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Cost-effective Conservation Planning for Species at Risk in Saskatchewan's Milk River Watershed: The Efficiency Gains of a Multi-species Approach

by

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Abstract

The federal Species at Risk Act requires economic analyses to be included in species at risk recovery plans. Recovery plans are often completed species by species and their economic analyses fail to employ modern analytical methods. A unique multi-species at risk recovery plan within Saskatchewan's Milk River Watershed provided the opportunity to calculate costs associated with native grassland conservation, develop optimization models that create cost-effective grassland conservation designs, compare the costs of cost-effective conservation designs with the costs of current proposed critical habitat polygons, and assess the improvements in efficiency associated with multi-species plans relative to single species plans. The cost-effective conservation plans were designed using Marxan software and included both direct and opportunity costs. The results of the optimization models suggest there is a potential for large efficiency gains if economic considerations are included in habitat conservation plans and if conservation plans are created for multiple species simultaneously.

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1 Introduction

Interest in cost-effective and systematic conservation area design – informed by sound economic data and used to protect biodiversity and species at risk – has begun to increase (Klein *et al.*2008; Meir *et al.*2004; Cabeza and Moilanen 2003). Countries that have made legal commitments within their country and the global community to protect and recover species at risk appear to be particularly active in this area. Canada is one such country. The Species at Risk Act (SARA), born out of international agreements, is Canada's legal framework for the identification, protection and recovery of species at risk (Environment Canada 2005). Historically, the plans for the protection and recovery of species at risk in Canada have failed to promote efficient, cost-effective protection and recovery because while economic considerations (cost-benefit analyses) are a required part of the process, they are often included too late in the process or in too limited a manner to provide meaningful input into the conservation process.

This thesis has been completed with the intent to assist the socio-economic analysis required for a multiple species at risk conservation planning initiative in Saskatchewan's Milk River Watershed – the South of the Divide Action Plan.[1,2] This document provides information on the costs of protecting and restoring native grasslands within the watershed.[3] This cost information was used to calculate the cost of protecting and restoring the grasslands located within the region's species' critical habitat areas.[4] These

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[1] The names 'Saskatchewan's Milk River Watershed' and 'South of the Divide region' are used interchangeably within this thesis. The South of the Divide region is delineated by the Milk River Watershed, and as such, both regions are geographically equivalent.

[2] The conservation actions that will be used to protect and recover the species at risk populations in the region have not yet been determined. As such, the conservation actions and costs outlined in this thesis are simply informative and neither prescriptive nor indicative of the final actions that will be undertaken by either the federal or provincial governments.

[3] Costs, within this document, include the foregone benefits of agricultural and oil and gas production as well as the direct costs of converting modified landscapes to native grasslands. Within this thesis, restoration refers to the conversion of annual cropland and tame pasture/hayland into native grasslands that will ultimately be able to provide habitat for grassland species at risk.

[4] Critical habitat areas for several of the species included in this document have not yet been legally defined. As such, the critical habitat areas used in this document should not be considered

costs could be used in conjunction with other conservation costs – predator control, translocation of individuals, research and monitoring, etc. – to calculate the total cost of protecting (and, optimistically, recovering) the species of the region as well as their grassland habitats.

While it is both useful and legally required to calculate the costs associated with protecting and restoring the a priori selected critical habitat grassland areas[5], it is interesting to consider how costs would change if an economic-ecological model or framework was used to select the grassland areas that would be protected and restored. This thesis used spatial economic and biological information for the Milk River Watershed to create several reserve site selection models. These models minimize the cost of grassland protection and restoration while meeting grassland habitat protection targets. While these models are not without limitation[6], they can be used to demonstrate the potential efficiency gains that can be achieved by including economic considerations earlier in the species at risk protection and recovery process.

The reserve site selection models were used to answer several questions. These questions included (a) whether or not protected grassland areas could be more efficiently selected if cost information was included in the selection process; (b) whether or not efficiency gains are possible if conservation areas were selected for several species simultaneously, and if so, what is the magnitude of efficiency gains; (c) whether or not there are added costs of maximizing the size of habitat patches, and if so, what is the magnitude of the added costs; (d) which protection and restoration activities could meet conservation targets at the lowest cost; and (e) how costs increase as overall grassland protection targets increase. The answers to these questions provide information on the potential role of economics in conservation area planning and can

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the legal definition of critical habitat in the Milk River watershed and will be referred to as proposed critical habitat designations. Please see Section 3.3 and Appendix A for information on the species at risk considered in this thesis.

