-oriented structural analysis can clarify underlying ecological function through the analysis of ecological structures, and provided the analytical data needed to identify how to better connect a fragmented ecosystem network and ensure the conditions necessary for their continued function are considered in the planning process (Battisti, 2013;

Zhang, & Wang, 2006; Forman 1995). First, this includes identifying the attributes that characterize the study area through gathering and analyzing data on key attributes and using landscape metrics to quantify their composition and configuration. Completing this with the use of mapping analysis tools enables a comprehensive picture of the landscape to emerge and provides the necessary information needed to define components of the ecological network. Second, this includes identifying which ecosystems to conserve and where to restore connectivity in relation ecosystem guidelines listed in Table 2.2 and to the four indispensable landscape patterns of: 1) Maintaining large patches of natural vegetation; 2) Maintaining wide riparian corridors; 3) Maintaining connectivity between patches, especially large patches; and 4) Maintaining heterogenous small patches within human-developed areas. In attempting to prioritize patches according to ecosystem guidelines and the four indispensable patterns, ecological networks can support the protection and better connection of ecosystems thereby helping to retain viable biological populations and their associated complex interactions, and facilitating the movement and flow of energy, species, and processes (Mokany, et al., 2013, p. 520; McRae, et al., 2012).

5.2.1 Characterizing Landscape Composition and Configuration

The mapping analysis complete in Chapter 4 brought out different ways to characterise the study area, all attempting to assist the analyst form a comprehensive picture of the landscape that could guide the definition of the ecological network. Characterization of ecological networks to reduce biodiversity loss as it relates to the biotic biophysical characteristic is concerned with the recognition of land cover type composition and configuration. The following section presents a synthesis of the research findings on the landscape metrics included in the SLPF, and how they support the characterization of land cover type landscape composition and configuration.

Landscape ecology principles characterize landscape composition in the context of the land mosaic and is concerned with identifying three fundamental ecological units: patches, corridors, and the matrix (Forman and Gordon, 1986). To identify these landscape structures, the SLPF provided two key landscape metrics – Patch Richness (PR) and Class Area Proportion – to evaluate key criteria like land cover type richness, area and location of land cover types. Ecological units were identified by using the data generated as part of the mapping analysis and applying landscape metrics to calculate PR and CAP, as well as utilizing the generated visual representation of the landscape to enable distinct land cover type forms to emerge. This type of characterization clarified the structural form of the landscape by identifying the land mosaic, its fundamental ecological units, and confirming the presence of a riverscape. This characterization also allowed for human-influenced landscape components to be evaluated in relation to natural land ecosystems and identify the structure they take in the landscape. These landscape evaluations revealed the dominance and rarity of land cover types in the sample sites and allowed for assumptions to be made on the influence of land cover types on biological diversity and ecological function.

In addition to structural form, characterization of composition is concerned with ecosystem richness, abundance, and diversity (Leitao et al., 2006, p. 20). Landscape ecology principles explain how ecological function is maintained by heterogeneous landscapes that encourage patch diversity and support complex interactions between biological elements of ecosystems. Furthermore, by reducing the loss of biodiversity and its associated functions, diverse and heterogeneous landscapes provide some level of defence against the effects of system scale landscape change possible with climate change (Henderson, Hogg, Barrow, & Dolter, 2002, p.3). This makes it important to ensure the definition of the ecological network not only characterises landscape composition by the richness of land cover types, but also by their abundance and diversity. Characterization of composition with the SLPF PR and CAP landscape metrics supported the evaluation of richness and abundance as they identified the types of ecosystems present in the landscape and their distribution as it related to surface area occupied. These evaluations supported the calculation of Shannon's Indices that allowed for landscape diversity and evenness to be measured and aided assumptions to be made relating to landscape heterogeneity.

When landscape configuration is considered, landscape ecology principles characterize configuration in terms of spatial arrangement, position, and orientation of structural elements (Leitao, et al., 2006). Characterizing landscape configuration in these terms provides deeper insight into landscape structures as it considers land transformation processes such as fragmentation and its effects on patch spatial patterns. This requires an ability to measure distance, clumping, and degree of contrast along edges between landscape structures (Leitao et al., 2006, p. 21). The SLPF provided a way to measure these factors with landscape metrics – Patch Number and Density (PN and PD), Mean Patch Size (AREA_MN) and Proximity (PROX) – that evaluated patch abundance, size, and proximity. In doing so, spatial arrangement, position and orientation were clarified, facilitating the ability to make assumptions relating to landscape ecosystem heterogeneity, fragmentation, and isolation. There were four main configurational characteristics that emerged from these evaluations.

First, configuration can be characterised in terms of the subdivision aspect of fragmentation. Fragmentation processes subdivide the landscape into smaller more isolated pieces creating a land mosaic with widely and unevenly separated patches (Forman, 1995, p. 408; Battisti, 2003). In clarifying patch subdivision, analysts can gain better understanding of patch abundance, distribution, size, and isolation. The SLPF provided the landscape metric PN to clarify subdivision, as it evaluated the number of like land cover type patches present in the landscape. This type of characterization of configuration clarified the relative abundance of patch types in the landscape thereby offering insight into site heterogeneity. The SLPF also provided the Patch Density (PD) landscape metric to evaluate PN as it relates to surface area occupied, which allowed for a patch per area unit value emerge and supported assumptions as to patch size and distribution. Furthermore, the mapping analysis associated with PN enabled a visual illustration of where patches were located in the St. Adolphe sample site clarifying patch isolation. Together, these landscape metrics provided insight into the degree of fragmentation experienced in the landscape by each land cover type class and effectively described spatial arrangement and position.

Second, size is important to consider in characterizing landscape configuration. As patches are subdivided by fragmentation processes, ecosystems increasingly reduce in size and become more isolated, subsequently losing ecosystem structures that support biological genetic material and species and changing ecological processes and functions present in the landscape (Farina, 2006; Mooney, et al., 2009, p. 48; Millennium Ecosystem Assessment, 2005, p. 33). Then, it is important to understand patch size as it can serve as a way to measure subdivision and provide insight into ecosystem fragmentation. The SLPF provided the landscape metric AREA_MN as a way to identify the area occupied by discrete patches. This offered insight into spatial arrangement and position by identifying patch size. Characterization of this sort provides a way to evaluate the impact patch size may have on the ecology of the landscape as well as to the overall patchiness of the landscape (Leitao, et al., 2006). As such, this type of characterization can clarify questions relating to ecosystem heterogeneity and fragmentation.

Third, configuration can be characterized in terms of ecosystem clustering. Ecosystem clusters represent a biological response to repeated landscape characteristics and are bound by the spatial elements that influence ecological function (Forman, 1995). The result is a heterogeneous land mosaic that exhibits a configuration arranged according to site specific landscape structural and functional characteristics (Forman, 1995). Then, identifying ecosystem clusters presents a way to interpret biological response to underlying functional controls and better understand landscape heterogeneity. Combination of SLPF landscape metrics clarified the aggregation aspect of patch clustering. For example, interpreting PN and CAP values in combination enabled the analyst to understand the distribution of patches in relation to the total surface area occupied by the land cover type, thereby clarifying patch spatial arrangement, position and orientation and allowing for assumption to be made relating to patch aggregation. Combining PN and AREA_MN supported conclusion made with PN/CAP evaluation by confirming the effect of size on spatial arrangement, position, and orientation. The mapping analysis demonstrated that clusters of ecosystems can be identified when these evaluations are combined with the PROX landscape metric, thereby providing a visual illustration of the spatial arrangement, position, an orientation of land cover types present in the sample site. This demonstrated how this type of characterization is necessary to understand ecosystem clusters and their effect on landscape heterogeneity and can support the interpretation of landscape fragmentation and isolation.

Finally, characterization of configuration must consider contiguity. While conserving ecosystems retains biodiversity and associated ecological structures, connecting ecosystems enables a higher degree of interaction between landscape structures and facilitates ecological function through better flow and movement of energy, materials, and organisms between structures thereby offsetting the effects of fragmentation (Mokany, et al., 2013, p. 520; McRae, et al., 2012; Theobald, et al., 2011, p. 2445; Park, 2015, p. 425; McRae, et al., 2012; Leitao et al., 2006, p. 12). Furthermore, the spatial-flow-principle suggested by Forman (1995) states that flow and movement will drop sharply with distance, less so between similar ecosystem types (p. 287), highlighting the need to measure contiguity between structures as it considers the continuous connection of ecosystems and their proximity. Contiguity was measured using the PROX landscape metric provided in the SLPF as it quantified the proximity of land cover types in relation their size and distance. The associated spatial analysis provided the visual representation of patch contiguity by highlighting patch distribution and relative distance between patches, facilitating effective communication of connectivity. This type of characterization clarified the spatial arrangement, position, and orientation of patches across the landscape, providing insight into the isolation and fragmentation of patches and enabling the evaluation of connectivity between patches of like type.

Overall, characterization of composition and configuration enables a comprehensive picture to emerge of the landscape, one that can be used to express the current state of the landscape and form the baseline needed to define ecological network components. With the use of landscape metrics outlined in the SLPF and the associated mapping analysis, analysts are provided with quantitative and spatially referenced data that supports the measurement of ecosystem richness, abundance, diversity, spatial arrangement, position, and orientation, and provides key information as to ecosystem heterogeneity and fragmentation. This baseline can facilitate the creation of scenarios that could build on the current state and explore future states that support a strategic approach to developing and implementing an ecological network plan that conserves and better links ecosystems (Leitao, et al., 2006).

5.2.2 Identifying Opportunities to Better Conserve and Connect Ecosystems

Characterizing landscape composition and configuration enables the current state of the ecological network to be defined. The SLPF provided the landscape metrics required to quantify and measure ecosystem type, area, size, proximity and location, the key criteria needed to characterize landscape composition and configuration as it relates to biodiversity. Further, characterization of this type enabled enhanced understanding of ecosystem heterogeneity, fragmentation and isolation, key landscape ecology principles that have substantial effects on biodiversity and ecosystem function. This enabled the current state of the ecological network to be defined in way that directly applied to biodiversity.

To further support biodiversity and continued delivery of ecosystem services, ecological networks should also be defined according to the ecosystem guidelines listed in Table 2.2 and the four indispensable patterns discussed above. While the characterization of landscape composition and configuration provides the current landscape context, the guidelines and the four indispensable patterns provide the guide to identify what ecosystems to conserve and better connect and develop a landscape pattern that preserves biodiversity and associated ecosystem functions. In doing so providing a way to value natural land ecosystems key to supporting biodiversity and enhancing ecological structure and characteristics. Precedents reviewed identified this as a critical component in developing an ecological network as this allows land use planners to prioritize lands that have high value relative to the objective, in this case to reduce biodiversity loss. This clarifies and spatially references elements of the physical environment and provides the necessary information needed to support the comprehensive community planning process. The following section synthesizes the research findings generated from landscape metrics included in the SLPF and associated mapping analysis, and how they support defining the ecological network as it relates to the ecosystem guidelines and the four indispensable patterns. However, it should be noted the sample site scale that the quantitative mapping analysis was completed at would make it difficult to develop an ecological network to support the four indispensable patterns and the ecosystem guidelines. The nature of these patterns and the criteria included in the guidelines are more applicable to larger landscapes and would be better suited for implementation at the municipal or regional scale. The following discussion provides an example of how the quantitative mapping analysis facilitates the comparison of data to the patterns and guidelines.

Maintain large patches of natural vegetation:

The fragmentation transformation process shapes the landscape by subdividing ecosystems thereby reducing their contiguity and creating a series of ecosystem clusters with varying patch sizes. Patch size has been shown to have substantial effects on species abundance and diversity and, although not as studied, on ecological processes (Forman, 1995). While benefits are associated with small patches (see sub section *Maintain heterogenous small patches within human-developed areas*), large patches generally support larger numbers of species, are less disturbed, and facilitate greater function thereby providing greater benefits (Forman, 1995; Farina, 2006, p. 133). Forman states that “a landscape without large patches is eviscerated, picked to the bone”, whereas “a landscape with only large patches misses few values” (p. 48). However, large patches are uncommon or rare (Farina, 2006, p. 133), making their preservation especially important. Then, to maintain large patches in the landscape that support greater biodiversity and ecological function would require that the ecological network prioritize the conservation of existing large patches.

Large patches can be identified using the information generated from characterizing landscape composition and configuration. Characterization of landscape composition with the PR landscape metric identified the land cover types present in the landscape, thereby providing a way to recognize the natural and human-influenced components and clarifying which natural ecosystem could be maintained. Characterization of the subdivision and size aspects of landscape configuration with the PN and AREA_MN landscape metrics identified the distribution of patch size within each land cover type class. This provided a way to identify large patches within each land cover type class and compare values to identified guidelines for optimal patch size. Additionally, measuring contiguity with the PROX landscape metric provided a way to evaluate and prioritizes large patches. The PROX landscape metric evaluated proximity as it related to patch size and distance, where a larger index value was given to large patches of near distance to like patch types. Because of this, higher PROX value patches were assumed to be large patches that had high potential to support greater movement and flow of energy, species, and materials on account of the spatial-flow-principle. This provided a way to value larges patches and prioritize for conservation patches with high potential to support greater biodiversity and ecological function; this practicum labeled patches simply as key and non-key patches where key patches were those with high PROX values relative to the land cover types class (Figure 4.19). As a result, the ecological network was defined in way that prioritizes the maintenance of not only large patches, but large patches that have a higher potential to support greater biodiversity and ecological function.

A limitation is present in the analysis as it is based on ecosystem type and not a particular species or ecological process. General assumptions can be made as to what species and ecological process may be supported in a particular natural land ecosystem, however, if objectives were to conserve a specific species or ecological process the analysis completed in this practicum may not appropriately identify priority ecosystem patches for conservation. The PROX analysis used to value large patches was completed using a 500m buffer known to generally support biodiversity and ecosystem function. If a particular species or ecological process was of concern, this buffer would need to be refined to better reflect the particular characteristics of that species or function to evaluate the effect large patches may have on that species or process of concern. This would likely require additional data on particular species biological characteristics and on other abiotic biophysical characteristics that could affect the ecological process, which may require other forms of analysis beyond the PROX evaluation to appropriately rank and identify priority patches.

Maintain wide riparian corridors:

Land mosaics in areas with rivers present take the form of riverscapes. Defining an ecological network to support biodiversity within such a context requires that the river system be considered in the context of the wider landscape and surrounding patch dynamics as these areas are species-rich systems that facilitate key terrestrial and aquatic habitat functions (Zhou et al., 2014, p. 148; Environment Canada, 2013). While the large patch evaluation discussed above provides a way to evaluate the surrounding terrestrial landscape patch dynamics, it does not specifically consider location of patches, namely their presence within riparian zones. Found adjacent to streams and rivers, riparian zones, or riparian corridors, are a complex environment that act as a transition zone between terrestrial and aquatic system where ecological function and habitat are influenced by the attributes of both ecosystems (Environment Canada, 2013, p. 43). As a result, riparian zones support numerous ecological functions including providing habitat for terrestrial species, contributing resources (e.g. woody structure, nutrients, shade) for aquatic habitat, and acting as a buffer between aquatic and terrestrial ecosystems (Environment Canada, 2013, p. 43). Then, maintaining riparian zones provides essential habitat that could reduce biodiversity loss and support the continued delivery of key ecosystem services in both terrestrial and aquatic ecosystems.

As vegetation within riparian zones can directly influence aquatic and terrestrial habitat and ecological function by supporting or disrupting major flows of energy, material, and species, natural vegetation within riparian zones should be maintained and protected to a minimum of 30 metres from both sides of a stream or river (Leitao, et al., 2006, p. 34; Environment Canada, 2013, p. 48) This width captures the area typically needed to maintain processes and functions present in riparian zones as well as facilitate the transition between terrestrial and aquatic environment (Environment Canada, 2013, p. 43). The mapping analysis completed as part of characterizing landscape composition and configuration allowed for landscape land cover types to be identified and enabled their form and location within the landscape to emerge. This confirmed the presence of a riverscape land mosaic, identifying waterways as linear corridors and the ecosystem patches adjoining streams and rivers. A key goal of the mapping analysis was to interpret this information in relation to the planning constraints present in the sample site; this included interpreting this information against the Provincial Land Use Policies' minimum set-back requirement of 30m upslope along all natural waterways. As a result, the mapping analysis provided visual tools (Figure 4.13, Figure 4.14, and Figure 4.15) to identify which land cover types fell within the 30m riparian zone buffer. This provided a way to identify existing natural land cover types within the riparian zone that could be prioritized to ensure a 30m buffer of natural vegetation is maintained. Furthermore, a way was provided to evaluate the degree of vegetation cover within this 30m for comparison against the ecosystem guideline of having 75 percent cover within the riparian area. Finally, when combined with the large patch analysis, the mapping analysis also provided a way to identify if any large patches fall within the riparian zone, thereby providing a way to further value these patches and enhance their priority for conservation.

A limitation is present in the analysis as it did not provide insight into the aquatic elements of the riparian zone and only provided insight into evaluating landscape patch dynamics of terrestrial elements. Riparian zone dynamics are influenced by both the aquatic system and broader terrestrial system, and as such consideration of stream and river characteristics that contribute to riparian zones and vice versa is necessary to ensure appropriate conservation and restoration of ecosystems that can effectively manage biodiversity and ecological function (Environment Canada, 2013). However, aquatic system characteristics are largely determined by landscape biophysical factors beyond land cover types like hydrology, soils, geology, and elevation (Environment Canada, 2013; Forman, 1995). Then, to consider the effects of aquatic system on riparian zones would require further insight into the abiotic biophysical characteristics that shape the aquatic ecosystem and associated dynamics that influence biodiversity and ecological function.

Maintain connectivity between patches, especially large patches:

In landscapes where substantial land conversion has occurred, like the sample site, maintaining connectivity relies on restoring lost natural ecosystems between existing natural land ecosystem patches. As fragmentation subdivides the landscape, contiguity between patches is affected and creates a series of patch clusters with reduced connectivity between them. Restoring lost ecosystems between ecosystem patches enables a higher degree of interaction between patches, facilitating better flow and movement of energy, materials, and species and allowing for better function between patches (McRae, et al., 2012; Leitao et al., 2006). However, as restoring all lost ecosystems is not likely possible in peri-urban landscape like the RM of Ritchot, it is critical to identify where potential lost ecosystems could be restored to best support ecological network objectives. This practicum had the objective to define an ecological network that reduces biodiversity loss to support continued delivery of associated ecosystems services. Then, restoration of connectivity would need to be defined in a manner that achieved this objective.

To ensure biodiversity and associated ecosystem services are supported, restoring landscape connectivity relies on evaluating all components of the land mosaic to ensure the quality and effect of the landscape matrix supports maximum landscape contiguity of non-built areas (Park, 2015, p. 425). This requires that patch and corridor connectivity be characterized and evaluated. At the patch level restoring connectivity is concerned with accentuating habitat amount and arrangement, whereas restoring corridor connectivity is concerned with reducing the number of gaps between ecosystems along linear features to promote dispersal (Park, 2015, p. 425; Forman, 1995, p. 155). While corridor connectivity is location specific, both corridor and patch connectivity are characterized through better understanding of the effective distance between ecosystem patches (Park, 2015, p. 425; Forman, 2005, p. 251). Distance is important to understand as the spatial-flow-principle demonstrated that ecological function decreases as the distance between like ecosystem patches increases (Forman, 1995, p. 287). Then characterizing connectivity as it relates to distance provides a way to identify areas to restore that are key to supporting biodiversity and continued ecological function.

The characterization of the contiguity aspect of configuration undertaken in the analysis with the use of the PROX landscape metric clarified the distance between patches of like type within a 500m and provided a way to visualize distance between patches with the use of "near lines". As this buffer reflected the typical distance that ecological function is best supported between patches, it allowed for ecological function to be generally considered in the evaluation of patch connectivity. In addition to patches of nearest distance being given higher values, higher PROX values were weighted toward large patches thereby providing a way to evaluate distance in relation to patch size. Like the large patch analysis, the PROX analysis provided a way to prioritize areas to restore ecosystem by enabling "near lines" to be valued according to their associated PROX value. This practicum valued "near lines" associated with high PROX values as key, highlighting the location where they are found in the landscape as priority for restoration (Figure 4.19). In this way, the analysis identified key areas for restoration that would best accentuate patch amount and arrangement. Furthermore, when combined with the mapping layer that identified the riparian corridor present, the analyst was provided a way to visualize patch connectivity within riparian zones and assess gaps along the linear feature. As such, a guide was provided to the analyst on where restoration activities could be focused.

A limitation is present in the analysis in that it was limited in distinguishing which natural ecosystem restoration would best support biodiversity and ecological function in comparison to other natural ecosystem types. For example, *Forests, Range and Grasslands*, and *Wetlands* were all found within riparian zones (Figure 4.16, Figure 4.17, Figure 4.18). To increase corridor connectivity PROX values suggest connectivity between like ecosystem, however, the analysis revealed that in the sample site there were often in areas with multiple types natural ecosystems. As such, if connectivity were to be increased between like ecosystems in the riparian zone it would be at the expense of other natural ecosystems. This begs the question: which natural ecosystem restoration would best benefit biodiversity and the ecological function of the landscape? While the PROX landscape metric is useful to identify key areas to better connect as it relates to landscape matrix connectivity, it does not consider specific attributes of natural ecosystems that may secure the quality and effect the landscape matrix. Then, while the PROX metric can serve to identify key areas for restoration, greater understanding of particular species and abiotic biophysical characteristic would be needed to prioritize the restoration of ecosystems that would most benefit landscape biodiversity and continued ecosystem function.

Maintain heterogenous small patches within human-developed areas:

Land conversion creates a shifting mosaic that changes landscape composition and configuration over time, influencing spatial heterogeneity and altering landscape structure and function temporally (Leitao et al., 2006, p. 14; Farina, 2006, p. 111). Now, as climate change increases the risk of serious disturbance with potential catastrophic effects, spatial heterogeneity and diversity are being seen as a way to reduce landscape vulnerability and add resilience to the potential risks as they mitigate the loss of complex biological interactions that support ecosystem function (Lovett, et al., 2005; Henderson, et al., 2002). Then, definition of the ecological network must consider aspects of heterogeneity and diversity if the ecological network is to continue supporting biodiversity and ecological function and reduce landscape vulnerability to climate change.