[5] Despite the multi-species nature of the South of the Divide project, to date, all critical habitat spatially selected within the region has been done on a species-by-species basis.

[6] See Section 4.1.1.2 for a discussion on the limitations of reserve site selection models with an emphasis on the challenges faced within the South of the Divide analysis.

facilitate discussions of how economics can be better included within species at risk policy and legislation. The following sections provide a brief discussion on species at risk conservation area planning, the role of economics in conservation area planning, the South of the Divide action plan, and the research approach and framework.

1.1 Species at Risk and Conservation Area Planning

Canada's Species at Risk Act (SARA), proclaimed in June 2003, is one component of Canada's three part strategy to protect species at risk (Government of Canada 2011). The other two components are The National Accord for the Protection of Species at Risk and the Habitat Stewardship Program (Environment Canada 2005).

SARA has three purposes: to protect wildlife from becoming extinct in Canada; to secure the recovery of extirpated, endangered, or threatened species; and to manage species of special concern to prevent them from becoming threatened or endangered (Environment Canada, 2005). Under SARA, the federal government is required to list species at risk; develop and implement recovery plans for the survival and recovery of species at risk; and monitor species at risk (Government of Canada 2011). Once listed, SARA provides protection to individuals of a species at risk and their "residences" if the species are either aquatic species, migratory birds, or are located on federal lands (Government of Canada 2011). Once a recovery strategy – indicating critical habitat for a species' survival and recovery – has been posted and accepted on the Species at Risk Act public registry, critical habitat on federal lands (or on any lands in the case of aquatic and migratory bird species) can be legally protected. Often SARA defers to provincial laws to protect species on private lands. However, the protection of habitat for species at risk on private lands appears to be based on cooperation and volunteerism rather than law. Section 2.9 of the Canada – Saskatchewan Agreement on Species at Risk (2007) states that both governments agree that "cooperative, voluntary measures are the first approach to securing the protection and recovery of species at risk" (Saskatchewan Conservation Data Centre 2010).

SARA's lack of jurisdiction on private land and the province's desire to use voluntary, cooperative stewardship for the protection of species at risk ultimately results in a requirement for cooperation amongst numerous stakeholders in order to protect species at risk (Kerr and Deguise 2004). However, cooperation and voluntary stewardship becomes complicated when coordinating multiple landowners (Kerr and Dequise 2004). Species at risk located on private lands have exhibited poorer recovery trends than species on federal lands due in part to the limited implementation of recovery tasks on privately owned land (Hatch *et al*. 2002).

Conservation area planning within SARA and Saskatchewan's Wildlife Act (1998) is strictly biology-based. Critical habitat is defined in subsection 2(1) of the Species at Risk Act as the "habitat that is necessary for the survival or recovery of a listed wildlife species" (SARA 2003). Critical habitat is largely a legal term with a definition that is so broad it results in considerable difficulty in the selection of critical areas for threatened and endangered species (Hall *et al.* 1997). Nonetheless, the identification of critical habitat – which may be commonly associated with a species' high quality habitat (Hall *et al.* 1997) – is legally required (SARA 2003). Critical habitat locations are ultimately selected species-by-species using a combination of field data and modeling techniques that account for species occurrence as well as the amounts, locations and attributes of habitat required for a species' persistence and recovery.[7] Once a species' critical habitat is identified it is included within the species' recovery strategy report.

Species recovery planning is a two-stage process as outlined in section 11.1 of the Canada – Saskatchewan Agreement on Species at Risk (Saskatchewan Conservation Data Centre 2010). The first step – the creation of a species' recovery strategy – determines whether or not the recovery of a species is technically and biologically feasible, and if recovery is deemed feasible, the plan will include recovery goals, objectives and strategies. The second step – the creation of an action plan – identifies and prioritizes recovery measures and includes a cost-benefit analysis of the implementation of the action plan. Thus, both recovery feasibility and critical habitat designation is decided in the absence of economic considerations. The only role provided by the economic analysis is an evaluation of the already decided upon recovery strategy.