In essence heterogeneous landscapes aim to maintain landscape diversity. Then to characterize landscape heterogeneity requires a way to quantify landscape diversity. This practicum quantified diversity by applying Shannon's Diversity and Evenness Indices, which revealed that while the landscape is not overly diverse it is fairly heterogenous. Sample site landscape richness (i.e. PR) was found to be fairly low as compared to the greater regional richness (i.e. RPR), however, the evenness value of the sample site was relatively high indicating a lower probability that patch types are the same throughout the landscape. These results suggest that the current state of the landscape may offer some resilience to climate change as it relates to the landscape heterogeneity. However, this value reflects the heterogeneity of a peri-urban context that considered natural ecosystems in combination with human-influenced landscape components. Therefore, the landscape benefits received from heterogeneity may not necessarily positively affect biodiversity and ecological function on account of potential negative effects associated with human land use. Then, to maintain landscape heterogeneity, even possibly increase it, while also maintaining positively associated ecological benefits would require that the three previously discussed indispensable patterns be considered in the context of their effects on heterogeneity. This way, the ecological network can be defined in way that its spatial patterns enhance biodiversity and better support ecological function while also maintain spatial heterogeneity.

The three indispensable patterns discussed above, describe how the ecological network can be characterized to maintain large patches, wide riparian areas, and connectivity between patches. These key landscape spatial patterns attempt to reduce biodiversity loss and support ecological function, however, in doing so they change the composition and configuration of the landscape. For example, restoring areas between like ecosystems to enhance connectivity would increase the interaction between patches. Over time this likely would result in the amalgamation of patches, changing both the overall land cover type patch number (PN) as well as its total surface area occupied (CAP). In addition, as patches amalgamate, average patch size would increase thereby creating more large patches in the landscape and reducing the distance between them. The combination of theses effects would make the landscape less subdivided and more contiguous thereby reducing landscape fragmentation effects like patch isolation and reducing the potential of intervening ecosystems stopping the flow and movement of energy, materials, and species. However, by doing so spatial heterogeneity may change as measures of diversity and evenness change. Then, spatial patterns defined with the ecological network must delicately balance the four indispensable patterns to achieve the most effective management results.

Most species and processes depend on an arrangement of land use found throughout the landscape matrix and rely on some level of connectivity throughout all areas of the matrix (Forman, 1995, p. 453). Forman (1995) suggest that the pattern that best supports this a "heterogeneous assemblage of small natural vegetation patches and a network of line corridors" (p. 453) as this not only supports the mass of species and processes in large, better connected patches, but also the isolated and scattered species and processes in the matrix that depend on smaller patches. Small patches serve as habitat for many small-patch restricted, edge and rare species and act as stepping stones for species dispersal, while also playing critical roles in landscape ecological processes (Forman, 1995, p. 48). Then, determining how to prioritize overall landscape spatial pattern will need to consider what the effects of protecting patches and restoring connectivity will have on the heterogeneity of small patches.

A limitation is present in the analysis as it did not provide a way to prioritize the preservation of small patches. However, patch cluster offered insight into where to potentially prioritize patch conservation and restoration to reflect existing patch clusters of ecosystems. These clusters provide a way to visualize where patches may begin to amalgamate as large patches are preserved and connectivity restored between them as well as visualize what and where patches fall outside these clusters. This provides clarity on the small patches that may serve as stepping stones in the landscape and provide a refuge for biological components in the landscape. In this way, the ecological network can be defined by patch clusters that will eventually amalgamate to form large patches, by the corridors that line the riparian areas in the landscape, and the small patches that act as stepping stones between them. This can support the development of a landscape that maintains heterogeneity while also supporting biodiversity and ecological function by preserving and restoring natural ecosystems clusters.

While the patch cluster maps produced from the mapping analysis provided a way to identify small patch spatial location outside of clusters, the quantitative analysis did not provide a way to prioritize their protection. With the use of the PROX landscape metric, the quantitative analysis produced a way to prioritize conservation of large patch and areas to restore to enhance their connectivity. As patches were deemed "key" when they had a high value PROX, priority for conservation was given to large patches of near distance. Therefore, the PROX value presents a limitation in how to prioritize small patches for preservation as well as areas to better connect them to neighbouring patches. Then, an alternative measure would be required to appropriately assess small patch value to the ecological network. This would likely require greater information on what species and ecological function are supported by the small patch that would necessitate more detailed information of biological and abiotic biophysical characteristic present in small patches.

5.3 Utility to the RM of Ritchot and Winnipeg Metropolitan Region

Key objectives of this research practicum were to inform the land use planning process as to how ecological network planning can build biodiversity related resilience into the landscape and develop a visual tool to communicate this concept. Landscape ecology principles provided the basis as to how to characterize the landscape to reflect key concepts important to reducing biodiversity loss. Landscape ecology principles also provided a list of ecosystem guidelines and four indispensable patterns that aim to reduce biodiversity loss by restoring greater network integrity. Together, this defined a baseline condition of the existing ecological network and identified opportunities for the protection and restoration of areas key to maintaining biodiversity and reducing its loss. From this, three main uses emerge for the RM of Ritchot and WMR: 1) Clarification of biodiversity and ecosystem services; 2) Scenario Planning; and 3) Application to land use planning. The following sub-sections discuss these three main uses.

5.3.1 Clarification of Biodiversity and Ecosystem Services

Climate change is threatening to reconfigure ecosystems and their associated complex interactions that support ecological function (Mooney, et al., 2009, p. 49). The literature review clarified that biodiversity provides a degree of landscape stability and resilience to potential climate change effects as biodiversity supports greater functional diversity and adds ecosystem capacity to withstand environmental change associated with climate change (Mooney, et al., 2009, p. 47; Ding & Nunes, 2014, p. 60). However, maintaining biodiversity relies on ensuring greater integrity of the ecological network as this promotes interaction between ecosystem structures where then spatial dynamics can better support ecological processes across the landscape (Lovett, et al, 2005). Landscape ecology principles clarify that greater biodiversity is generally achieved with greater patch richness and associated spatial heterogeneity. While this is desirable in the context of biodiversity and ecological function, increased diversity of human influenced land cover types could have negative consequences on landscape function as a result of effects associated with land conversion and fragmentation. Therefore, it is important to understand the composition and configuration of land cover types before interpreting patch richness and spatial heterogeneity.

Landscape metrics applied as part of the quantitative mapping analysis evaluated ecosystem type and area which allowed for the characterization of composition as well as evaluated patch size, location, and proximity which allowed for the characterization of configuration. Characterizing composition with the Patch Richness (PR) landscape metric identified the types of ecosystems present, highlighting the presence of four natural ecosystem types in the landscape: *Forest, Range and Grasslands, Waterbodies*, and *Wetlands*. Furthermore, characterization of configuration with the identification of land cover type location identified the presence of a fifth natural ecosystem type, Riparian areas. This clarified which natural land cover types in the landscape to conserve and restore to preserve habitat, species, and genetic biological resources and their associated ecosystem services. While, all natural ecosystems provide some degree of biological resources and ecosystem service, rare ecosystems may be prioritized for protection and restoration as they are critical to maintaining biodiversity and ecological functions in the landscape The analysis clarified rare ecosystems in the landscape and highlighted the rarity of the *Wetland* land cover type. While wetland patches may on average be larger than *Forest* patches (Table 4.4), wetlands occupied much less total surface area in the landscape (Table 4.1), making wetlands especially important to maintaining biodiversity and the continued provision of ecological services in the landscape. The analysis also demonstrated that although there are more natural land cover types present in the landscape than human-influenced elements, Class Area Proportion (CAP) calculations (Table 4.1) reveal that the human-influenced land cover types occupy more landscape surface area than natural ecosystem land cover types. While natural ecosystems represent a fair degree of the richness in the landscape, human-influenced land cover types occupy more area (Table 4.1). As such, human-influenced elements are likely exerting a strong influence on biodiversity and ecological processes and may be impacting the delivery of potential ecosystem services.

Further characterization of configuration provided clarity on the spatial elements of landscape composition that may have an effect on heterogeneity and subsequently allows for further understanding of site biodiversity and ecosystem services. For example, with the use of the Patch Number (PN) landscape metric the analysis demonstrated that *Forest* and *Range and Grassland* land cover types are fairly subdivided, meaning patches are on average smaller and their networks are relatively fragmented. Smaller more fragmented patches suggest less biotic diversity and reduced ecological function as a result of less interaction between patches (Forman, 1995). While subdivided patches may have implications related to patch size and connectivity, they contribute to maintaining landscape heterogeneity. The Shannon's Evenness Index provided a way to quantify heterogeneity (Table 4.2) and confirmed the presence of fairly heterogeneous landscape. Furthermore, while the *Agriculture* land cover type may not be a matrix as its CAP values suggest (Table 4.1), it is likely that it still exerts strong effects on other patch types due to its high CAP value. As such, the greater subdivided *Forest* and *Range and Grassland* land cover types may reduce the loss of biological components associated with those natural ecosystem patch types in a landscape with a strong agricultural presence.

As landscape heterogeneity reduces the risk of biodiversity loss associated with land use modification and impending climate change effects, redundant natural land cover types present in peri-urban landscapes like the RM of Ritchot may allow biological components and ecological functions to persist in the face of disturbance brought on by climate change (Leitao, et al., 2006, p.79). This is because redundant natural land cover type would help provide added capacity to the landscape to withstand the effects of climate change that may reduce the potential for species regime shift, reducing the potential for biodiversity loss that may support the continued delivery of ecosystem system services. As many of the ecosystem services listed in Table 2.1 have the potential to mitigate effects of climate change in the RM of Ritchot, maintaining and enhancing the presence of natural land cover types in the landscape through conservation and restoration may add landscape resilience to anticipated effects.

In addition, the mapping analysis provided a way to visualize biodiversity in the landscape. By identifying ecosystems types and patches a spatial pattern emerged that allowed for ecological structures and ecosystem clusters to be identified (Figure 4.9, Figure 4.10, and Figure 4.11). Furthermore, evaluation of spatial configuration factors like proximity provided a way to visualize connectivity in the landscape (Figure 4.9, Figure 4.10, and Figure 4.11). This enabled for a way to visualize where species richness may be clustered in the landscape thereby providing a way to locate where in the landscape biodiversity may be congregated and where the links between ecosystem may exist that could help better maintain biodiversity across the landscape. Landscape heterogeneity was also clarified visually by demonstrating the spatial distribution of patches across the landscape. Because the mapping analysis demonstrated the surface area of each patch, a way to visualize patch size and their distribution in relation to their size was provided thereby facilitating the visualization of heterogeneity according to patch size. Together, this provided a way to graphically present the physical elements of the landscape as they relate to the ecological network and identify the significant natural features that may support biodiversity.

A limitation was present in the analysis in that it did not provide clarity on biodiversity beyond the habitat level. This means that no clarity was provided as to species or genetic level biodiversity. Biodiversity related analysis completed as part of defining ecological networks in Ottawa, Halifax, and Edmonton all explored biodiversity beyond the habitat level and included evaluation of species and genetics specific criteria. For example, to capture species level biodiversity criteria in addition to ecosystem class level factors, Ottawa examined biodiversity factors relating to time of absence since disturbance, representative flora, and habitat maturity. Halifax also looked at species level factors by examining species rarity, richness, and diversity, but also included genetic level factors by including criteria related to reservoirs of genetic diversity. In this way, their ecological networks were defined to capture other ecological hierarchical scale's of biodiversity beyond the habitat level. To define the ecological network as it relates to species or genetic level biodiversity would require a greater understanding ecological and biological concepts factors such as species composition, life cycle, and behaviour, which would necessitate methods and metrics that quantify relevant species or genetic level criteria. Furthermore, to address climate change related vulnerabilities to biodiversity would require greater understanding of species response to anticipated changes as this would guide conservation and restoration goals towards patterns that accommodate future landscape conditions.

A similar limitation is presented as it relates to ecosystem services. The identification of ecosystem types allowed for assumptions to be made as to the potential ecosystem services provided by ecosystems present (Table 2.1). However, the analysis did not provide a way to confirm which ecosystem services are actually being delivered, nor did the analysis provided a way to quantify the degree of ecological function. Ecosystem services related analysis was completed as part of defining the ecological network in Edmonton. To capture ecosystem services delivered by ecosystems, Edmonton examined ecological function in terms of the biotic, i.e. biodiversity, and in terms of the abiotic, i.e. water management, climate regulation, risk mitigation, waste management, and food production. This way, the ecological network was defined in a way that maintained both landscape biotic and abiotic function. The research undertaken as part of this practicum did not include criteria to evaluate specific abiotic ecological functions as undertaken by Edmonton. This would require greater understanding of the landscape composition and configuration of abiotic biophysical components as ecosystems tend to provide differing levels of function depending on their location in the landscape and the associated abiotic biophysical characteristics present (Environment Canada, 2013). Furthermore, this would require different methods of analysis as those undertaken in the research did not quantify the degree of ecological function. Yet, this would be critical to developing an ecological network that truly provides climate change resilience.

Overall, a more robust ecological network would be defined should other ecological hierarchal scales and abiotic biophysical characteristics be considered when evaluating biodiversity. However, this may present a challenge to municipalities who lack resource and knowledge capacity as a species and genetic level understanding of biodiversity would likely require some level of species-specific primary data collection and other methods to quantify and interpret biodiversity. Primary data collection and other methods to quantify and interpret ecological function would also be required.

5.3.2 Scenario Planning

A key objective of the Sustainable Land Planning Framework (SLPF) Prognosis planning phase is to develop a vision of the landscape to address the goals and objectives of the ecological network in order to develop options for ecosystem protection and restoration that will help achieve this future vision of the landscape. The characterization of landscape composition and characterization provided a way to define the current ecological network and evaluate its components in relation to ecosystem guidelines and the four indispensable patterns key to reducing biodiversity loss. This revealed the baseline condition of the ecological network and identified key patches to protect and key “near lines” to restore connectivity. However, it did not evaluate the impact of protecting large patches, restoring connectivity in locations of key near lines, or protecting the ecological network as identified by ecosystem clusters and spatial heterogeneity patterns. Then, prior to recommending strategies to develop the ecological network, a vision to work towards must be established and comparison of different ecosystem protection and restoration options is needed to ensure the suggested strategies meet desired goals (Leitao, et al., 2006, p. 45).

Figure 4.19 can serve to provide the framework upon which a future vision of the landscape can be developed. Developed on the principles of landscape ecology, Figure 4.19 illustrates a vision for the ecological network in the sample site of St. Adolphe and highlights areas to prioritize for conservation and restoration. The quantitative mapping analysis undertaken in this research set the baseline condition of the ecological network that enabled for the emergence cluster patches and the definition of the ecological network. The interpretation of this baseline condition in relation to ecological criteria provided a way to identify areas to prioritize for conservation and restoration. In doing so, offering a spatial reference to envision the ecological network and priority areas for conservation and restoration. Building on this baseline, ecosystem guidelines listed in Table 2.2 offer a way to evaluate the current condition of the ecological network against optimal criteria found to support biodiversity and maintain ecological structures and characteristics. Numerous ecosystem protection and restoration guidelines exist that aim to maintain biodiversity and rely on an understanding of patch type, area, size, location, and proximity (Environment Canada, 2013). As such, the quantitative mapping analysis undertaken would provide a suitable baseline for many guidelines to be compared to. This allows the analyst to set objectives to work towards to render the current state of the ecological network toward one that meets set guideline criteria.

For example, literature suggests that to maintain biodiversity, identifying and protecting ecosystems above minimum levels prior to urbanization is key (Environment Canada, 2013) as protection becomes increasingly difficult with land conversion. Furthermore, ecosystem protection above minimum levels can act as a precautionary approach to potential climate change impacts on biodiversity as it supports sufficient species population to ensure the minimum generic ecosystem services are maintained in the landscape (Environment Canada, 2013). Minimum levels can vary depending on land cover type. Table 2.2 suggests minimum percent landscape area coverage guidelines for forests, riparian areas, and wetlands thereby providing a goal for the future landscape to achieve. With the use of the CAP and PLAND landscape metrics, a way is provided to establish current landscape percent coverage and starting point to compare options in effort to work towards achieving minimum levels in the landscape. Should minimum levels not exist, as is the case for grasslands, Environment Canada (2013) suggest working toward achieving a percent coverage that reflects historical ranges of ecosystems (p. 84). Table 4.6 offers a comparison of the baseline PLAND values to optimal values and clarifies that existing *Forest* and *Wetland* patches do not meet optimal values. As discussed in Chapter 2, grasslands in the RM of Ritchot historically constituted approximately 55 percent of the land cover (Hanuta, 2006). As Table 4.1 indicates, the current *Range and Grassland* PLAND value is well behind the historical range percent area coverage value. By identifying patch clusters, Figure 4.19 has identified a defined spatial area that would most benefit from increased connectivity through patch restoration. The identification of the spatial arrangement and form of the ecological network provides a guide as to where to generally begin restoration to increase natural ecosystem PLAND values, and identification of key “near lines” clarify where to begin restoration to add the most value to ecological network as it relates to the key evaluation criteria of patch size and proximity. Figure 4.19 also provides a way to identify which site are priorities to conserve within the identified ecological network to assist in maintaining PLAND values.

Another example could include the application of optimal patch size guidelines. As discussed in *Section 5.2.2*, large patches have greater positive ecological benefits by supporting more species, being less disturbed, and facilitating greater ecological function. Ecosystem guidelines listed in Table 2.2 identify optimal patch size for natural ecosystems, and Table 4.8 compares these guidelines to the largest patch sizes found in the sample site. Table 4.8 clarifies how the largest *Range and Grasslands* land cover type patch meets the desired optimal patch size guideline, whereas the *Forest* land cover type does not. This indicates that the large *Range and Grassland* patch should be prioritized for conservation as a result of its desired effects on ecological structure and function. The results also indicate that more effort is required to conserve and restore *Forest* patches in effort to create a large forest patch that meets the optimal guideline. Figure 4.19 can be useful in guiding where this should occur, as it identifies what and where existing key patches could be conserved and not reduced in size. Furthermore, the ecological network identified in Figure 4.19 clarifies where patch restoration could occur to best connect existing key patches and work towards amalgamating patches to create larger *Forest* patches, and the key “near lines” indicate where restoration activities should begin.

Using ecosystem guidelines as goals, comparison of preservation and restoration options is possible as there is an objective to work towards. However, the ecosystem guidelines used in this practicum present a limitation. The guidelines were developed for the Great Lakes region of Ontario, and as such do not represent the same ecozone as represented in the RM of Ritchot. The

RM of Ritchot is located in the Prairie Ecozone and was largely composed of grasslands prior to settlement (Agriculture and Agri-Food Canada, 1998) and therefore differs for the conditions in the Great Lakes region. Then, guidelines with greater emphasis on the grassland ecosystem than included in the Environment Canada guidelines, are needed to reflect local conditions and set conservation and restoration goals. Furthermore, the quantitative mapping analysis presented was limited in comparing conservation and restoration options as it did not offer a way to compare which options best reduce biodiversity loss. This is important to consider as suggested options for restored connectivity would likely result in the removal of a natural ecosystem in favour of another. For example, the analysis identified that riparian zones in the sample site are composed of a mixture of *Forest*, *Range and Grassland*, and *Wetland* patches (Figure 4.16, Figure 4.17, Figure 4.18). Although each land cover type supports a variety of biological resources and ecosystem services, the research did not provide a way to determine which ecosystem would have the most value to protect in terms of species/genetic biodiversity and ecological function. Therefore, there would be impact to species richness and spatial heterogeneity, effecting both biodiversity and ecosystem services.

A similar situation arises when considering options for restoration. For example, within the sample site, the St. Adolphe Coulee riparian zone appears to have areas with less than 75 percent area coverage (Figure 4.16, Figure 4.17, Figure 4.18), and therefore, may require restoration of ecosystems to ensure minimum percent area coverage values as per ecosystem guidelines (Table 2.2). However, restoring ecosystems requires consideration of both biotic and abiotic biophysical characteristics and spatial dynamics as both have substantial effects on biodiversity and ecosystem function (Environment Canada, 2013). Not only would this require better understanding of abiotic biophysical characteristics in the riparian zone and surrounding riverscape but would also require a way to compare the effects of restoration options to and on spatial dynamics as restoration would change species richness and spatial heterogeneity. Therefore, a way is also needed to compare ecosystem restoration options to determine which provide the most value to biodiversity and ecosystem services.

In addition, to define an ecological network that adds landscape resilience, planners and decision makers will need to consider how conservation and restoration can sustain the biological resources that support ecosystem services that mitigate climate change effects. In the RM of Ritchot this means defining a network that conserves and restores ecosystems that can add resilience to flooding, drought, heat stress, fire, and pest outbreak. The natural land cover types identified in the sample site provide ecosystem services could mitigate these effects (Table 2.1). Then, determining the capability of patches present to provide ecosystem services that add resilience would be key to identifying the natural lands to conserve and restore. Furthermore, the expected changes to biodiversity as a result of climate change effects will result in a landscape that reflects an environment currently not present in the landscape. This will require clarification as to whether the goal of natural lands is to support biodiversity as it today or what it will be in the future as this will determine if conservation and restoration should focus on historical or present land cover types, or a combination of both.

To compare ecosystem protection and restoration options, Leitao et al. (2006) suggest a strategic scenario planning approach be used, one that evaluates defined criteria for a future landscape by developing scenarios that reflect various spatial strategies (p. 45). Landscape metrics would be used to calculate baseline conditions, and, through the comparison of proposed scenarios, would be used to assess the impacts of potential changes on ecosystem biodiversity (Leitao, et al., 2006, p. 45). While the quantitative mapping analysis provided a way to define the ecological network and begin prioritizing what patches and areas to protect and restore by valuing sites as "key", scenario planning can render prioritization more robust by associating further value to patches. Value would be determined by calculated results acquired with landscape metrics that would highlight which scenario would have the most positive impact on meeting ecosystem guidelines and hence on ecosystem biodiversity. Then, results can be used to select the scenario that best supports desired objectives. This provides a way to more comprehensively value patches and clarify patch protection and ecosystem restoration priorities. In doing so, scenario planning can guide ecological network planning strategies toward a spatial pattern that best maintain ecosystem biodiversity and support ecosystem services while considering climate change resilience.