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[7] See the amendment to the recovery strategy of Lungle and Pruss 2008 for a brief discussion on the information used in the identification of critical habitat. The amendment is available on the Species at Risk Act's public registry at http://www.sararegistry.gc.ca/virtual_sara/files/plans/rs_sage_grouse_sec_2-6_1009_e1.pdf

1.2 The Role of Economics within Conservation Area Planning

The consideration of economic costs and benefits has the potential to play an important role in efficient conservation area planning. By properly accounting for the costs and benefits associated with different courses of action for habitat protection, the limited resources available for species conservation could be strategically allocated to maximize net benefits (Naidoo and Ricketts 2006; Margules and Pressey 2000; Csuti *et al.* 1997). However, to date, most conservation area planning articles focus on the biological benefits of conservation areas and ignore the economic costs and benefits (Naidoo *et al*. 2006; Stewart and Possignham 2005).

In an ideal world each conservation plan would have the biological and economic information necessary to construct its own cost and benefit curves for biological protection. This could be achieved regardless of how biological protection is measured whether it is the number of individuals or breeding pairs of a species, the probability of species persistence, or, commonly in the case of SARA, the species' habitat area (Figure 1.1). The benefits curve would include all market and non-market values of varying biological targets. The cost curves would include all implementation and opportunity costs associated with meeting the varying biological targets. Typically the benefit and cost curves take the shapes shown in Figure 1.1 (costs increase at an increasing rate and benefits increase at a decreasing rate). The curves illustrate how economic-ecological trade-offs (in standardized monetary units) vary as a function of biological targets. These curves provide the basis for a cost-benefit analysis which allows optimal biological targets to be selected within a conservation planning problem. Optimal biological targets are set where the positive difference between benefits and costs is maximized (i.e. net benefits are maximized) and it can be shown mathematically that this occurs where the slopes of the curves are equal (i.e. marginal benefits equals marginal costs).

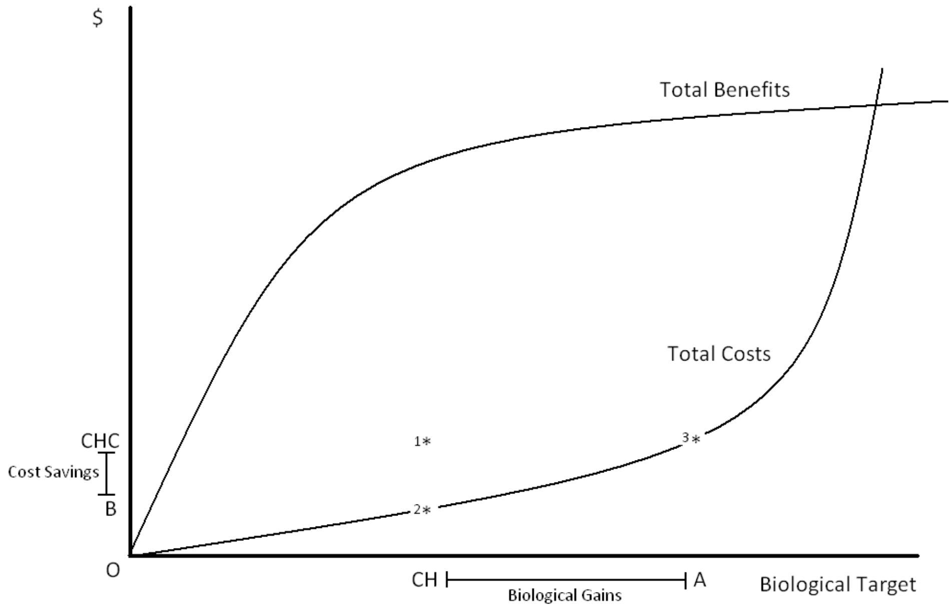

Figure 1.1. Simplified cost and benefit curves for a conservation planning problem (Boardman *et al*. 2010).