5.3.3 Application to Land Use Planning

The previous sections have demonstrated that a quantitative mapping analysis like the one undertaken as part of this research practicum can inform land use planners as to how to define a land cover type ecological network to enhance landscape connectivity and reduce ecosystem biodiversity loss. The following section discusses how such an understanding can assist planners in organizing and defining land use spatial patterns to guide growth while meeting environmental objectives. This will be discussed in the context of two scales of land use planning: municipal and regional.

Municipal Land Use Planning Application:

A baseline of key physical landscape elements underlying the ecological network was provided by the quantitative mapping analysis that could inform the vision for a municipality set in the comprehensive community plan and compliment other land use plans, strategies, and programs. The information and products produced could provided a way to identify compatible and competing land uses as well as synergies between them, which could then contribute to decisions that better support spatial patterns that more efficiently uses land and links different projects and functions (Brandt & Vejre, 2004; Priemus, et al., 2004). The precedents reviewed from Ottawa, Halifax, and Edmonton all demonstrated that this was common practice, where ecological network plans where integrated within the greater municipal and regional land use planning context. In doing so, ecological network structure and function were considered in a multifunctional context that attempted to integrate land uses into a common framework.

Land designations reflect policy areas that aim to address the physical, social, environmental, and economic objectives of the community (Province of Manitoba, 2015, p. A-2). The quantitative mapping analysis undertaken in this practicum revealed the ecological network in spatial relation to existing land designations in the RM of Ritchot and existing land uses (Figure 4.13, Figure 4.14, Figure 4.15). Land designations are associated with policy statements that describe how the municipality wants to develop land and the measures it intends to use to implement the plan's vision (Province of Manitoba, 2015, p. A-2). Development and land use rules are then established with the zoning bylaw which aims to implement the objectives of land designation policy areas (Province of Manitoba, 2015, p. A-2). As such, land designations may inherently support or be a barrier to developing an ecological network.

The analysis undertaken in this practicum can inform municipal land use planners as to how the existing land designation policy framework may or may not support the protection and restoration of the ecological network. For example, the research identified three distinct policy areas and demonstrated that much of the *Forest, Range and Grasslands,* and *Wetland* ecosystem patch clusters found in the sample site where located within an Environmental Policy Area (Figure 4.13, Figure 4.14, Figure 4.15). This policy areas aims to respect the prescribed setbacks near riverbanks and minimize disruptions to aquatic habitat including wetland and riparian areas (Lombard North, 2011, p. 22). As such, the Environmental Policy Area sets the policy conditions necessary to maintain natural ecosystems and may further support the protection and restoration of natural ecosystems that would help develop a cohesive ecological network.

However, natural ecosystems were also found within other policy areas like the Urban Centre Policy Area and Green/Agricultural Policy Area, whose policies differ from the Environmental Policy Area and may offer a different level of support for the protection and restoration of ecosystems and development of the ecological network. This means that the land designation framework may inherently challenge planners in their efforts to protect and restore ecological network components. Then, understanding the relationship between the existing ecological network, its future landscape goals, and the land designation framework can be especially important when updating the comprehensive community plan as this provides an opportunity to better align policy across land designations to support a cohesive ecological network. Furthermore, as zoning bylaws are expected to be reviewed whenever the comprehensive community plan is updated (Province of Manitoba, 2015, p. A-3), better alignment of land designations with the requirements of the ecological network provides an opportunity to ensure the rules governing development and land use better respect the needs of the current and future ecological network. This can facilitate the development of zones within areas key to the protection and restoration of the ecological network that would support land use planning mechanisms that may be needed to maintain existing ecosystems and re-link the fragmented landscape (Firehock, 2015, p. 20).

Ensuring the policy framework reflects the needs of the current and future ecological network allows for the municipal land designation policy framework to support the structures and functions important to the objectives of the ecological network. In this way, the policy framework can proactively guide growth and development to more appropriate locations that have fewer negative impacts on ecological network composition and configuration. For example, the quantitative mapping analysis demonstrated that the *Cultural Features* land cover type was largely clustered in two patches within relatively close distance to one another (Figure E-3), suggesting the clustering of current urban land use. As the RM of Ritchot is anticipated to grow, the policy framework could direct growth and development toward these existing clusters to reduce negative effects on the ecological network caused by land conversion associated greater urban development. Furthermore, policy governing urban areas could then be developed to help meet criteria set by ecosystem guidelines and better reflect the four indispensable patterns within their design as well as ensure better connection to surrounding natural areas (Forman, 2019).

The policy framework could also considerer how the associated *Infrastructure* land cover type could be developed as a response to growth in a way that minimizes fragmentation effects on the ecological network. The analysis identified existing *Infrastructure* land cover type as a barrier to connectivity, as it was often present in areas identified as key “near lines” (Figure 4.16, Figure 4.17, Figure 4.18). While it might be difficult to remove the barrier caused by existing *Infrastructure* land cover types, future land use planning could consider in tandem how development of infrastructure and urban settlement affect the ecological network. This would provide an opportunity for the policy framework to encourage and direct infrastructure development associated with growth in a clustered way that protects natural areas and minimizes the negative ecological effects caused by fragmentation (Forman, 2019). Then, considering growth and development in this context enables a more comprehensive picture of the landscape to emerge, one that attempts to reduce conflict with landscape ecological dynamics by better integrating abiotic, biotitic, and cultural landscape resources.

Consideration of other human-influenced land uses beyond urban will also be important in the RM of Ritchot context, especially as it relates to agricultural land uses. The research identified the high presence of agriculture in the sample site that constituted approximately 47 percent of the landscape surface area (Table 4.1). As discussed in the literature review, modification of the landscape toward a more agricultural landscape took place in areas with suitable soil and drainage conditions, often located in upland areas of the landscape. In essence, the upland areas of the municipality were modified from grasslands to agriculture. In the sample site, the fairly modest presence of forest is located largely within riparian zone, areas that were likely deemed unsuitable for agriculture and therefore saved from conversion to other uses. However, should quantitative mapping analysis be replicated at a higher scale or within an upland location, the result would likely reflect a higher abundance of agricultural lands as compared to the sample site. What this tells us is that ecological network connectivity in the RM of Ritchot and likely the region will need to be considered within a highly modified, agricultural land use context. Therefore, climate change resilience will need to be built into an agricultural landscape.

Peri-urban locations with agricultural land use like the RM of Ritchot are areas of substantial heterogeneous structure and function and have increasingly required strategies that focus on diversification and adaptability to secure their survival (Caldwell, et al., 2017). Integrating an approach like ecological network planning within an agricultural context would enable for landscape ecology principles to be applied to productive lands. This would facilitate the identification and consideration of natural lands within an agricultural landscape which could inform strategies for their conservation and restoration within a productive landscape. This could include developing policy that encourages and maintains natural ecosystem micro habitats like large trees, wood lots, shelterbelts, grasslands and wetlands within the agricultural landscape. In doing so, policy could support the development of stepping stone patches that facilitate ecological flows, add heterogeneity to the landscape, and enhance biodiversity in an agriculture dominated landscape (Forman, 2019). This could also include exploring the value agricultural lands provide to biodiversity and ecosystem services as agricultural lands deliver a number of ecosystem services that contribute to human well-being and livelihoods. Concepts like agro-ecology could be explored to identify strategies to developing policies that could support an ecological approach to agricultural land use and development. In this way clarity would be provided as to whether agricultural lands would be of most value to conserve or convert to natural lands to achieve optimal support for biodiversity and ecosystem services. Together, these considerations could support spatial patterns that enhance biological resources and ecosystems services and builds climate change resilience within the agricultural landscape.

Overall, what becomes evident is that the quantitative mapping analysis completed in this practicum provides a way to spatially locate land uses in a municipality and guide growth and development toward areas that reduce negative effects on the ecological network while also identifying land uses that may be in conflict with either the protection or restoration of the ecological network. Furthermore, the analysis can provide a way to explore the relationship between the ecological network and the land designation policy framework, thereby providing a tool that can help guide policy decisions toward those that support the dynamic structure and functions of the ecological network. This can provide the policy framework to evaluate the relationship between land use and guide spatial landscape patterns toward a configuration that better support a multifunctional landscape and considers key land uses, like agriculture, in the context of ecological protection and restoration.

Regional Land Use Planning Application:

Growing metropolitan areas become increasingly interdependent as functional linkages are established across jurisdictional boundaries thereby creating communities reliant on common interests (Anderson, 2015). Regional land use planning is an effective tool to establish a vision based on common interest as it establishes a single planning and development decision-making framework that aims to improve functional linkages between municipalities by better understanding the complex links between municipal land uses and their competing and complementary aspects (Government of Australia, 2015). This reduces fragmentation among the various municipal governments that compose a metropolitan region as it identifies the imposed inefficiencies of decisions made by one municipality to another (Feiock, 2009). Regional land use planning attempts to address these inefficiencies by encouraging better cooperation and collaboration between municipalities to support the coordination of land use planning and development in a way that increase the diversity of function in the landscape (Smits, 2015). This can help guide the region toward a vision that is multifunctional in essence where spatial patterns both accommodate growth and development while also considering environmental protection.

The Winnipeg Metropolitan Region's (WMR) Regional Growth Strategy (RGS) sets the common vision for the metropolitan region, thereby providing the guide to regional land use planning efforts. This practicum aimed to investigate how to address the RGS action item to recommend policy to define and legislate the protection of the ecological network to ensure resiliency in built into the region. As the quantitative mapping analysis undertaken as part of this practicum provides a way to define the ecological network to ensure resiliency is built into the region, it identifies key physical features in the landscape that provide the baseline conditions needed to develop policy areas to protect the green space network. However, the WMR does not have legislative authority to set policy in the metropolitan region and therefore could not legislate its protection. The *Capital Region Partnership Act* provides the legislative directive for metropolitan municipalities to discuss common issues relating to land use planning, infrastructure development, and environmental protection, and develop regional solutions (Province of Manitoba, 2006), however, policy setting authority resides at the municipal governance level. Because policy decisions of a municipality have external effects on the ecological network of other municipalities, initiatives involving resource systems, like establishing an ecological network, rely on functional collective action (Feiock, 2009, p. 358). As such, without a formal structure to set policy at the regional scale the WMR will need to encourage collective action amongst individual municipalities to set policies that define and protect the ecological network in a similar way across the region. Then, to encourage the application of the quantitative mapping analysis in municipalities as discussed in the previous section and satisfy the action item set in the RGS will rely on a substantial degree of cooperation and collaboration amongst municipalities to coordinate land use and infrastructure growth and development and environmental protection. By collaborating, the region can identify ecological network components that fall outside municipal boundaries that may create value for the network as a whole and coordinate land use and development accordingly. However, this will require fragmentation between local governments across the metropolitan region be reduced, which will rely on a motivation for cooperation (City-Region Studies Centre, 2007).

Defining the ecological network to legislate its protection will require municipalities prepare and interpret the relevant information necessary to identify components of the ecological network and opportunities for its protection and restoration. However, municipalities are often limited in their planning capacity and resources to address such emerging issues (Friedmann, 1971). As such, municipalities may be motivated to cooperate and collaborate on a regional scale as regional land use planning provides an opportunity for individual municipalities to access surplus capacity and secure specialized expertise from other jurisdictions and the regional planning body (Urban Systems Ltd., 2005). This would be especially important for municipalities interested in undertaking an analysis like the one completed as part of this practicum as it requires an understanding of complex scientific concepts, an ability to undertake data collection and interpretation, as well as digital mapping capabilities. Then, regional land use planning provides a way for municipalities to access expertise and make available experience and knowledge not necessarily obtainable to individual municipalities.

The WMR could play an important role in adding capacity and resources by coordinating municipal land use to link the various local systems. The region can facilitate collaboration between municipalities to encourage the development of homogeneous land designation framework, both within municipalities and across them, that creates partnerships while also reducing duplication and policy conflict across the region (Feiock, 2009, p. 369; Government of Australia, 2015). This would attempt to reduce fragmentation of the municipal policy framework across the metropolitan region and create an aligned, consistent land use designation framework that best supports the implementation of ecological network protection. This could help develop a spatial pattern in the region that considers the cross jurisdictional functional relationships between settlement structures, regional economic systems, and resources cycles helping to create a common regional identity that encourages it to act as a single entity (Anderson, 2015). To do this, the WMR could hold planning workshops with key expert stakeholders to discuss the concept of ecological network connectivity, regional priorities that would affect the network, and the vision for the landscape. Stakeholders could include: Municipal Planners/Planning Districts, Watershed Planning Authorities, International Institute of Sustainable Development, Ducks Unlimited, Manitoba Heritage Corporation, and Keystone Agricultural Producers among others. This way, the development of the ecological network could seek external input and adapt the concept to reflect stakeholder input.

In addition to standardizing the municipal policy framework, the WMR could assist in standardizing the way the ecological network is defined. For example, the WMR could establish a common land cover type classification system to characterize and quantify the ecological network and produce a template to be used in municipalities. This would reduce the potential for discrepancies in the quantitative analysis and ensure the development of a mapping tool that facilitates compatible comparison of landscape metrics across the region. In doing so, reducing unnecessary variation, inconsistency, and complexity in how the ecological network is defined across the region and creating objective criteria to evaluate the protection and restoration of ecosystems. In this way, municipalities across the WMR could share a similar vision that would support the development of an ecological network across municipal boundaries.

Overall, the ecological network quantitative mapping analysis undertaken could be applied at a regional scale but because of the current regional governance structure, regional planning would likely take more of supporting role as opposed to an authoritative role. In taking this supportive role, the WMR can encourage municipalities through collaboration to take coordinated policy action that supports the protection and restoration of ecosystems in municipalities. Then, municipalities can support the development of an ecological network in a multifunctional context and guide growth and development in a way that better aligns with metropolitan structure and functions while supporting regional biodiversity. In doing so, building climate change resilience into the region.

5.4 Summary

This chapter provides a synthesis of the research finding and analysis to understand how land cover type classification and quantification of landscape composition and configuration define the ecological network, identify opportunities for connectivity, and the utility this presents the RM of Ritchot and the WMR. The chapter outlined the critical need to develop a classification system that reflects ecological network objectives to ensure the accurate quantification of landscape compositing and configuration. The chapter demonstrated how the SLPF and the ArcGIS program facilitated a pattern-oriented quantitative mapping analysis despite its shortcomings. This revealed that composition is characterized by ecosystem richness, abundance, and diversity whereas configuration is characterized by subdivision, size, clustering, and contiguity. The chapter clarified how characterization of landscape composition and configuration defined the ecological network and provided a way to evaluate its components in relation to the four indispensable patterns key to reducing biodiversity loss. This identified how the ecological network could be defined to consider spatial patterns that develop a cohesive, connected ecological network that supports biodiversity and continued delivery of ecosystem. While the quantitative mapping analysis provided limited information as to biodiversity and ecosystem services, it provided a broad understanding that could serve as the basis for future analysis to render the definition of ecological network more robust. The chapter provided information as to how the quantitative mapping analysis could serve as the baseline to conduct scenario planning that would identify the option that best supports spatial patterns that maintain biodiversity and the continued delivery of ecosystem services. This could then support municipal land use planning develop a vision for the landscape that considers within its land designation policy framework provisions to protect and restore the ecological network while also considering the multifunctional aspects of the landscape and guide growth and development in way that least disrupts the cohesion of the network. Finally, the chapter revealed that although regional land use planning in the Winnipeg Metropolitan Region can not implement policy to protect the ecological network, it can facilitate collaboration between municipalities to reduce duplication and political conflict and add capacity and resources to developing an ecological network in the region. This provides an opportunity to motivate municipalities to act together and coordinate land use and development in a way that standardizes the land designation policy framework and the way the ecological network is defined in effort to guide growth and development while protecting the ecological network. The next chapter responds to research questions, provides recommendations for future research, and provides a conclusion to the research practicum.

Chapter 6: Conclusion

6.1 Introduction

This practicum provides a small contribution to determining how to integrate ecological connectivity within the municipal framework of the Winnipeg Metropolitan Region. This research sought to address a gap in practice as to how to apply landscape ecology principles to support reduced biodiversity loss and enhanced connectivity to meet the region's environmental stewardship priorities. This practicum also sought to develop a visual tool to help communicate a defined ecological network and opportunities for its connectivity and facilitate the protection of the network in the municipal land use and development policy framework. Using the ArcGIS spatial mapping tool, the visual tool developed provided a way to visualize results of landscape metric evaluation. The Sustainable Land Planning Framework guided the selection and application of landscape metrics necessary in capturing key criteria needed to evaluate landscape composition and configuration. The visual tool helped better define, measure, and evaluate the ecological network that could support the development of future land use planning policies that reduce biodiversity loss and guide growth and development towards a spatial pattern that least disrupts the formation of a cohesive ecological network.

To define and measure ecological network connectivity, a comprehensive literature review was conducted that explored landscape ecology principles and its links to biodiversity and climate change in effort to understand its connections to the land use planning context. The literature review informed the development of the visual tool and highlighted key steps to take and criteria to use to evaluate the current condition of an ecological network and determine where connectivity can be enhanced. A precedent review of ecological network plans was completed where plans were reviewed from the City of Ottawa, City of Edmonton, and the Halifax Regional Municipality. The precedent review clarified how other jurisdiction have defined and organized their ecological network within their local planning contexts. Finally, a quantitative mapping analysis was completed with the use of landscape metrics provided by the Sustainable Land Planning Framework and the ArcGIS spatial analysis tool. This demonstrated a practical approach to communicating the definition and measurement of the ecological network. The quantitative mapping analysis was also used to demonstrate the potential application of the tool as a way to consider biodiversity and ecological network connectivity within the municipal and regional land use planning context.

The research methodology enabled research findings to be generated, analyzed, and synthesized in effort to address research questions. The following sections of this chapter respond to research questions, offer suggestions for future research, and finally, provides this practicum's conclusion.

6.2 Responding to Research Questions

This practicum aimed to develop a visual tool that could be adapted and used by municipal and regional planners to provide decision-makers with a framework to define the ecological network and facilitate its protection. The study sought to address two objectives by answering six research questions.

> *Research Objective A:* To demonstrate how landscape ecology principles can be used to quantify existing land cover types, define the ecological network, and identify opportunities for connectivity in the RM of Ritchot to inform how to address municipal and regional policy objectives and build resilience into the landscape.
>
> *Research Objective B:* To develop a visual tool for municipal and regional planners and decision-makers to better understand, define, and communicate ecological network planning as it relates to biodiversity in the RM of Ritchot.

To help guide the development of a visual tool, this research used landscape ecology to establish the necessary criteria for evaluation and ecological network planning to guide the process of developing an ecological network. The Sustainable Land Planning Framework was used as methodology for quantitative analysis of the landscape as it provided applicable landscape metrics to measure landscape composition and configuration and steps to calculate results. Landscape land cover types were classified to reflect objectives of the ecological network and mapped using the ArcGIS spatial analysis program to visually illustrate components of the ecological network. Once a baseline context was established, application of landscape metrics enabled the visual tool to reflect key evaluation criteria and facilitate identification of key areas to protect and restore ecosystems to reduce biodiversity loss and enhance ecological network connectivity. This also allowed for clarification as to how such a visual tool could be used to understand, define, and communicate the ecological network in the land use planning process and guide growth and development in a way that protects the network. The following section provides a response of some detail to research questions and how each question was answered.

Q 1 How can landscape ecology principles be used to define land cover type ecological networks and better understand how connectivity can support biodiversity and the continued provision of ecosystem services?

The literature answered the research question starting by providing a detailed understanding of biodiversity and its connection to ecosystem services, then exploring landscape formation and dynamics with the use of landscape ecology principles, ending with how to define an ecological network to reduce biodiversity loss by following the principles of landscape ecology. In doing so, the reader is provided an understanding as to how landscape ecology principles can define components of an ecological network and clarified why landscape connectivity is important to consider when attempting to reduce biodiversity loss and continued delivery of ecosystem services. The landscape ecology principles discussed in the literature were applied in Chapter 4 and expanded on in Chapter 5. The answer to how landscape ecology principles can define land cover type ecological networks and better understand connectivity to support biodiversity and the continued provision of ecosystem services was made evident in these chapters. Chapter 4 demonstrated the application of landscape ecology principles by measuring key criteria with landscape metrics from the Sustainable Land Planning Framework and revealed the landscape's composition and configuration. Chapter 5 clarified that ecological networks are defined by key characteristics of landscape composition – structural form, ecosystem richness, abundance, and diversity – and configuration – ecosystem subdivision, size, clustering, and contiguity - and by the four indispensable patterns that shape its future state. Since forming a cohesive, connected network that supports the continued flow and movement of energy, material, and species is a key objective of an ecological network, it must be defined in way that not only protects ecosystems of high biodiversity value but also restores connectivity between ecosystems in areas that support ecological processes across the landscape. Chapter 5 showed that defining ecological networks in this way provides a degree of understanding of ecosystem class level biodiversity present in the landscape and the associated potential ecosystem services produced. However, the significant omissions in this regard include species or genetic level biodiversity insight as well as specific ecosystem services provided and their degree of function.

Q 2 In what ways can enhanced understanding of ecological network connectivity help to organize and define land use in the Municipality of Ritchot and the Winnipeg Metropolitan Region to add biodiversity related climate change resilience?

This question was answered by the literature review as it explained the scientific as well as land use planning aspects of this question. First in terms of the science aspects, the literature explained the connection between biodiversity and climate change, the impacts of land use on biodiversity, and the way in which ecological network connectivity can add climate change resilience. Secondly, in terms of the land use planning aspects, the literature revealed the higher level international, national, and provincial policy guiding municipal biodiversity and climate change efforts, introduced how ecological network planning could be integrated within the municipal planning framework and organize and define land use, and provided the process to follow to develop an ecological network. This allowed for the reader to understand that ecological network planning takes a multifunctional approach that integrates landscape ecology principles into the planning process by creating a baseline of underlying physical features and protecting them with supporting policy enacted through the comprehensive community plan. The research question was also answered by the research discussed in Chapter 4 as it demonstrated the application of integrating an ecological network within the municipal planning framework. This was demonstrated by illustrating the composition and configuration of the ecological network in relation to the existing policy framework, which enabled spatial patterns to emerge. In doing so, the spatial relationships between ecological and human structures was demonstrated and the key physical features of the landscape identified. This enabled evaluation of physical features against the land use planning framework to best reduce biodiversity loss and support ecological processes, in doing so adding climate change resilience. Furthermore, the literature review and Chapter 4 demonstrated the need to understand past historical landscape conditions to assess land use change through time as this may assist in providing historical land transformation context. This enabled for the identification of current key physical features to be compared to the historical context and guide ecosystem protection and restoration priorities towards historically significant areas. In doing so, a way was provided to organize and define land uses that may best facilitate a cohesive network that supports biodiversity and adds related climate change resilience.

Q 3 What lessons can be identified from other municipalities and regions attempting ecological network planning that could be applied to municipalities within the RM of Ritchot and the Winnipeg Metropolitan Region?

This question was answered by the precedent review undertaken which provided a detailed summary as to how each jurisdiction defined their green/open network, followed by how the defined ecological network was used to classify the landscape, ending with how ecological network protection was integrated within the land use planning policy framework. Chapter 5 expanded on these themes and highlighted three key lessons for the RM of Ritchot and the WMR. First, to define the ecological network it is critical to ensure the classification system used to identify components reflect the desired goals and objectives of the network and the distinct local context, spatial scale, species, and processes of concern. Second, it is necessary to rank ecosystems key to reducing biodiversity loss as this facilitates a way to prioritize lands for protection and restoration that have high functional value related to the stated objective of the ecological network. Third, ecological network plans provide the baseline of physical landscape features that can underly and compliment other municipal and regional land use plan, strategies, and programs. These three key lessons can ensure an ecological network is appropriately classified and quantified, prioritized in a way that best meets the needs of desired objectives, and simultaneously compliments the wider municipal and regional planning framework.

Q 4 How can land cover types be classified and quantified? What landscape metrics related to biodiversity should be used?

The literature review answered these questions by explaining how landscapes are quantified by measuring factors of landscape composition and configuration, how biotic components measured at the ecosystem class (i.e. land cover type) scale can quantify a degree of biodiversity, and finally how landscape metrics can be used to characterize and measure spatial patterns. This provided the reader an understanding of the aspects influencing classification and the general evaluation criteria related to land cover types – ecosystem type, area, size, location, and proximity – to consider and include when quantifying land cover type biodiversity factors. Chapter 4 answered these questions by demonstrating how land cover types can be classified and quantified. The chapter demonstrated how a methodology that uses the Sustainable Land Planning Framework in combination a spatial analysis program like ArcGIS can provided a way to select and apply appropriate landscape metrics that can quantify key evaluation criteria. An omission of the SLPF is that it fails to identify how to define the parameters of a patch as well as fails to offer instruction on how to acquire data through digital mapping analysis thereby forcing an element of mapping expertise on the analyst. This question was further answered by findings of Chapter 5. This chapter clarified how quantification of landscape composition and configuration is highly influenced by the classification scheme used as it is developed as a result of goals and objectives of the ecological network, the dataset used in the mapping analysis and the distinctions made by the analyst. Then, the classification scheme used will highly influence the quantitative analysis and results obtained. The chapter also explained how if a desired objective is to quantify land cover type transformation through time, then a consistent classification system that reflects a similar scale and context is imperative as this supports the evaluation of key criteria that allows for an accurate depiction of landscape composition and configuration change thru time.

Q 5 What is the current condition of ecological connectivity in the Municipality of Ritchot? Where are the gaps in the ecological network? Where is the landscape fragmented? How are urban and agricultural land uses organized? What are the spatial landscape conflicts and opportunities to enhance connectivity?

This question was answered by the quantitative mapping analysis completed in Chapter 4 that determined the current composition and configuration of the ecological network, which allowed for the determination of where the network was fragmented and where gaps existed. Fragmentation was mainly addressed by understanding aspects of patch subdivision, size, clustering, and contiguity, where the Sustainable Land Planning Framework provided the landscape metrics to measure these aspects. This clarified the number of patches within an ecosystem class, their relative area, arrangement, position, and proximity, and enabled the recognition of areas of biodiversity conglomeration, and key patches and "near lines". This identified key areas to preserve and network gap areas to restore and address connectivity. The analysis also answered two parts of the question by identifying how urban and agricultural land uses were organized in relation to identified natural ecosystem clusters, in doing so showing the potential landscape conflicts to enhancing connectivity between natural ecosystem patches and clusters. Opportunities to enhance connectivity were demonstrated by evaluating ecosystem patches and clusters as they related to land use designations and waterbody and wetland buffer areas as these policy areas inherently provided an opportunity to protect existing ecosystems and support the restoration of ecosystems for better connectivity. This also demonstrated the spatial conflicts the land designation framework may present protecting the ecological network by identifying the relationship between the network and the land designations that would support growth and development.

Q 6 How can the visual tool inform land use planners on how to define a land cover type ecological network? How can this tool assist in guiding growth and shaping land use patterns while also achieving municipal and regional environmental objectives?

The quantitative mapping analysis discussed in Chapter 4 answered the first part of this question. First, the analysis demonstrated how a visual tool can depict the current condition of an ecological network based on quantitative evaluation made possible by landscape metrics like those in the Sustainable Planning Framework thereby informing planners on how define a baseline context of network. Second, the visual tool makes possible the visualization of key patches and "near lines" that can inform planners on how define an ecological network that best supports biodiversity and enhances connectivity. Third, the visual tool provides a way to visualize ecosystem clusters, key patches, and "near lines" together, providing an opportunity to guide scenario planning visioning and option evaluation and inform planners as to what ecological network strategy would best support spatial patterns that maintain biodiversity and associated ecosystem services. The second part of this question was answered with the findings of Chapter 5. The chapter explained how the visual tool informs planners by allowing land uses to be spatially located, in doing so identifying existing land uses and patterns in relation to the ecological network. This provides a way for planners to consider growth and development options in the context of the ecological network and direct it toward areas that would least affect the development of cohesive, connected network. Furthermore, the visual tool informs planners by providing a baseline of key physical landscape element underlying the ecological network that can then be used to inform and compliment other key land uses like agriculture and support a multifunctional landscape approach to land use planning. Chapter 5 also explained that although the WMR does not have policy setting authority, the WMR can motivate municipalities to cooperate and collaborate at regional scale to establish a common policy framework that protects the ecological network within municipalities and thereby across the metropolitan region. This may require the region add capacity and resources through coordination of municipal land designation frameworks and standardization of the ecological network land cover type classification. In doing so, the visual tool could inform planners as to how to define an ecological network across the region in a consistent way that could encourage its protection and restoration of while also creating a multifunction network that support metropolitan growth and development.

6.3 Suggestions for Future Research

The research undertaken as part of this practicum contributed to the information available on how municipalities in the Winnipeg Metropolitan Region can support ecological network protection by demonstrating how landscape ecology can be applied to understand, define, and communicate ecological network planning. The following section discusses elements of the research that were raised in Chapter 5 Discussion and describes next steps to undertake to address these points.

6.3.1 Develop a More Robust Ecological Network

A suggestion revealed from the synthesis of the research results and analysis was to define the ecological network in a more robust fashion by including additional measures to value ecosystem patches. This would allow patches to be further ranked and enable the ecological network to better prioritize for protection and restoration patches that have high biodiversity and ecosystem services value. Chapter 5 provided two main suggestions as to how the visual tool could be developed that would allow for a more robust definition of the ecological network:

- Explore and evaluate biodiversity at other hierarchal scales, and
- Explore and evaluate abiotic ecological functions.

Biodiversity exploration and evaluation at other hierarchal scales would include the species and genetic levels and could focus on analyzing factors of species composition, life cycle, and behaviour. Abiotic ecological function exploration and evaluation would include better understanding of the landscape’s biophysical characteristics beyond land cover types and could focus on confirming ecological services present in the landscape and quantifying the degree of ecological function provided. The intent of both these suggestions is to find a way to more fully evaluate the value of patches and ensure a more comprehensive evaluation is used to rank patches for prioritization and restoration. This would provide an opportunity to explore evaluation criteria not included in this research practicum. This way, when the ecological network is defined and integrated into the planning process, lands suggested for protection and restoration would reflect more robust criteria and better support the establishment of a baseline context that reflects multiple ecological biotic and abiotic functions.

Part of the process of further exploring and evaluating these factors would include the collection and analysis of new primary data. This may provide an opportunity for the Winnipeg Metropolitan Region to add capacity and resources to municipal planning as primary data collection and analysis could be retrieved at the regional scale and allow for standardization of additional criteria across the region. Furthermore, completing this exercise at the regional scale may allow municipalities to access funding unavailable to them otherwise to undertake such research, like the Manitoba Conservation Trust. The Trust was established in 2018 as a way for the Province of Manitoba to invest in local projects that support the implementation of the *Made-in-Manitoba Climate and Green Plan* (Province of Manitoba, 2019). The Trust aims to support projects that deliver a broad range of ecosystem services and benefit watersheds, habitat and wildlife, connect people and nature, advance innovation and conservation planning, and enhance soil health on Manitoba's working landscapes (Manitoba Habitat Heritage Corporation, n.d.,a). As further exploration and evaluation of biodiversity and abiotic functions in the Prairie Ecozone would support better understanding of ecosystem services and benefits to these project areas, the Trust may be a realistic option for municipalities to access funding to undertake this type of work. However, municipalities are not eligible applicants, whereas, as a not-for-profit agency the Winnipeg Metropolitan Region would be (Manitoba Habitat Heritage Corporation, n.d.,b). Such an opportunity can be used to motivate collaboration amongst metropolitan region municipalities whilst encouraging the coordination and standardization of the ecological network across the region, while also providing a valuable service to municipalities that they may not be able to undertake individually.

6.3.2 Refine the Visual Tool to Better Inform the Planning Process

To integrate ecological network analysis and implementation into the planning process and support the use of the visual tool as a practical planning tool, better understanding of the relationship between the existing ecological network, its future goals, and the land designation framework is needed to enable policy alignment across land designations and support a cohesive ecological network. In this regard, future research could focus on two key factors: facilitating scenario planning and supporting a common land designation policy framework.

Facilitate Scenario Planning

While the recommendation provided in *Section 6.3.1* would provide a way to more robustly evaluate individual patch value as it relates to other hierarchical scales and ecosystem services, the research synthesis revealed a need to further rank prioritization and restoration options as they relate to the value provided to the landscape as a whole. Chapter 5 revealed how scenario planning presents a way to compare the existing ecological network to past conditions and future aspirations in effort to determine which spatial pattern option best benefits the landscape. While the methods deployed in this research to understand past conditions provide a broad understanding of historical context and land transformation through time, they were unable to quantify this transformation. As such, comparison of the current ecological network to past conditions is limited. Future research in this regard could focus on how to quantify past conditions and involve environmental reconstruction techniques like map digitization and standardization of classification. This would facilitate the complex analysis associated with quantifying the landscape by rendering historical data in a more manipulative digital form and attempt to reduce the comparative limitations associated with classification system, scale, and context of historical maps.

The methodology undertaken in this research provided the baseline condition of the ecological network to which options for a future landscape could be compared to, however, evaluating options to this future state requires an understanding of a goal for the future landscape. This requires a vision for the landscape be established, one that not only set goals related to biodiversity but a vision that integrates these goals with desired objectives for growth and development. The research cited Environment Canada's guidebook for habitat conservation and restoration targets that could act as possible biodiversity goals for the RM of Ritchot, however, these targets are focused on the biodiversity of the Great Lakes areas of concern in Ontario. While many objectives may be applicable to the RM of Ritchot and Winnipeg metropolitan region context, others may not. Then, future research could focus on developing similar guidelines for Winnipeg metropolitan region context with greater emphasis on the Prairie Ecozone, or at minimum the Manitoba context. By establishing these guidelines in the appropriate context, a municipality could set biodiversity targets that best suit the area and better reflect the role of grassland ecosystems. This would facilitate scenario planning by enabling the comparison of the baseline context to different options for ecosystem protection and restoration that help the municipality meet biodiversity targets specific to a Prairie Ecozone. The ecological network could then be defined in a way that integrates biodiversity targets and help the municipality consider this network in relation to growth and development objectives.

Finally, further research is required to explore concepts and strategies that integrate ecological principles with agricultural land use and development. This would support the application of the visual tool to the greater landscape and acknowledge the significant impact of agricultural land use to biodiversity and ecosystem services. In this way, information could be gathered on how natural lands can be conserved and restored within productive lands and how agriculture could better support biodiversity and ecosystem services. This would help clarify whether agricultural lands should be conserved or converted to achieve optimal support for biodiversity and ecosystem services, and best build climate change resilience into the landscape. Together, these recommendations can enable the evaluation of the existing ecological network to past conditions and the evaluation of ecosystem protection and restoration options to a desired future landscape. The Winnipeg Metropolitan Region could facilitate the use of the visual tool in the capacity discussed by applying for funding to the Manitoba Conservation Trust. Recommendations could be developed into projects that would present a way to advance planning in the Manitoba by providing information on the historical ecological context in a digitized format, by establishing key guidelines to guide biodiversity planning in the WMR, and by clarifying the relationship between agriculture, biodiversity and ecosystem service. In this way, the WMR would be provided key information to standardize the evaluation of ecological network options, and its subsequent definition and development in metropolitan municipalities.

Support a Common Land Designation Policy Framework

While the RM of Ritchot has implemented a land designation policy framework that may support the protection and restoration of the ecological network, it is unknown whether the remaining municipalities of the Winnipeg metropolitan region have similar policy frameworks. Furthermore, should this type of policy framework exist in other municipalities, it is unknown whether policies across the metropolitan region would allow for the functional connectivity across jurisdictions. This is a crucial component to establishing a successful multifunctional approach like ecological network planning across a region. To reduce fragmentation of policy among local governments, future research could focus on collecting the information required to build a comprehensive understanding of municipal policy frameworks in place across the region. This research could focus on analyzing the commonalities between policy frameworks and the barriers to coordinating a common framework. As establishing an ecological network across the region requires functional collective action, findings could highlight the benefits to each municipality should a common framework be adopted and be used to motivate regional collaboration towards this policy structure. This could involve the exploration of tools and templates used in other jurisdictions to establish a common framework without the use of a regional authority, and how these tools and templates could be tailored to the Winnipeg metropolitan region context.

6.4 Conclusion

The research undertaken demonstrated the complexity associated with developing a connected ecological network across municipalities in the Winnipeg metropolitan region to add climate change resilience. Developing connected ecological networks relies on understanding the scientific aspects that govern landscape ecological structures and processes, the influence these have on the relationship between biodiversity and ecosystem services, and their connection to climate change resilience. The research demonstrated that even with this knowledge, developing a network to add biodiversity related climate change resilience requires an understanding of other hierarchal scales and abiotic biophysical characteristics, thereby adding complexity. Furthermore, developing a connected ecological network relies on an understanding of the planning aspects that influence land use spatial patterns, how patterns can be directed to support connectivity and biodiversity, and the strategic and policy frameworks that guide and support connectivity efforts. To succeed in this endeavour, the research revealed the importance of a multifunctional approach to developing an ecological network as it integrates the ecological requirements of the network with human-influenced needs. However, in doing so, further complexity is added to the development of the ecological network as multiple human-influenced forms of structures and processes could be considered.

Fortunately, the methodology used in this research simplified the complexity of developing the baseline condition of the ecological network. By using landscape ecology principles as the basis of evaluation criteria, the key factors needed to evaluate landscape composition and configuration were revealed. The Sustainable Land Planning Framework simplified the selection of landscape metrics to evaluate these keys factors and quantify landscape composition and configuration. Completing this exercise with the use of a spatial analysis tool like ArcGIS provided a way to obtain and analyze complex data that facilitated its interpretation and enabled an understanding of and a way to visualize the existing ecological network in the landscape. This provided an opportunity to identify spatial patterns and relationships between land uses. While the research did not focus on the value human-influenced land cover types specifically provide to biodiversity, it provided the baseline landscape context to begin to explore the relationships between these areas and the natural ecosystems that surround them that may impact biodiversity. The research also provided a way to understand the relationships between the policy framework that governs land use and the existing ecological network to begin exploring commonalities and barriers to ecological network protection. This enabled an understanding of how a municipality can consider the ecological network within their land planning framework and how the WMR can support these efforts despite not having policy setting authority. Although there is much more to learn to implement an ecological network, this exercise showed how municipalities can take steps toward considering biodiversity and climate change within their policy framework and assist meeting provincial and national commitments to international biodiversity and climate change conventions.

Overall, the research undertaken as part of this practicum achieved its objectives. However, it demonstrated that ecological network connectivity is but one aspect of building climate change resilience into the landscape. Climate change planning incorporates many aspects of the landscape, with each aspect having complex factors to consider that render building resiliency into the landscape difficult. Yet, the 2018 IPCC report made clear that without local and regional land-use behaviour changes toward those that mitigate and adapt landscape to climate change, limiting global warming may not be possible (Intergovernmental Panel on Climate Change, 2018). As such, there is then urgency for the RM of Ritchot and the WMR to consider methods such as the one explored in this practicum that add landscape resilience to climate change to limit its negative effects to communities and human well-being and livelihoods.

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Appendix A: Historical Maps

Figure A-1 **Map of the Province of Manitoba 1871** (Province of Manitoba, 1871)

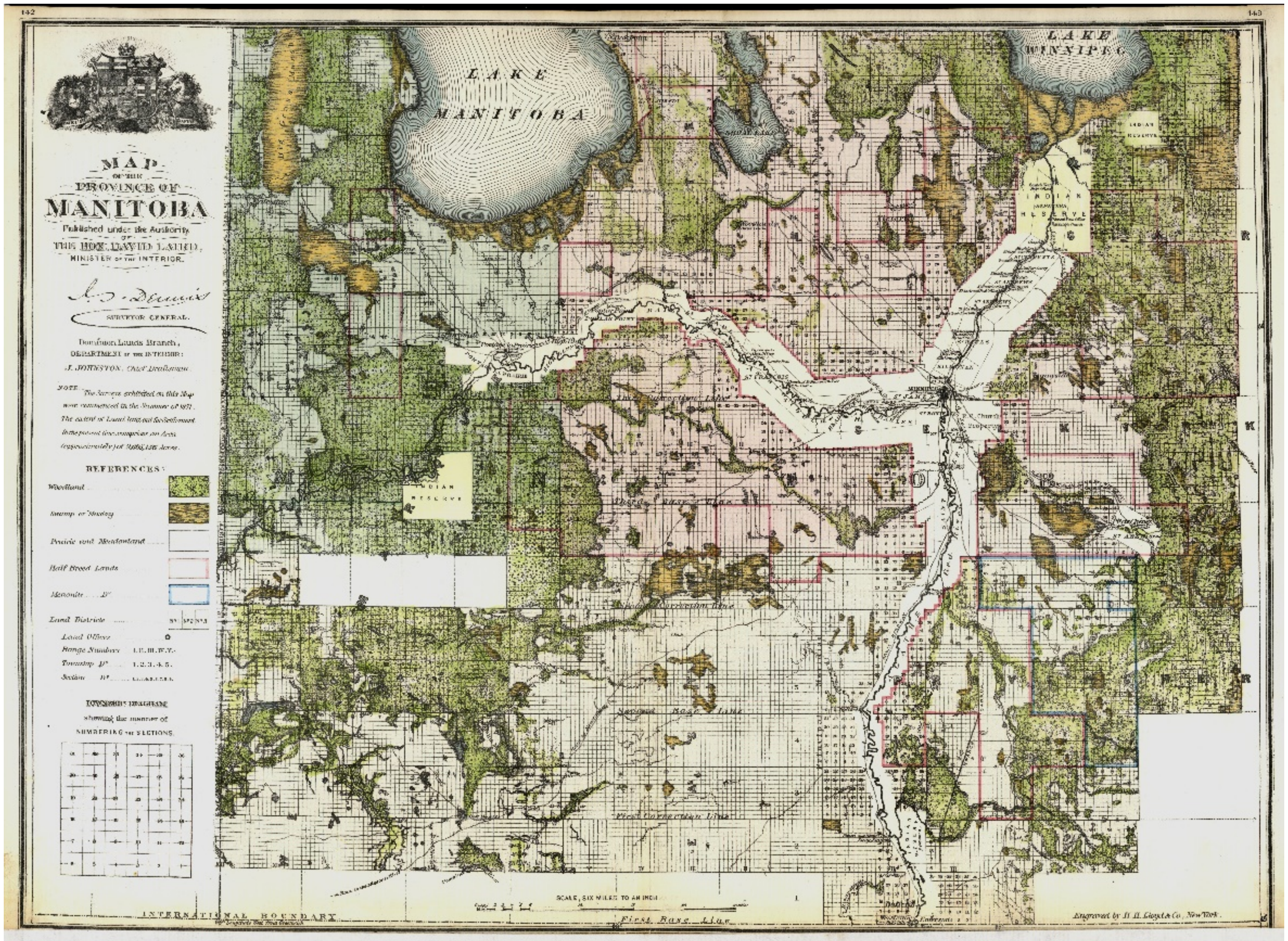


Figure A-2 **Map of the Prairie Region, 1880, Plate No. 7** (Fleming, 1880)

Figure A-3 **Map of Southern Manitoba 1930** (Government of Canada, 1930)

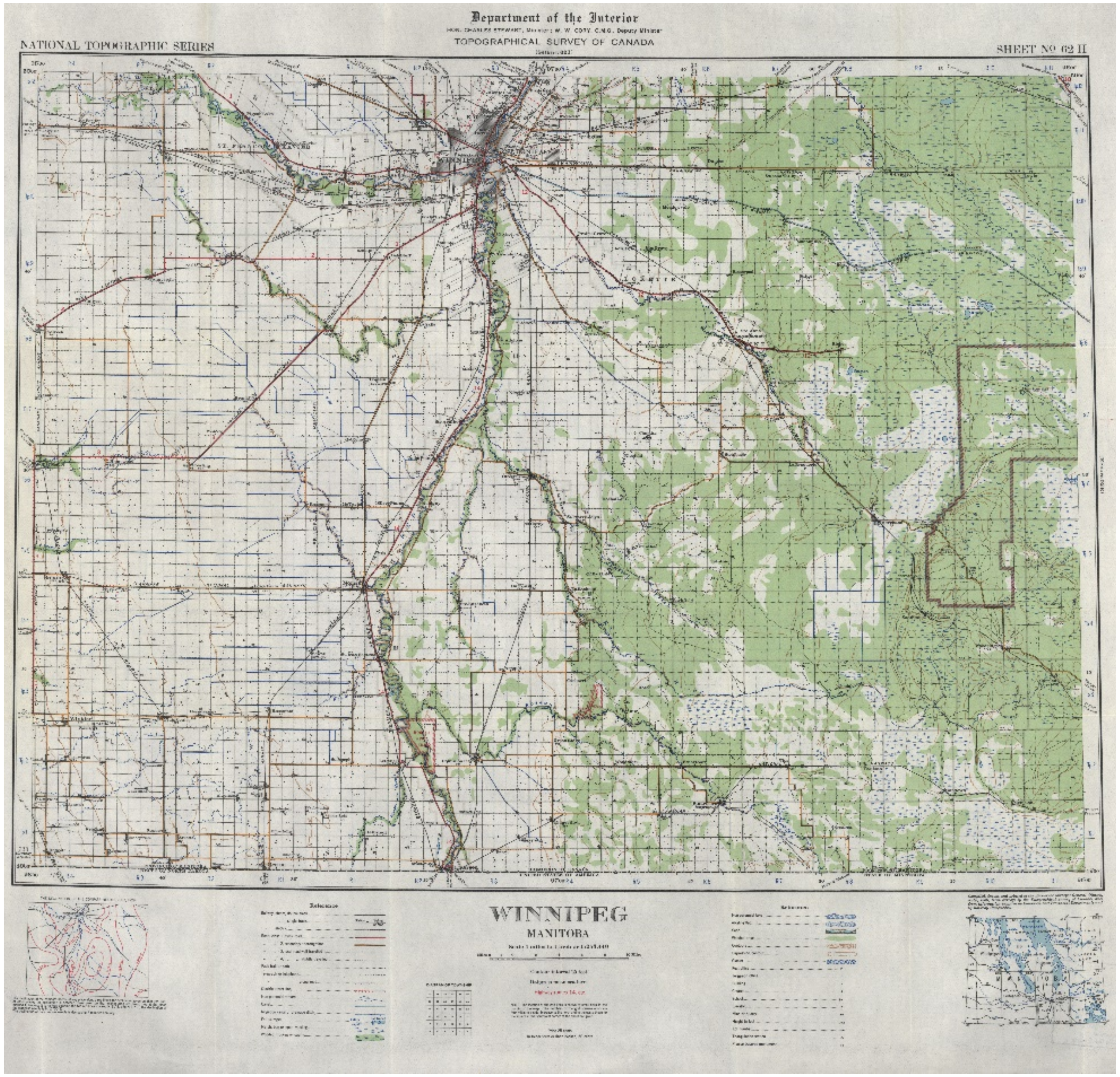


Figure A-4 **Map of Southern Manitoba 1950** (Government of Canada, 1950)

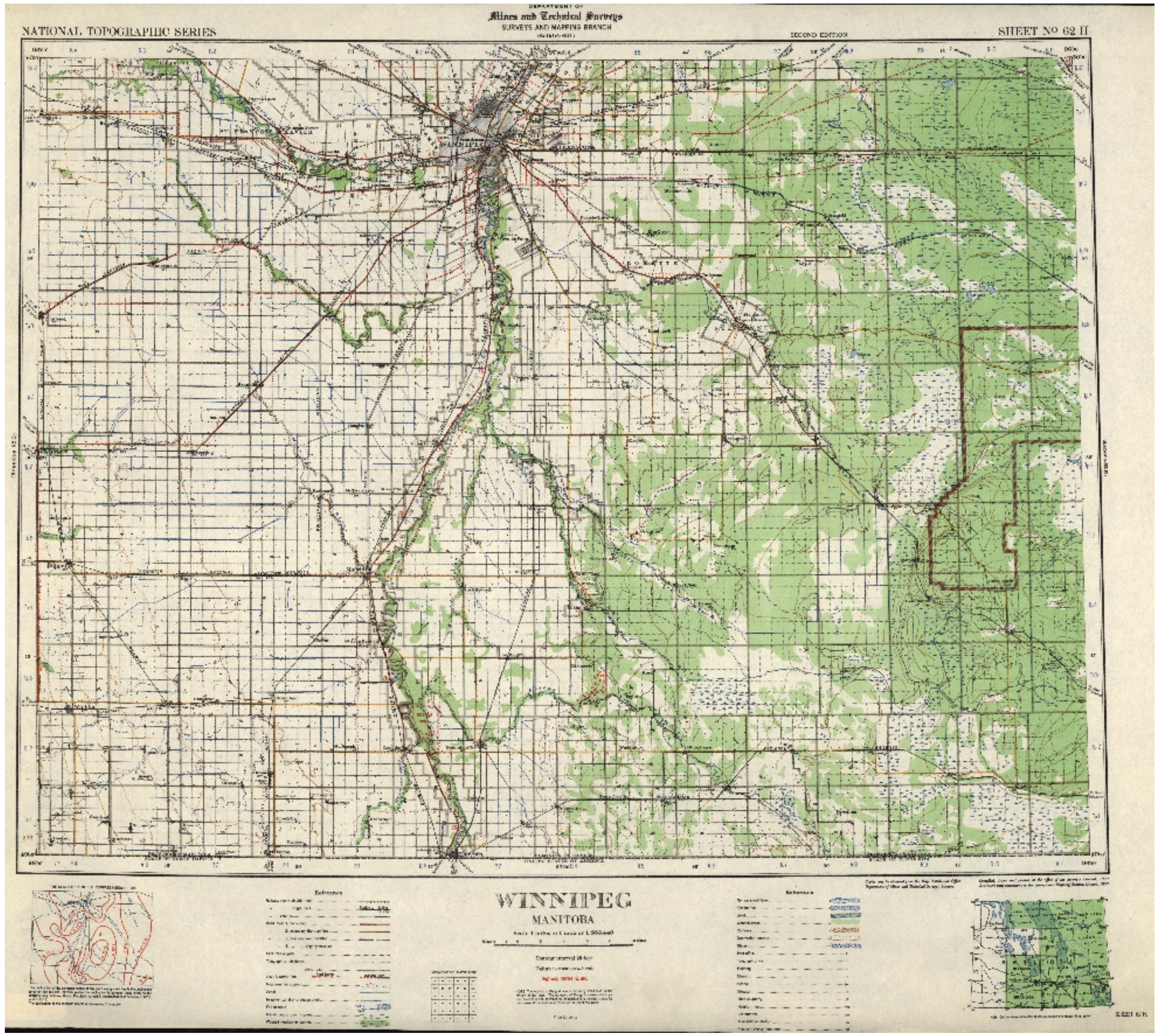


***Figure A.-5* Map of St. Adolphe 1969** (Province of Manitoba, 1969)

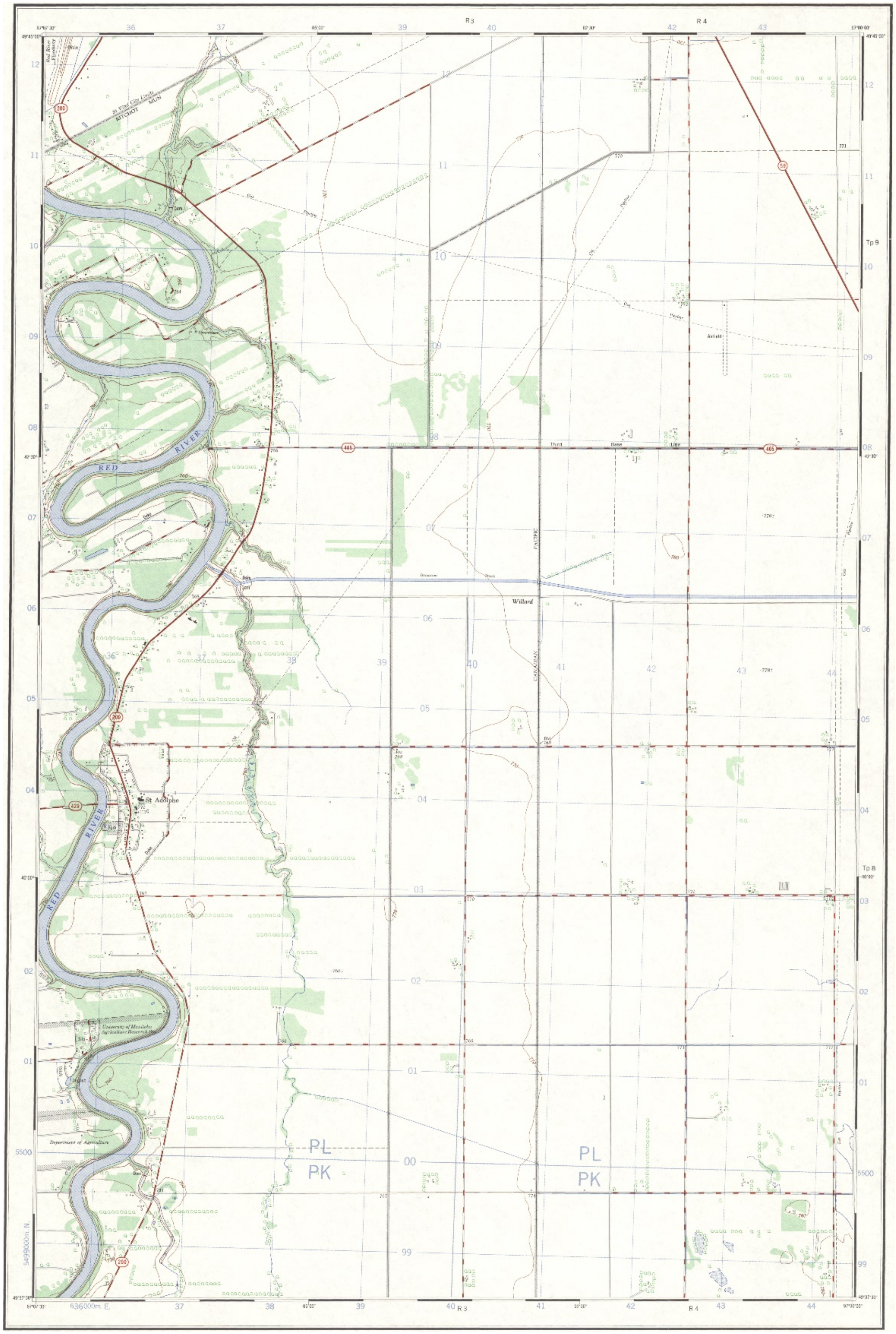
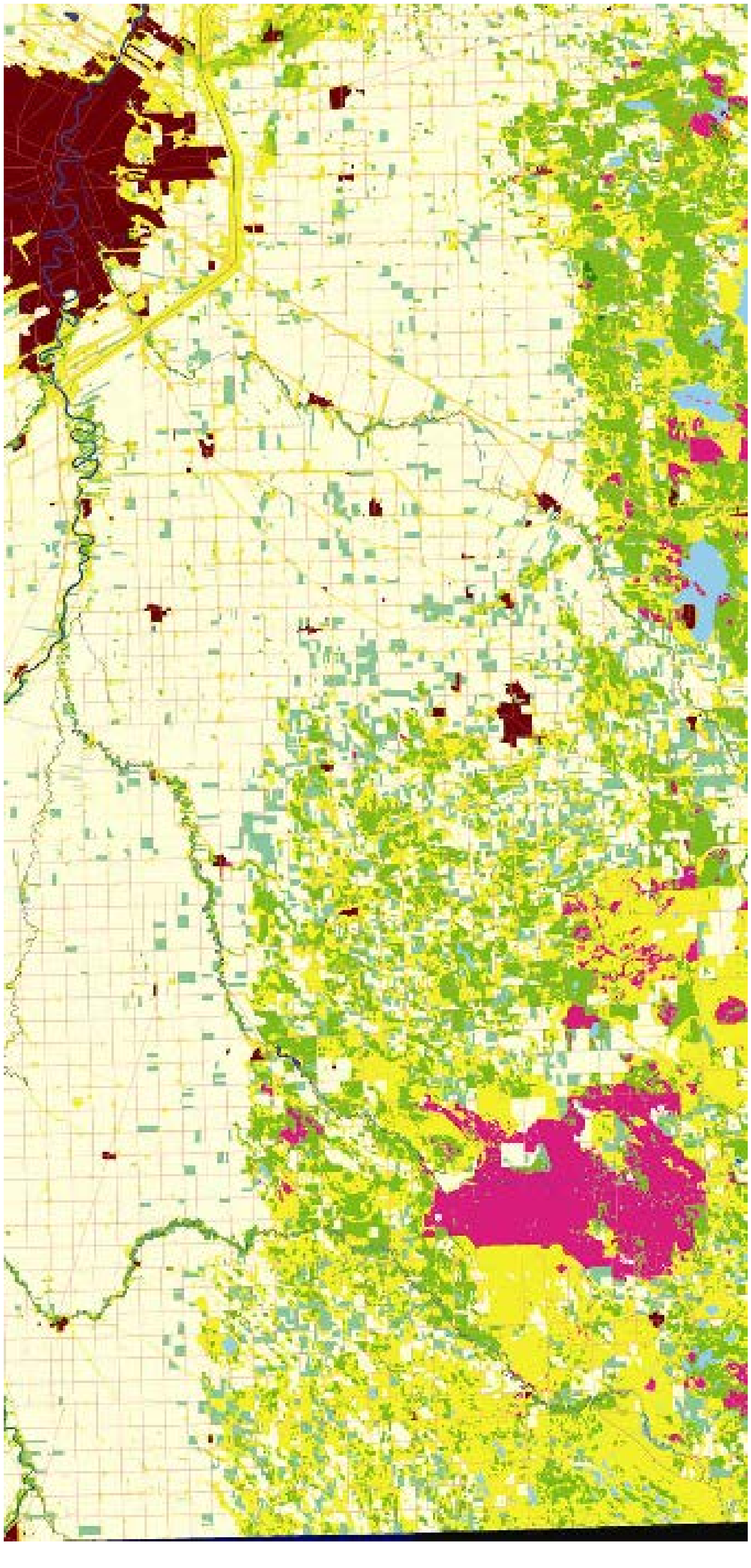


Figure A-6 **Vegetation Cover RM of Ritchot 1999** (Province of Manitoba, 2003a)



Appendix B: List of Shape Files

Feature	Dataset (shapefile)	Reference
Land Cover Type	lcv_winnipeg_2006_shp	Province of Manitoba, 2013a
	lcv_woodridge_2005_shp	Province of Manitoba, 2013b
Waterways	062h11_water_c_l.shp	Province of Manitoba, 2004
Municipal Boundary	bdy_municipality_py_shp	Province of Manitoba, 2018b
Land Use Designations	MG_DEV_PLAN_POLY.shp	Province of Manitoba, 2016

Appendix C: Description of Land Cover Types

Dataset: lcv_winnipeg_2006_shp and lcv_woodridge_2005_shp

Reference: Province of Manitoba, 2013a; Province of Manitoba, 2013b

Text as described in the above mentioned refence:

"Abstract:

This dataset contains coverage of various size, depicting land use / land cover features, which were compiled based on Landsat Thematic Mapper (TM) imagery. The pixel resolution of this data is 30 meters. Upon classification, seventeen land classes are mapped, these being agricultural crop land, forage crops, grassland, open deciduous, deciduous, coniferous, mixed wood forests, treed rock, bogs, marshes and fens, bare rock, burnt areas, forest cutovers, open water, cultural features, roads and trails, fens.

Purpose:

To display land use / land cover features used by earth resources management agencies and for environmental monitoring.

Supplemental Information:

Land Use/Land Cover Mapping of Manitoba

1. Agricultural Cropland: All lands dedicated to the production of annual cereal, oil seed and other speciality crops. This class can be further sub-divided into three crop 0% - 33%, 34% - 66%, and 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 Bodies: All open water - lakes, rivers, streams, ponds and lagoons.
4. Grassland/Rangeland: Mixed native and/or tame prairie grasses and herbs. May also include scattered stands of willow (Salix L.), choke cherry (Prunus virginiana), pin cherry (Prunus pensylvanica) and saskatoon (Amelanchier alnifolia). Many of these areas are used for cutting of hay and grazing. Both upland and lowland meadows fall into this class. There is normally less than 10% shrub or tree cover.
5. Mixed wood Forest: 25% - 75% of the canopy is coniferous. May include patches of treed bog, marsh or fens less than two hectares in size.
6. Marsh and Fens: Wet areas with standing or slowly moving water. Vegetation consists of grasses and/or sedge. Marshes will include common hydrophytic vegetation such as cattail and rushes. Fens will be formed on minerotrophic sites. Areas are frequently interspersed with channels or pools of open water.
7. Treed and Open Bogs: Peat covered or peat filled depressions with a high water table. The bogs are covered with a carpet of Spagnum spp. and ericaceous shrubs and may be treeless or treed with black spruce (Picea mariana) and/or tamarack (Larix laricina).
8. Treed Rock: Exposed bedrock with less than 50% tree cover.

9. Coniferous Forest: 75% - 100% of the canopy are coniferous. Pine (Pinus spp.) and spruce (Picea spp.) are dominant species. May include patches of treed bog, marsh or fens less than two hectares in size.
10. Burnt Areas: Burned forested areas with sporadic regeneration and can include patches of unburnt trees.
11. Open Deciduous: Lands characterized by rough topography, shallow soil, or poor drainage. Supports a growth of shrubs such as willow (Salix spp.), alder (Alnus spp.) saskatoon (Amalanchier spp.) and/or stunted deciduous (Populus spp.) tree cover. An area could have up to 50% scattered tree or shrub cover.
12. Forage Crops: Consists of perennial 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 are included here.
13. Cultural Features: Built-up areas such as cities and towns, peat farms, golf courses, cemeteries, shopping centres, large recreation sites, auto wreck yards, airports, cottage areas, race tracks.
14. Forest Cutover: Areas where commercial logging operations have clear-cut or partially removed a standing forest. Includes areas which have been recently replanted.
15. Bare Rock, Gravel and Sand: Exposed areas of bedrock, sand dunes, and beaches, gravel quarry/pit operations, mine tailings, borrow pits, and rock quarries.
16. Roads and Trails: All highways, secondary roads, trails, cut survey lines, right-of-ways, railway lines and transmission lines.
17. Fens: 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."

Appendix D: Precedent Review Summaries

City of Ottawa

Table D-1 **Ottawa Summary Context**

Plan Name	*Greenspace Master Plan: Strategies for Ottawa's Urban Greenspaces*
Municipal Context	1 municipality – formed in 2001 from the amalgamation of 11 municipalities
Land area	6,676 km^2 (Statistics Canada, 2017d)
Population (2016)	1,323,378 (Statistics Canada, 2017d)
Plan Implementation Date	August 2006

Plan Overview

Since the early 19th century, Ottawa has been integrating greenspace plans into the planning process, however, the concept of a greenway system has only been included in its development plan and by-laws since the 1990s. Prior to the amalgamation of the eleven municipalities that now constitute the City of Ottawa, all municipalities had various mandates and priorities for parks, recreation and the preservation of natural features, each with their own structures of governance and planning practice. With the amalgamation in 2001, steps were taken to identify the network of natural and open spaces across the region and develop a comprehensive understanding of greenspace to a set strategic direction for their management and extension. To address this goal, Ottawa's official plan, *Ottawa 20/20*, directed the civil service to develop a vision for the city's greenspaces; as a result, the *Greenspace Master Plan* was released in August 2006. The plan was built on the region's tradition of greenspace planning but further integrated the concept of a greenspace network into the core of its planning strategies. It was developed using research, geospatial data, analysis, and planning coordination and was completed by characterizing and identifying greenspaces and the network of greenspaces, setting objectives and strategic directions, and aligning policy.

The plan's network approach considers ecological and social functions together and applies a systems perspective to greenspace planning. Five objectives guide the plan and form the basis of its vision: 1) Adequacy of supply; 2) Accessibility to all communities, 3) Quality in design and character, 4) Connectivity among greenspaces, and 5) Sustainability through management plans (City of Ottawa, 2006, p. 9). As the plan predicted that Ottawa's population would grow by fifty percent and reach 1.2 million people by 2021, achieving these objectives was intended to support the protection and extension of the greenspace network in light of predicted growth. The plan made greenspace protection and extension a priority as it recognized the value they provided to overall quality of life, and as such identified a connected network as key to supporting greenspace health. However, the plan only focused on the greenspaces within the urban boundary, a small portion of the Greenbelt, and the adjacent areas where urban development is permitted, and did not include connectivity to rural areas. The plan did acknowledge the connection of urban greenspace to those beyond the urban boundary as an integral component of the broader network and identified a similar greenspace plan for rural

Characterizing the Ecological Network and Connectivity

Part of developing Ottawa's Greenspace Master Plan involved characterizing and mapping the municipality's greenspaces and establishing a network of greenspaces. Key to this was determining what was considered a greenspace, where they were located, and the role each played in the landscape. Furthermore, to establish the network the plan emphasized a need to understand the level of network connectivity that existed, the gaps in the network, how gaps could be filled, and the greenspace network extended. By doing so, the plan was able to support the development of strategies that would enhance public access to greenspace and guidelines to acquire new public land and better connect the network.

To characterize, map and establish Ottawa's greenspace network, the plan applied landscape ecology principles and an ecosystem approach to analyze the broadest spectrum of land cover types that contributed to greenspaces. In this context, the plan considered greenspaces as land that "served one of two purposes: Provision of recreation and leisure opportunities for use and benefit of the public, and Preservation of the natural environment and environmental systems" (City of Ottawa, 2006, p. 10). As such, greenspaces were classified in three broad categories: 1) Natural Lands; 2) Open Spaces and Leisure Lands; and, 3) Other Open Space. To categorize greenspaces, all Natural Lands and Open Space and Leisure Lands were identified and mapped using existing regional vegetation and landform maps. Data sources used included former municipal development plans, by-laws, secondary plans, land use inventories, scientific studies, planning studies, and provincial databases (City of Ottawa, 2006, p. 17). Based on these findings, land cover types identified were classified under either the Natural Lands category or the Open Space and Leisure Lands category; the Other Open Spaces category was combined with the Open Space and Leisure Lands category.

The plan considered the urban greenspace network as a "connected and protected network of natural lands (i.e. wetlands, woodlands, river corridors, and steep slopes) and open spaces and leisure lands that structures the urban area; strengthens distinct communities; incorporates natural features; provides opportunities to improve environmental quality; and increases accessibility to open air recreation" (City of Ottawa, 2006, p. 30). This included both private (e.g. cemeteries, golf courses) and public lands (e.g. parks, sports fields, multi-use paths). In addition, the network enhances land environmental function, preserves diversity, and enhances opportunities for open space and leisure lands. A connected greenspace network facilitates these functions and reduces the importance of a single greenspace by shifting the importance to the network as a whole. As such, the plan focused greenspace management efforts on increasing access to the network of greenspaces rather than on solely increasing the amount of greenspace

(City of Ottawa, 2006). In this way, the plan recognized that some lands hold greater ability to deliver a higher level of ecological and human function, diversity, and access, and focused planning efforts to better connecting these greenspaces to the network. To identify and map land cover types that deliver a higher level of function, the plan determined the role each land cover type played in the landscape and the functions they provided. The plan used a variety of data sources, like those used to categorize greenspaces, to assess the function of Natural Features and Open Space and Leisure Features. Greenspace categories were ranked in terms of their role or function and described as either: Primary Lands, Supporting Lands, or Contributing Lands; and given a value relative to identified functions. As a result, the plan was able to identify lands that have a high functional value and best for protecting and extending the greenspace network and areas that may be better suited to urban development.

Integrating ecological connectivity into the planning process

Ottawa's *Greenspace Master Plan* complements key strategies like Ottawa's development plan, growth strategy, and Human Services Plan (includes parks and recreation areas), Environmental Strategy, and Transportation Master Plan. The plan compliments these plans and strategies by serving as a reference for land use planning and decision making as to how to direct development that enhances the greenspace network and reduces its fragmentation. By defining, identifying, and mapping greenspaces, the plan provides a way for land use planners to consider greenspace composition and configuration in the landscape and consider the network's relationship with other landscape elements. In doing so, the greenspace network is considered within the larger planning framework and informs the planning process on how to organize the landscape. In this way, the plan makes the greenspace network a permanent and defining fixture in the city landscape (City of Ottawa, 2006, p. 30). Specifically, the plan does this by:

- Identifying land that physically connects greenspace within the urban boundary and to rural areas beyond the boundary;
- Providing clarification on where to enhance links between greenspaces to preserve diverse natural features and functions that maintain municipal sustainability; and
- Providing clarification on where to protect and extend culturally valuable landscape features that ensure the health and vitality of the municipality (City of Ottawa, 2006, p. 31).

Greenspace categories were ranked in terms of their role or function and described as either: Primary Lands, Supporting Lands, or Contributing Lands; and given a value relative to identified functions. As a result, the plan was able to identify lands that have a high functional value and best for protecting and extending the greenspace network and areas that may be better suited to urban development.

In addition to identifying and mapping the greenspace network, the plan also provides a way to prioritize greenspace network protection and restoration through its use of a ranking system. By ranking greenspaces, the plan identifies the functional value of greenspaces and can establish its importance to network relative to its functional value. In doing so, the planning process can identify lands with a high functional value and establish priorities for better protecting/enhancing greenspaces and connecting network. Then, the maps produced as part of the analysis become important tools in facilitating communication of the network to decision-makers as it clarifies where to direct urban growth and where to protect and extend the greenspace network, as well as inform plans and strategies that guide day-to-day activities. Specifically, the plan does this by:

- Accommodating recreational interest by improving access to greenspace via pathways and linkages;
- Providing guidance on land management and greenspace acquisition decisions;
- Engaging with community and providing opportunity for stakeholder participation in the development and management of greenspace network features; and
- Identifying suitable locations for new recreation facilities as well as suitable locations for upgrade and enhanced connectivity of existing facilities. (City of Ottawa, 2006, p. 31)

For example, Ottawa developed the *Pathway Network for Canada's Strategic Capital Region: 2006 Strategic Plan* to develop a city-wide pathway system. The Pathway Network Strategic Plan had as an objective to better connect the pathway system across neighbourhoods and enhance pathway system access and connectivity to the greater greenspace network. By using the Greenspace Master Plan to identify greenspace network access priorities, the Pathway Network Strategic Plan was able to identify areas that would benefit from improved pathways and linkages. In this way, the Greenspace Master Plan was used to compliment other key planning strategies, like those related to transportation, while ensuring underlying greenspace network structure and function were considered in the planning process.

To achieve the goal of the five greenspace objectives, numerous strategies are considered in the plan. Among them, the strategies considered to achieve connectivity are focused on land that fills gaps in the network or extends it. An objective of this strategy includes facilitating ecological connectivity to support the linkages between natural lands that support biodiversity and maintain ecological function. Planning mechanisms used to implement policies that facilitate these strategies include: land use planning; development review process; undertaking public works and building infrastructure; partnering with others; managing land; and land acquisition. The plan acknowledges the network as evolving and recognizes that the strategies set out will need to be considered on an on-going basis across a broad range of municipal functions (City of Ottawa, 2006, p. 55). The various planning mechanisms provide decision-makers with tools to consider the greenspace network across municipal objectives and solidify the role of the greenspace network in managing growth and development.

Halifax Regional Municipality

Table D-2 **Halifax Summary Context**

Plan Name	*Halifax Green Network Plan*
Municipal Context	1 municipality – formed in 1996 from the amalgamation of 4 municipalities
Land area	5,496 km^2 (Statistics Canada, 2017e)
Population (2016)	403,390 (Statistics Canada, 2017e)
Plan Implementation Date	June 2018

Plan Overview

In 2018, the Halifax Regional Municipality (HRM) released the *Halifax Green Network Plan*. The plan focused on all open spaces, both private and public, in the region and the interconnected network they form, examined the ecosystem functions and benefits they provided, and outlined strategies to preserve, protect, and manage them. The plan was initiated in 2015 as a result of a policy directive included in the 2014 Halifax Regional Municipal Strategy to:

> *"protect and preserve connectivity between natural areas and open space lands, to enable their integration into sustainable community design, to help define communities, to benefit the Municipality's economy and the physical health of its people, and to reflect and support the overall purposes of this Plan.*" (Halifax Community Planning & Economic Development Standing Committee, 2018, p. 3)

Originally entitled the *Greenbelting and Public Open Space Priorities Plan*, the Halifax Green Network Plan was developed using research, public and stakeholder engagement, geospatial data, analysis, and planning coordination and was completed by summarizing and analyzing the current state, establishing baseline cultural data, setting objectives and strategic directions, and aligning policy.

With population growth, the HRM recognized that a plan was needed to encourage sustainable land use patterns and guide growth while protecting vulnerable environmental functions, better managing open space demand and resources, and reducing conflicts between environmental sustainability and recreational amenities (O2 Planning and Design, 2017, p. 16). To achieve these goals and balance the needs of sustainability and development, the plan included a framework that followed five core planning concepts to guide planning and decision making. These core concepts included: regional landscape planning, community shaping landscape patterns, ecological landscape patterns, interconnected and multifunctional space, and community resilience. Understanding patterns at a regional scale provided the plan with an ability to study natural processes at the landscape scale and integrate landscape ecology concepts to planning practice. Biodiversity was evaluated at the ecosystems, species, and genetic levels, and where patch richness, area, size, and connectivity where measured and assigned a value based on its importance to landscape ecosystem network function. The plan did this by identifying open spaces in terms of edges, wedges, patches, and corridors, and integrated the human dimension by discussing the cultural landscape as a landscape element. The plan aimed to understand the patterns created by communities and ecological elements and aimed to better support sustainable community growth and land use patterns that add community environmental, economic, and social resilience. Finally, the plan recognised that multifunctional open spaces were important to achieving resilience, and their interconnectedness was key to increasing their multifunctionality.

As the plan considered open spaces as interconnected and interdependent, it included a comprehensive scope of regional growth and development and open space conservation, protection, and preservation. It understood that decisions made for one open space would affect another, and as such applied a landscape systems approach to open space planning that considered the regional urban and rural contexts. The plan's vision was to determine an open space network through public involvement and multisector collaboration, which has multiple ecological, recreational, socio-cultural and economic functions and shapes sustainable, resilient human and ecological communities that offers citizens healthy, productive, beautiful and enjoyable spaces (Halifax Regional Municipality, 2018, p. 44). In this way, the plan aims to promote long-term sustainability by shaping settlement patterns, protecting ecological function, retaining land for resource production like agriculture and forestry, and providing citizens recreational opportunities (Halifax Regional Municipality, 2018, p. 17).

Characterizing the Ecological Network and Connectivity

To develop the Halifax Green Network Plan, it was necessary to characterise and map open spaces in the HRM. Key to this was determining what was considered an open space and where open spaces were located in the region. By doing so, the HRM was able to define and understand the open spaces that constituted the regional green network. The plan considered all open spaces as natural, working, recreational, built and cultural landscapes, and defined them as: "…publicly or privately owned, undeveloped land or water, intended to be preserved for agricultural, forest, community form, ecological, historical, public safety, or recreational purposes" (Halifax Regional Municipality, 2018, p. 19*).* In these terms, to highlight the multifunctional ability of open spaces and their importance to economic, social and environmental vitality, the plan organized open spaces into five themes: Ecology, Working Landscapes, Community Shaping, Outdoor Recreation, and Cultural Landscapes. Each theme represented different roles that open spaces provide and contribute to the overall plan vision.

To define and identify the green network, two key studies were undertaken prior to the development of the green network plan: *State of the Landscape Report* and *Cultural Landscape Framework Study*. These studies, in combination with related provincial and federal plans, policies, and regulations and public consultation, provided the background information and analysis needed to identify key issues and opportunities of the green network. They provided the open space inventories and included the biophysical, cultural, economic, historical and planning contexts used to develop baseline datasets. Using developed baseline datasets, open space elements were identified based on the key themes: Ecology – 24 elements, Working Landscapes

– 10 elements, Socio-Cultural Landscape – 39 elements (the socio-cultural landscape elements combined elements from the Community Shaping, Outdoor Recreation, and Cultural Landscapes themes). Identified elements were chosen based on factors important to key themes. For example, elements in the ecology theme were important areas for biodiversity, rare species, natural patches, wetlands, riparian areas, and surficial geology (Halifax Regional Municipality, 2018, p. 35). Whereas Working Landscape elements supported the HRM's economy and those of Socio-Cultural Landscapes related to recreation, history, culture, and spirituality. Themed open space elements were identified on maps using land cover types, key features and sites, and land use planning designations.

The plan recognized that not all identified open spaces have the same role and do not provide the same value to the green network. Using the datasets created, identified open space elements were assigned a value based on their importance to various landscape functions and consolidated into maps (Halifax Regional Municipality, 2018, p. 34). By providing a value to each element, their importance to the green network was highlighted. The background materials used to define open spaces were also used to value them, as they identified key issues and key opportunities relating to each theme. In terms of ecology, higher value was assigned to elements that were important to healthy ecosystem functioning as it related to the evaluation criteria listed above. Working Landscapes assigned higher values to elements important to the regional economy, whereas socio-cultural landscape elements with important cultural value were assigned a higher value. Each theme summed its values to give the region a total landscape value, and maps were generated for each theme to reflect these values. The green network was identified by combining these maps and demonstrating only the highest valued ecological, working landscape, and socio-cultural landscape elements. This facilitated planning prioritization and decision-making towards open spaces that provided high value. By doing so, the maps became important tools to supporting planning decisions that reflect various priorities and core planning concepts.

Integrating ecological connectivity into the planning process

The Halifax Green Network Plan was developed to provide an approach to achieving a balance between conservation, growth and development. The plan was designed to clarify the open space network and its ecosystem functions and benefits in effort to support the land use planning and design objectives of: maintaining ecologically and culturally important systems; promoting sustainable natural resource and economic development; and, identifying and defining land suitable for parks, corridors, and greenspaces (Halifax Regional Municipality, 2018, p. 18). Defining landscape elements according to themes enabled the HRM to evaluate various components of the landscape based on different economic, social, and environmental functions. The use of maps to identify where elements were located supported the analysis of their composition and spatial configuration, providing key baseline information to planners. By using a visual tool like maps planners were able to better communicate the idea connectivity to decision makers and integrate the concept within the municipal planning process.

The plan aligned its priorities with key strategies like Halifax's Regional Plan, by-laws, and priority plans. As the green network plan defined and identified key open spaces in the region, it informed the planning process by:

- Identifying cultural, historical, and natural assets in need of protection and preservation; and
- Identifying opportunities to further protect open spaces, wilderness areas, natural beauty and sensitive environmental areas (Halifax Regional Municipality, 2018, p. 32).

The HRM used this information to inform and complement its key planning strategies and the organization of land use by:

- Guiding development towards land use practices that effectively used land, energy, infrastructure, public service, and facilities, and promoted overall healthy lifestyles;
- Guiding the creation of open space across the region; and
  Supporting development patterns that promoted economic, social and environmental objectives (Halifax Regional Municipality, 2018, p. 32).

For example, the plan is being used to inform the development of a Culture and Heritage Priority Plan and has been used to update existing plans like the Transportation Priorities Plan (2014) and the Urban Forest Master Plan (2012). In addition, open space network considerations have been integrated into three key municipal responsibilities: public service delivery, resource conservation, and community shaping (O2 Planning and Design, 2017, p. 3). By considering the plan in all these planning contexts, HRM planners are provided more information to better understand a land parcel's larger role within the region and better support land use and open space policy decisions (Halifax Regional Municipality, 2018, p. 21).

Realizing the plan's vision is addressed by numerous strategies. Strategies are organized by theme, where each theme has a specific goal, key considerations that should inform actions, objectives that support the theme goal, and specific and measurable actions that support each objective. They aim to inform procedures, partnerships, and decision-making to better manage, improve and expand the regional open space network (Halifax Regional Municipality, 2018, p. 47). Planning mechanism used to implement actions include: land use planning, park network management, current and future project work, and partnerships. By using the various planning mechanisms, planners and decision-makers are provided a way to support the vision, goals and objectives of offering environmentally and culturally important open spaces, while managing growth and promoting sustainable development.

City of Edmonton

Table D-3 **Edmonton Summary Context**

Plan Name	*Breathe: Edmonton's Green Network Strategy*
Municipal Context	1 municipality
Land area	685 km^2 (Statistics Canada, 2017f)
Population (2016)	932, 546 (Statistics Canada, 2017f)
Plan Implementation Date	August 2017

Plan Overview

In 2017, the City of Edmonton released its green network strategy, *Breathe*. The strategy replaced the former *Urban Park Management Plan* and expanded the plan's focus from only municipal parks to a broader network scope that included all public outdoor open spaces as well as the points connecting spaces. The strategy focused on planning physical infrastructure and provided a framework for decision making that considered the composition, function, and configuration of open spaces, and outlined strategic directions to preserve, enhance and manage the green network. The strategy was developed because it was identified as a city priority project of the municipal strategic plan, *The Way Ahead: City of Edmonton Strategic Plan*. The strategy was developed using research, public and stakeholder engagement, geospatial data, analysis, and planning coordination and was completed in a series of stages including: context review, supply and demand analysis, objective and priority setting, and policy alignment.

Edmonton's *Breathe* strategy recognized that population growth, changing demographics, limited resources, increased demand for recreation, and shifting environmental conditions would increasingly pose a challenge to providing high functioning, connected open spaces (City of Edmonton, 2017, p. 2). The City of Edmonton is anticipated to accommodate up to seventy percent of the regional growth in coming year totaling approximately two million residents, double its current population (City of Edmonton, 2017). As such, the strategy considered the regional context as a core network concept and ensured objectives aligned with regional priorities. To ensure a sufficient supply of diverse open spaces, the strategy aimed to support municipal planning and decision-making processes that enable a green network to develop and manages open spaces to meet the needs of the future (City of Edmonton, 2017, p. 8).

To ensure sufficient distribution of high-value open space functions and services, the strategy followed a multifunctional network planning approach (City of Edmonton, 2017, p. 16). This approach identified open spaces as areas of overlapping services and functions and described how the green network could support broader city objectives relating to land use planning, active transportation, and drainage networks. The strategy's vision was created around these concepts, with the goal to create an integrated, connected, and layered green network that considered multiple open space types and functions and supported diverse natural and cultural opens spaces while providing economic and quality-of-life benefits. In this way, the strategy aimed to form a green network that was ecologically resilient, promoted health and wellbeing, facilitated connecting people to natural and cultural heritage, and celebrated cultural and ecological character (City of Edmonton, 2017, p. 13).

Characterizing the Ecological Network and Connectivity

Edmonton's Breathe strategy characterized its green network as a series of connected open spaces and corridors that provide numerous services to people and the environment. The strategy defined open spaces as outdoor publicly accessible places that promoted health and well-being, recreation, and mobility and supported environmental sustainability and resilience by providing ecosystem services and protecting natural lands (City of Edmonton, 2017, p. 17). The strategy classified open spaces into five types: Municipal parks (e.g. district park); Civic spaces (e.g. plaza); Corridors (e.g. utility corridors); Other jurisdictional parkland (e.g. institutional campuses); and Other public open spaces (e.g. school sites). As Edmonton's strategy focused on the function that each open space provided to people and environment it recognized that open space functions are interconnected and form overlapping networks (City of Edmonton, 2017, p. 17). To reflect this, the strategy classified open spaces into three broad functional network categories: Ecology, Wellness, and Celebration. The Ecology Network layer included open spaces that supported and enhanced the environment, whereas the Wellness Network layer included open spaces that promoted healthy living and well-being. Finally, the Celebration Network layer included open spaces that connected people to each other and built a sense of place. Combined with the Urban Infrastructure Network layer, these network layers form Edmonton's green network.

As the strategy identified open spaces as the physical foundation of the green network (City of Edmonton, 2017, p. 16), a comprehensive understanding of their structure was required. By defining the structure of each functional network layer, the strategy was able to identify the landscape ecological and human components that influence the network's composition and configuration. The definition of the Ecology Network was based on the principles of landscape ecology, where patches, corridors, and the matrix where identified. Patches were considered natural areas, and classified as: regional core natural areas, local natural areas, pocket natural area, and natural area buffers. Corridors were considered open spaces that connected patches and included: regional landscape corridors, ravine corridors, greenways and utility corridors, stepping-stone corridors. The strategy identified that Edmonton existed within an urban matrix, and considered the network embedded within this context, while also considering its role within the larger regional network system. The Celebration Network layer was defined as multifunctional open spaces that offered a range of cultural services and reflected historic landscapes. The strategy identified three types of open spaces for this network layer: Civic celebration spaces (e.g. heritage site), celebration streets (e.g. pedestrian oriented streets), and celebration access corridors (e.g. cycling routes). The Wellness Network layer was defined as open spaces that promoted active living and were fundamental to physical and mental wellbeing. For this network layer, the strategy identified two types of open spaces: Wellness elements (e.g.

playground), and wellness corridors (e.g. greenways). Each network layer component was identified using geospatial analysis.

To ensure the green network considered landscape function, the strategy examined the functions network structures contributed to the three broad functional categories. It did this by first defining what functions are provided by open spaces to people and environment based on these categories. It identified six open space functions for the Ecology Network, five for the Celebration Network, and four for the Wellness Network. As the plan recognized the multifunctionality of landscape components, it acknowledged that open spaces could contribute to more than one function. To reflect this, each theme evaluated the functionality of every identified open space, where landscape metrics where used to assign open spaces a functional score for their ability to support the identified layer functions. Open space functional scores were then combined to provide an overall score for each open space in the network layer. This analysis enabled the strategy to generate maps for each network layer detailing the level of function (i.e. low, moderate, of high support of functions) an open space provided in that network layer.

The strategy also acknowledged that open spaces not only provide multiple functions within a functional category but can also support function across categories. To reflect this multifunctional nature, the green network was constructed by integrating all network layers. The strategy defined the network by identifying all high function scoring open spaces across the municipality. These open spaces contained multiple amenities, programs and services that contributed to celebration and wellbeing but also supported ecological function. The strategy mapped these spaces to highlight areas of overlapping functionality and identify areas that would most benefit from network protection and enhancement. Using such a map supported land use planning decisions that more effectively used public land as it supported initiatives that improved functionality, connectivity and access instead of only focusing on increasing open space supply (City of Edmonton, 2017, p. 16).

Integrating ecology in the planning process

Edmonton's *Breathe Strategy* was developed to direct open space management and expansion in anticipation of population growth and increasing demand for open spaces that improved health and provided benefits to human wellbeing. The strategy was created to identify the green network and guide directions to maintain and enhance the functionality of open spaces. Defining network layers by functional themes allowed for a multifunctional landscape planning approach to emerge and ensured a range of high support functions be considered in the planning process. The strategy provided planners and decision-makers a tool that integrated ecological principles with the human dimension, and allowed for data driven, spatially explicit decisions to be made on the management of the municipality's open spaces (City of Edmonton, 2017, p. vii). In addition, it provided a way to evaluate the network at a variety of scales by providing information on open spaces on both an individual and network scale and allowed for their functional evaluation by network layer or as a whole. As such, the strategy facilitated decisions on the management of the network overall by identifying where alterations could be made to benefit and boost performance of the system (City of Edmonton, 2017, p. 16).

The *Breathe Strategy* provides direction to land use planning and decision-making by providing a strategic foundation and policies to guide open space planning throughout the green network. The strategy complements and aligns with the Edmonton's Strategic Plan and its six subsidiary strategic plans including: Municipal Development Plan; Transportation Master Plan; Edmonton's People Plan; Environmental Strategic Plan; Financial Sustainability Plan; and Economic Development Plan. Furthermore, the strategy supports and aligns with the Metropolitan Region Growth Plan and aims to enhance recreational and ecological connectivity with the region. As such, *Breathe* is an adaptive plan that influences and responds to legislation, strategies, plans, programs, and agreements of above-mentioned strategic plans (City of Edmonton, 2017, p. 4). The adaptability of the plan influences how decision are made in the planning, development and management of the green network, and enables the strategy to better support the growth of multifunctional open spaces in response to increasing demands and needs.

As the *Breathe Strategy* defined and identified the various open space structures and functions of functional network layers, the planning process was informed by:

- Identifying the diversity and distribution of open space structures and functions across the landscape, including total amounts, different types, arrangements and accessibility;
- Identifying the functional quality of open spaces as per multiple functional factors;
- Identifying the value of individual open spaces and their value to the overall green network; and
- Identifying opportunities to enhance connectivity to areas at the larger regional scale (City of Edmonton, 2017, p. 44).

By using the defined ecological network as the underlying layer of important physical features, *Breathe* is able to guide the organization of land use by:

- Ensuring open spaces are managed as one connected system;
- Supporting strategies that address green network distribution, quantity, diversity, and supply for various neighbourhood types (i.e. central core, mature areas, established areas, developing areas, urban growth areas, and industrial areas); and
- Supporting investment that addresses specific network gaps and enhances open space function (City of Edmonton, 2017).

In this way, *Breathe* is able to support the key strategic development plans listed above. For example, *Breathe* helps guide neighbourhood development in the Municipal Development Plan by identifying open spaces and their connections thereby guiding land use and infrastructure decisions. In this way, *Breathe* was able to guide the Transportation Master Plan by supporting the creation of a sustainable transportation system that encouraged more efficient movement and created welcoming transit nodes that encourage ridership.

Achieving the vision identified in the green network strategy is addressed by various strategic directions. Strategic directions are arranged in themes, where each theme has a specific objective, key issues and context are provided, associated functions are identified, policy actions are discussed and initiatives to achieve strategic objectives are provided. An integrated, multifunctional green network is the objectives of policy actions (City of Edmonton, 2017, p. 84). Planning mechanisms used to implement strategic directions include: planning and design; management and operations; engagement and partnerships; and analysis and monitoring. Using these tools provided planners and decision-makers with an effective and creative opportunity to manage the green network for today and into the future, while also ensuring communities were involved in the planning process and ensuring informed decisions were made based on data acquired through monitoring and evaluation (City of Edmonton, 2017, p. 84).

Appendix E: Ecosystems Patch Networks: Baseline Maps

Figure E-1 **All Land Cover Type Patches**

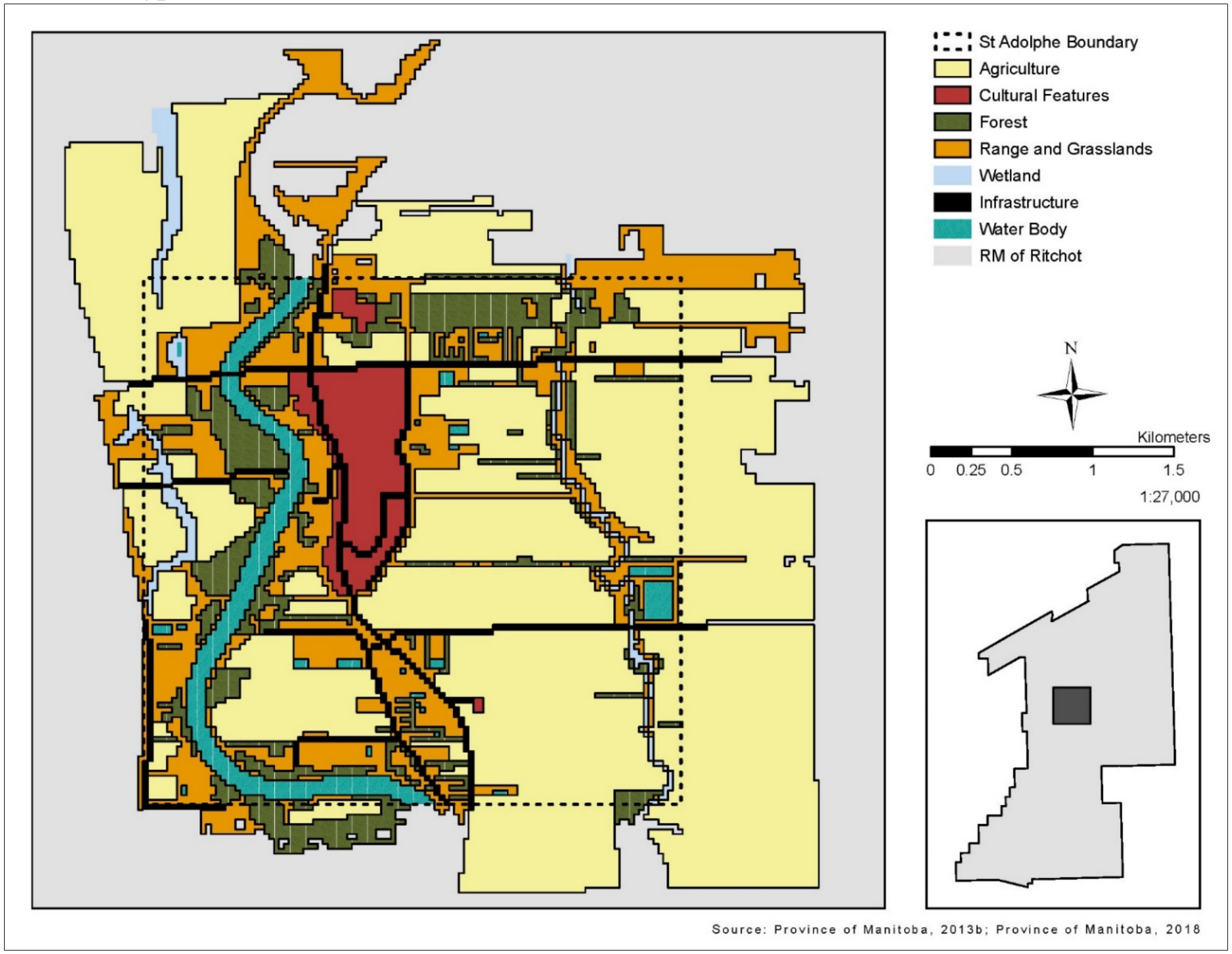


Figure E-2 **Agriculture Land Cover Type Patches**

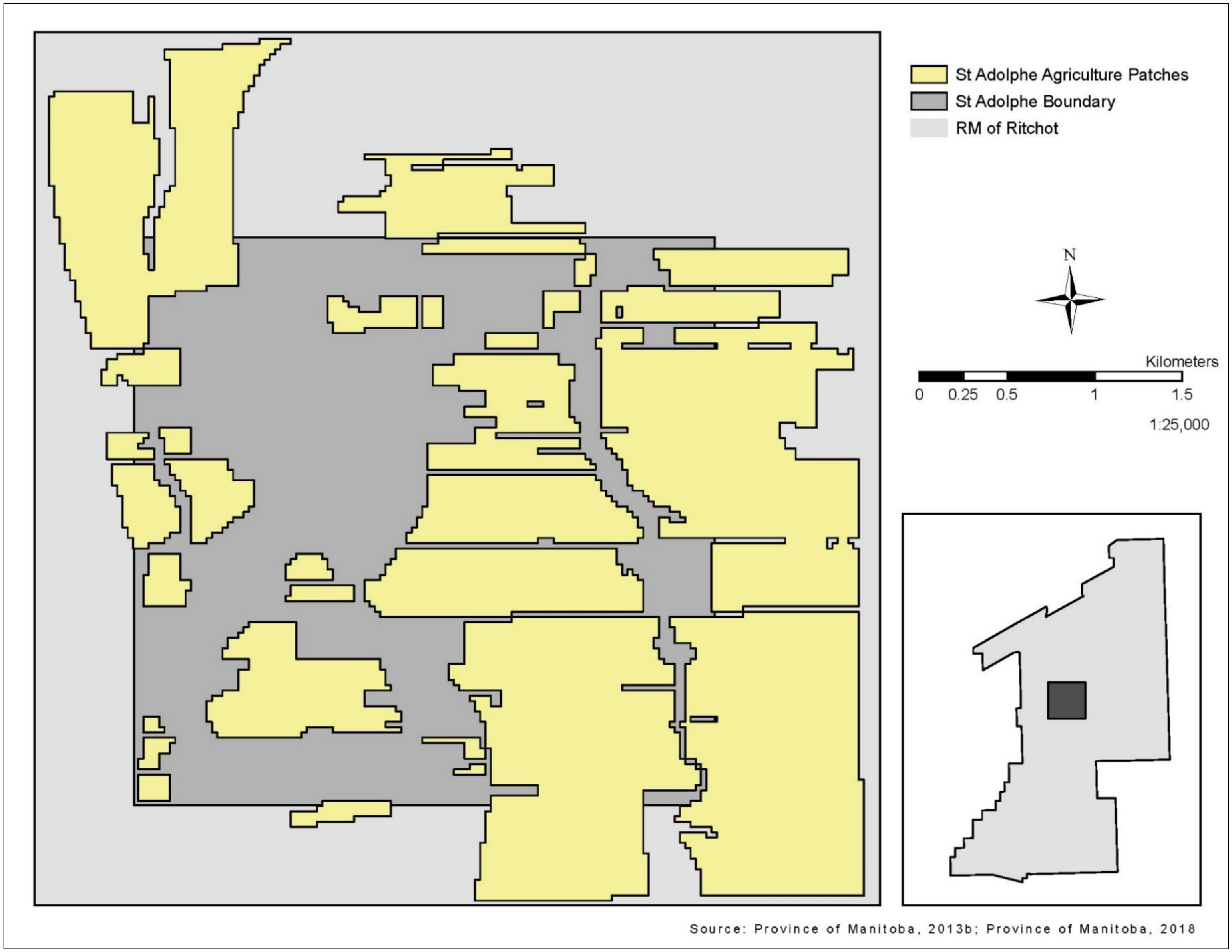


Figure E-3 **Cultural Features Land Cover Type Patches**

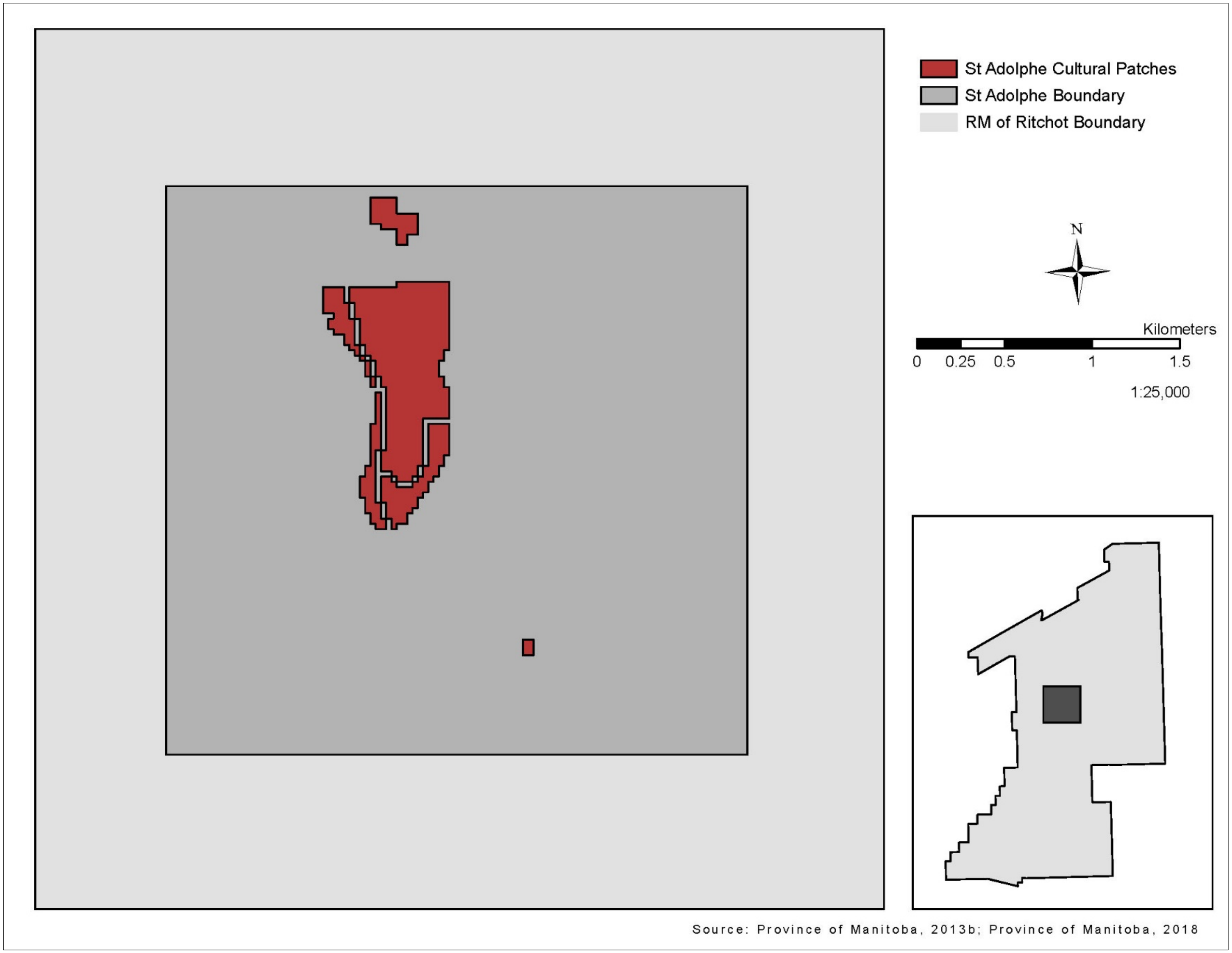


Figure E-4 **Forest Land Cover Type Patches**

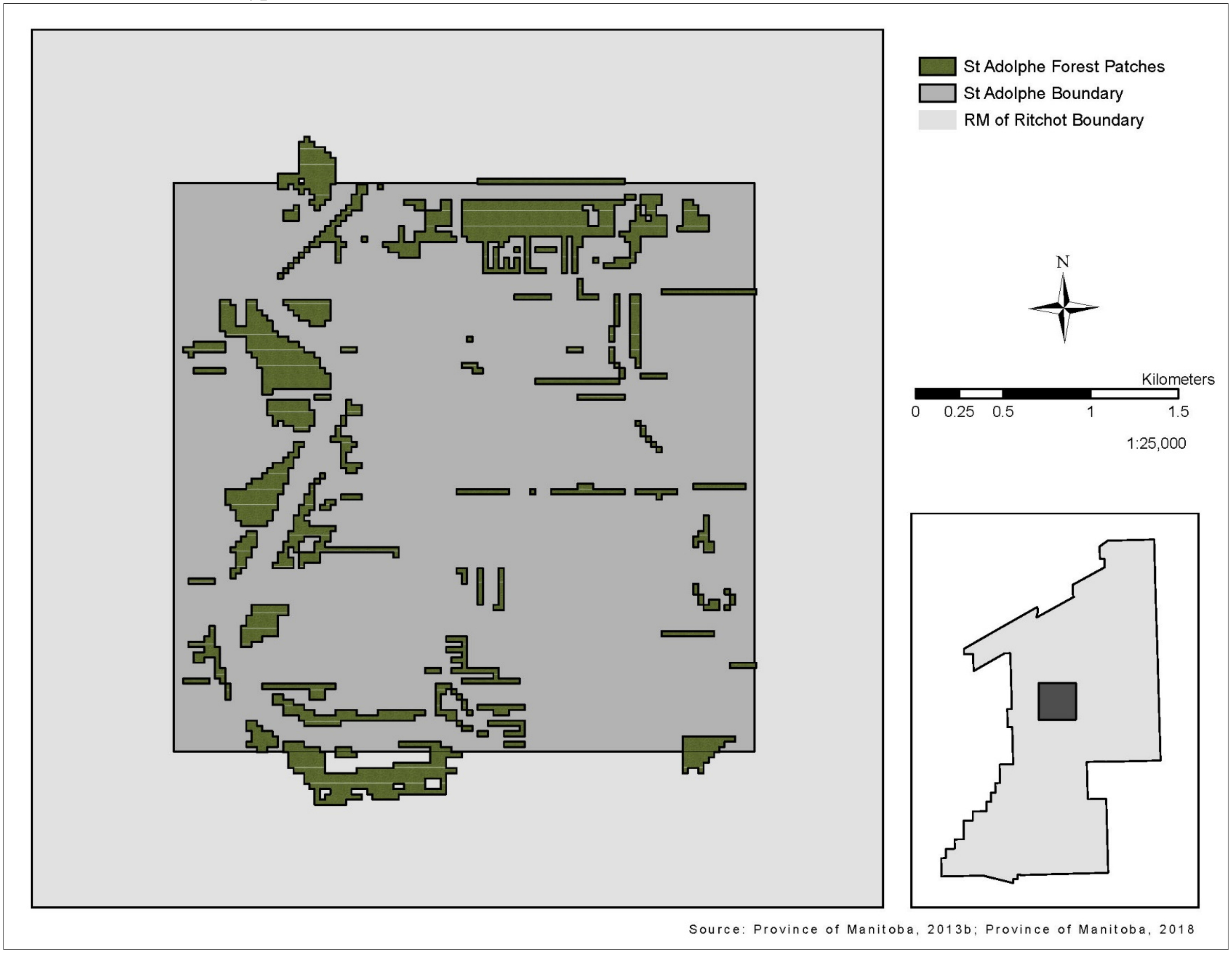


Figure E-5 **Range and Grasslands Land Cover Type Patches**

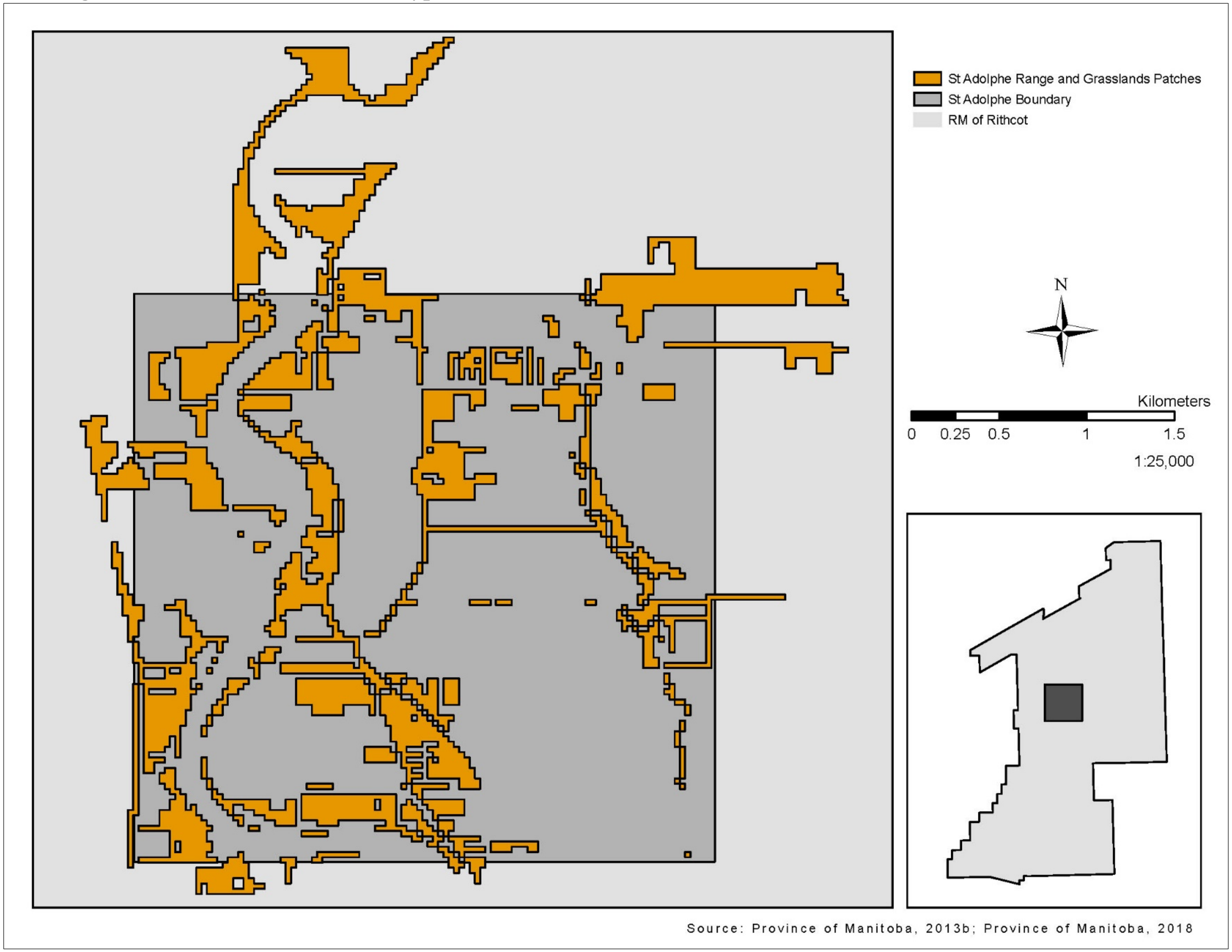
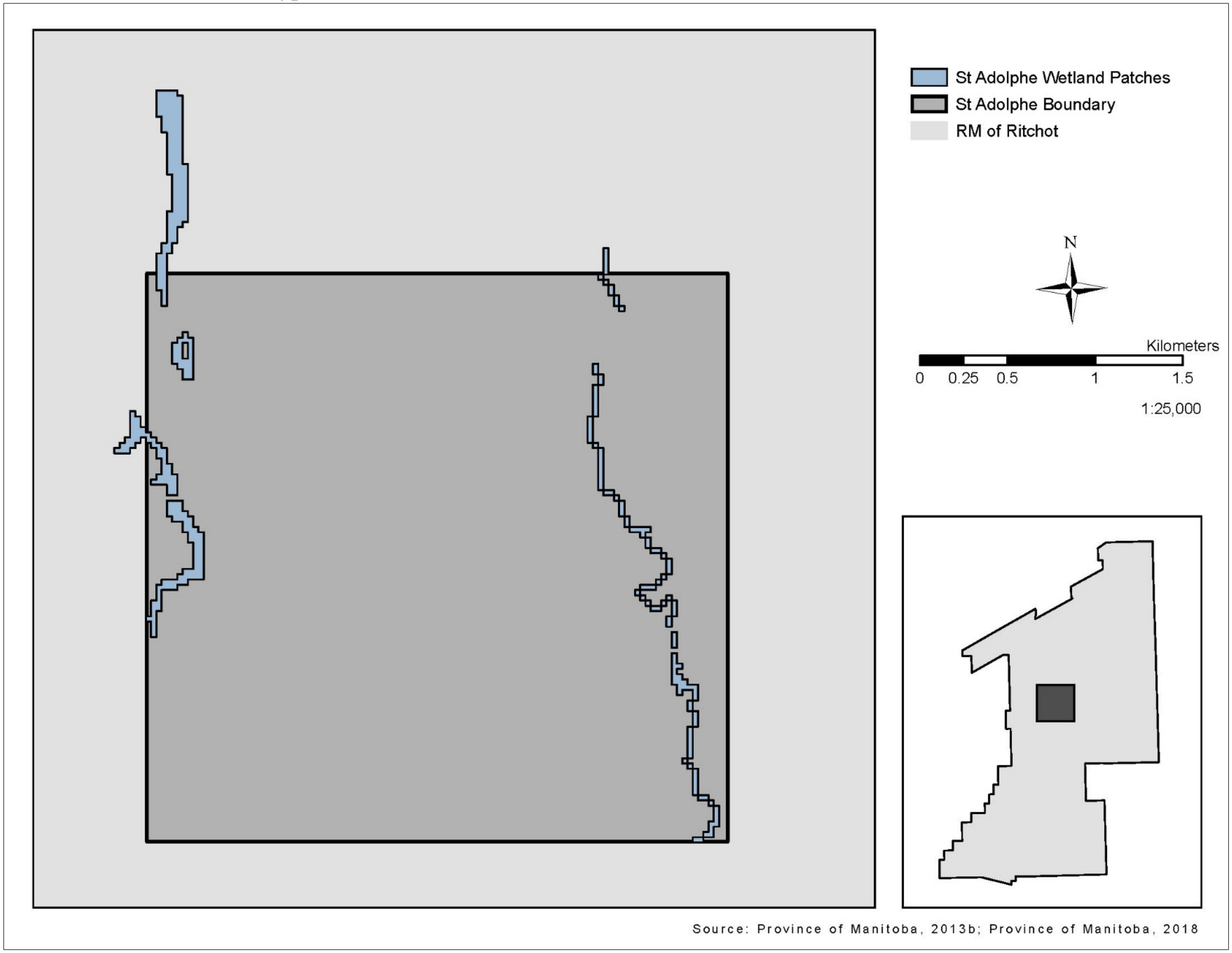


Figure E-6 **Wetlands Land Cover Type Patches**



Appendix F: Ecosystem Patch PROX "near lines" Baseline Maps

Figure F-1 **Agriculture Land Cover Type PROX "near lines"**

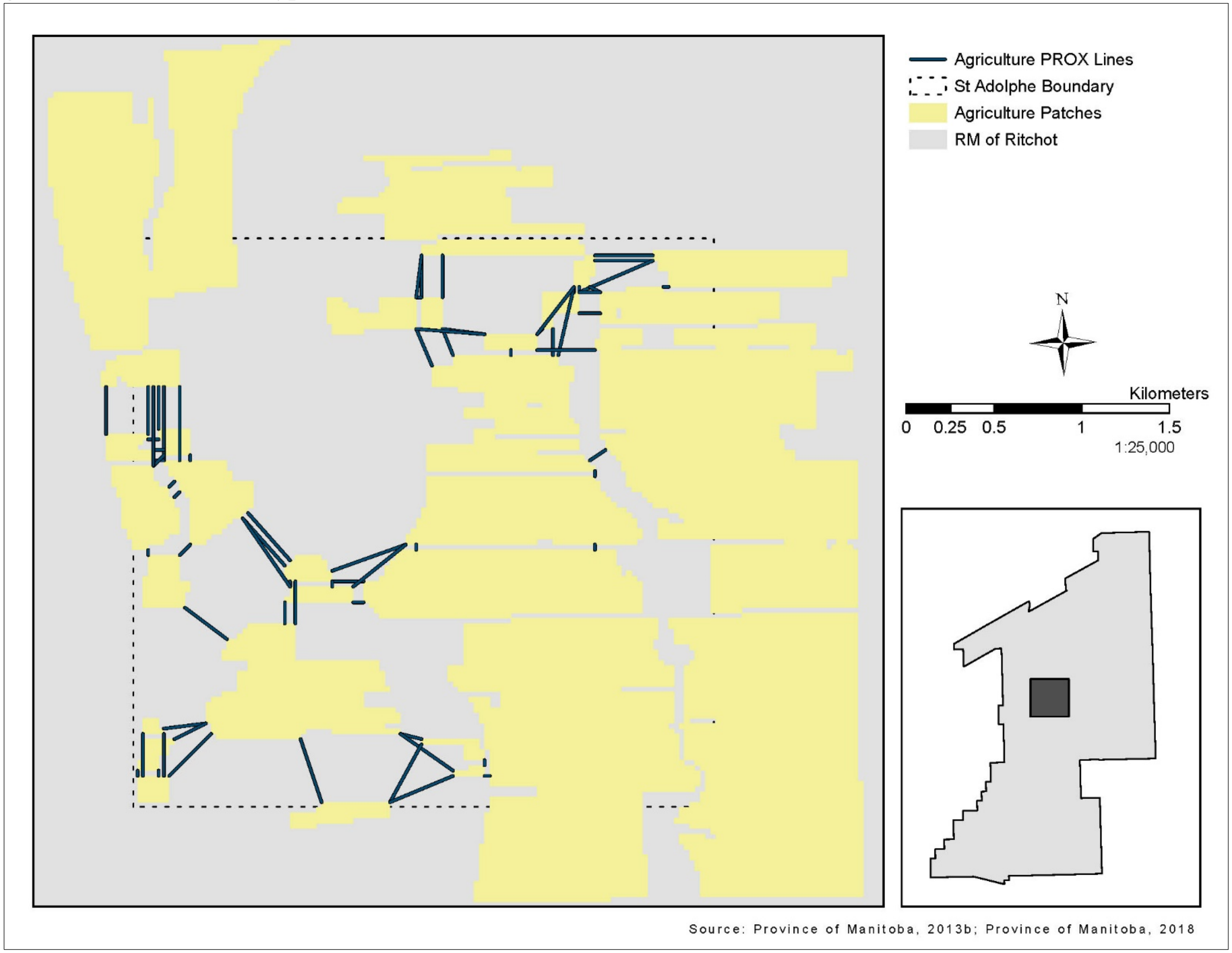


Figure F-2 **Cultural Features Land Cover Type PROX "near lines"**

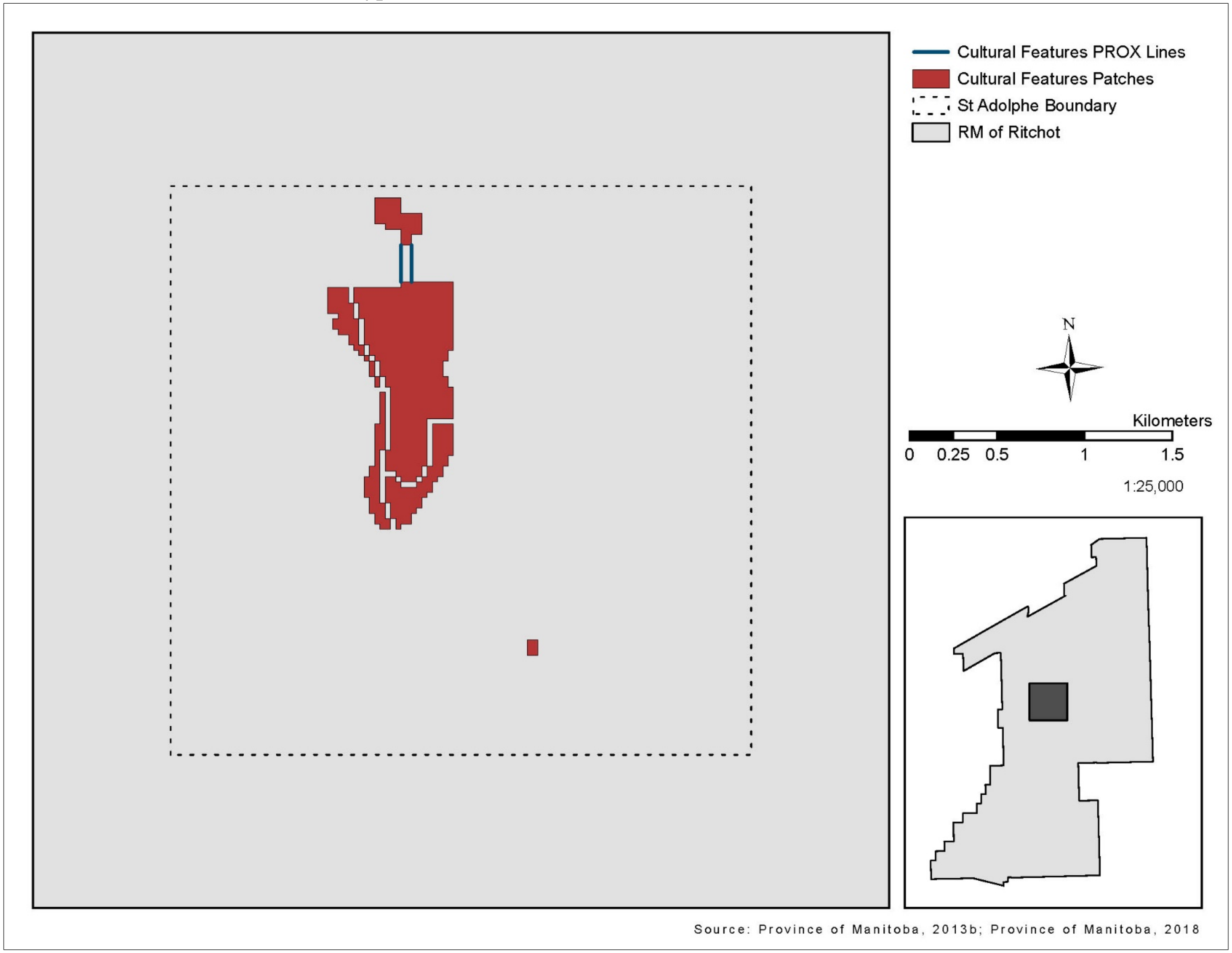


Figure F-3 **Forest Land Cover Type PROX "near lines"**

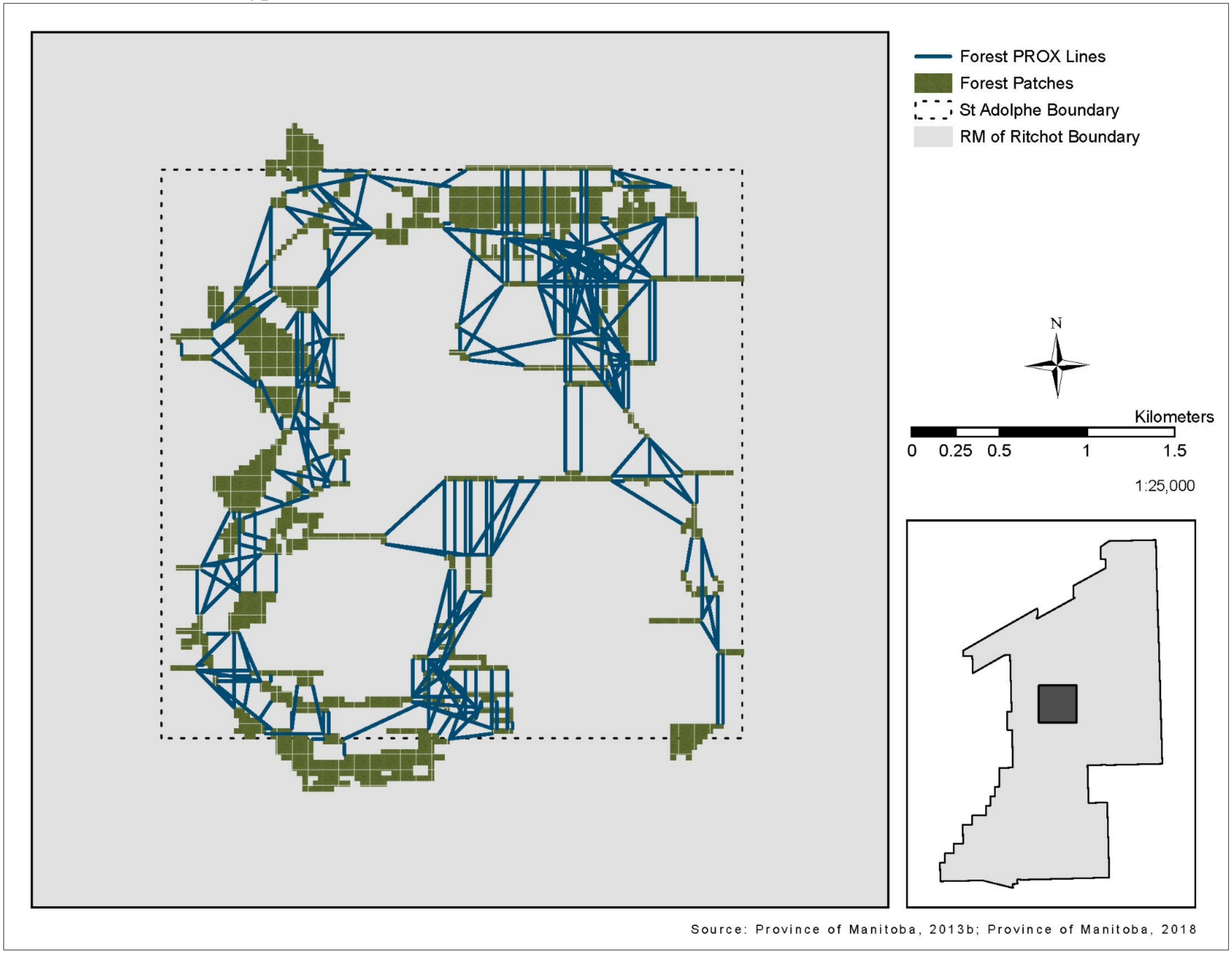


Figure F-4 **Range and Grasslands Land Cover Type PROX "near lines"**

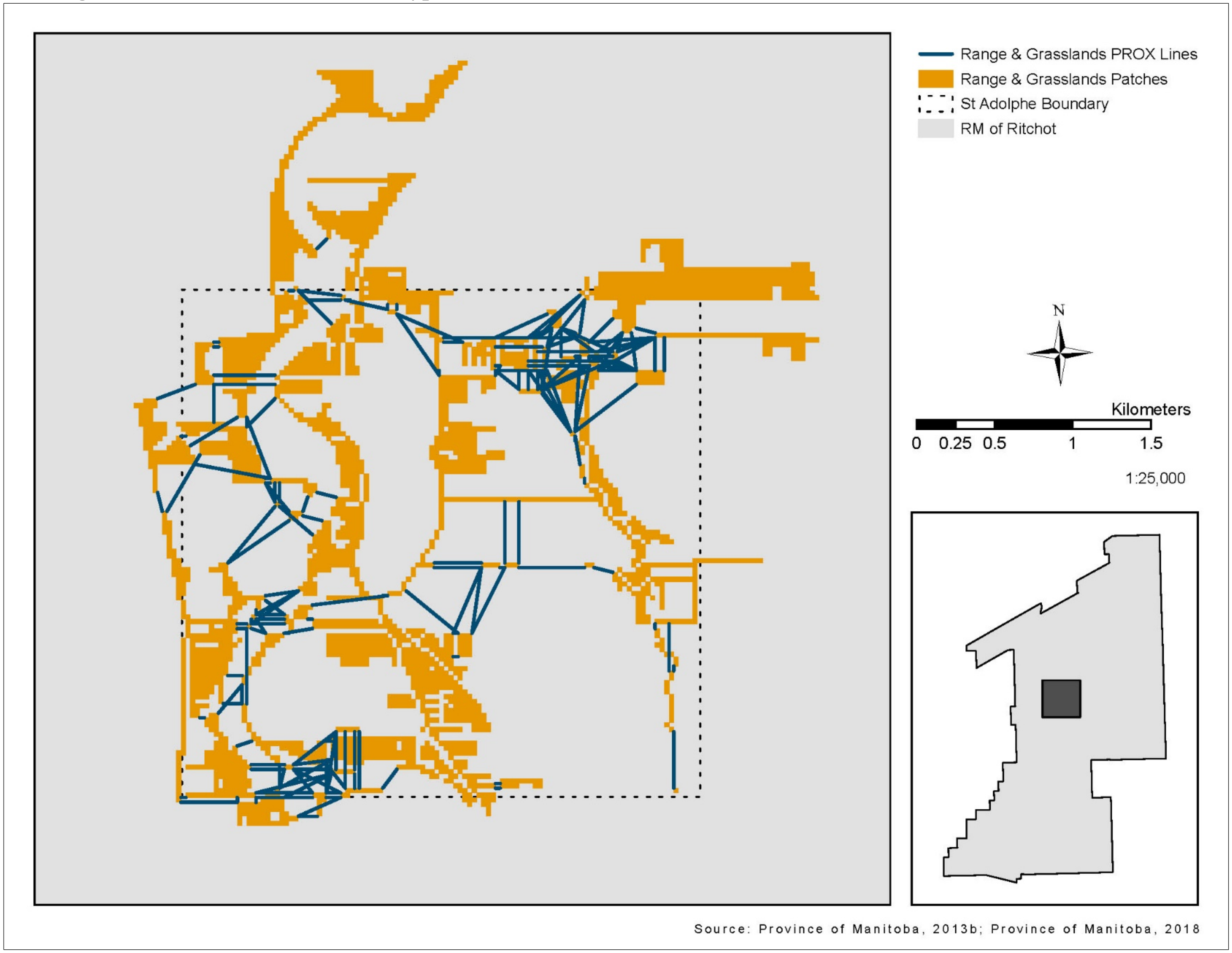
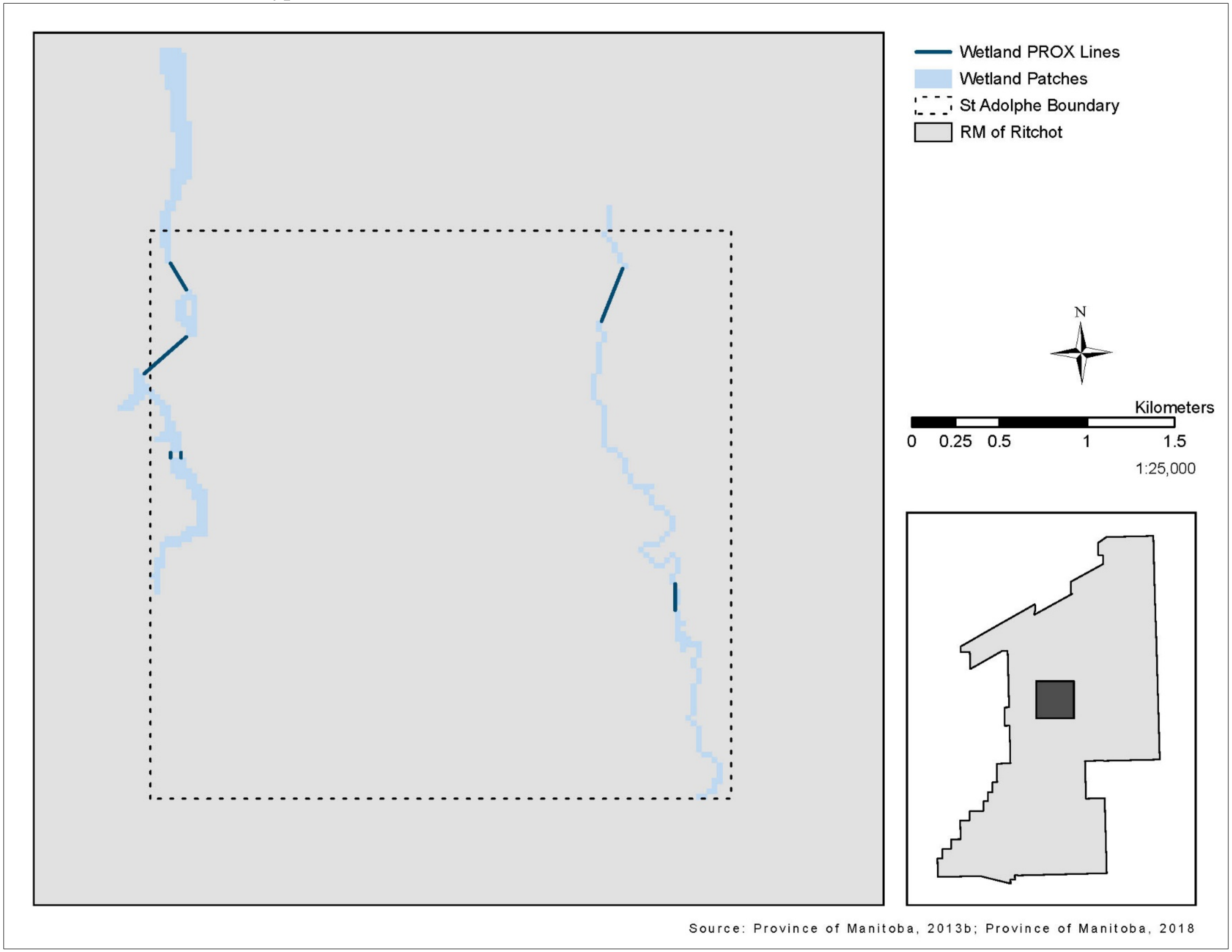


Figure F-5 **Wetland Land Cover Type PROX "near lines"**



Appendix G: Red River Designated Flood Area

Figure G-1. **Red River Designated Flood Area Map**