Unfortunately the economic benefits of meeting biological targets (number of individuals or breeding pairs of a species, probability of species persistence, or, commonly in the case of SARA, species' habitat area) are rarely calculated due to the difficulty of determining the non-market value of species at risk. The result is that the benefits curve in Figure 1.1 is seldom calculated and traditional cost-benefit analysis is not possible (Naidoo *et al*. 2006). Cost-effectiveness analyses, where costs are expressed in monetary terms but benefits remain measured in biological units, replace cost-benefit analysis in such cases. The most efficient plan, in the case where benefits are not calculated, is simply the plan that delivers a pre-determined conservation target for least-cost (Naidoo *et al*. 2006). Fortunately, consideration of the costs of conservation planning alone offers significant opportunities to achieve efficient conservation objectives in a world of limited resources (Naidoo *et al.* 2006; Stewart and Possingham 2005). The quantification of both biological targets and the costs of protecting those biological targets allow ecological-economic models and economic analysis to determine cost effective and highly efficient conservation plans (Carwardine *et al.*2008). Improving the efficiency of conservation plans is likely to be important when habitat protection is located on privately-owned or resource-rich land which requires difficult trade-offs to be considered.[8]

The cost curve (Figure 1.1) created within a cost-effectiveness analysis provides information on the cost of an efficient conservation plan at every biological target. By illustrating the economic trade-offs required at each habitat protection level (i.e. the trade-off between higher biological targets and the higher costs necessary to meet the target) the cost curve can provide valuable information for decision makers such as whether or not the economic trade-offs required to meet certain biological targets are economically or politically feasible. For example, if the desired biological target is on the flat part of the curve, little to no additional cost is required to increase the target and decision makers may increase the habitat target. But, if the current habitat target is on the steep part of the curve, a very small decrease in the biological target can result in large reductions in total cost in which case decision makers may marginally decrease the biological target in order to meet budget requirements or political acceptance of conservation plans.

Figure 1.1 can also be used to demonstrate the potential biological and economic gains that can be achieved by conducting a cost-effectiveness analysis for critical habitat designation. A species' recovery strategy, under SARA, legally requires the calculation of species recovery costs (Subsection 49(1e) of the Species at Risk Act). Within the species' recovery strategy, the location and amount of critical habitat required for the survival and recovery of that species at risk is designated. It is the cost of protecting this designated habitat that needs to be calculated and reported within the species' recovery documents. Figure 1.1 provides a stylized example that illustrates the information gains possible as a result of a cost-effectiveness analysis for conservation area planning. Within Figure 1.1, the cost of protecting the critical habitat target, CH, is CHC (cost of critical habitat). This point is located at point 1*. However, an equivalent area of land, CH, can be protected for a cost of B if habitat is selected using an optimization framework that minimizes costs while still meeting the habitat targets. This

[8] Locating habitat protection on least-cost areas will be especially important in the case of private land which may require the implementation of financial incentives or conservation programs to meet conservation targets.

is point 2* in Figure 1.1. Substantial cost-savings are possible if efficient conservation plans are created. However, if the budget available for conservation is CHC, efficiently planning conservation areas using an optimization framework can increase a biological target with no additional cost. For example, a much larger area of land (A) can be protected for the same cost of protecting critical habitat (CHC). This is point 3* in Figure 1.1.

An additional argument for explicitly considering economic costs within conservation planning is that it is better to explicitly (and accurately) include costs within the processes of assessing recovery feasibility and setting biological objectives rather than implicitly (and perhaps inaccurately) include economic considerations. While there may be support for the idea that economic considerations should not be included in what may seem a purely biological task, there are potentially large consequences (biologically or economically) of failing to recognize that conservation targets are never truly free of economic considerations and political dialogue (Wilhere 2007). Excluding the explicit consideration of economic considerations does not rid conservation planning from the implicit consideration of economics and value judgments (Wilhere 2007), the inclusion of which can ultimately result in sub-optimal conservation plans.[9] Properly calculated protection and recovery costs should be used to assist in the difficult decision of where to place critical habitat on privately-owned and -managed land, or on land with high economic value. It is best to make informed economic-ecological trade-offs based on quantitatively measured values.

Currently, economic costs play an important role in conservation planning within Canada because SARA requires a cost-benefit analysis of each species at risk's action plan (subsection 49(1e) of the Species at Risk Act). However, a more sophisticated

[9] An example of implied economic consideration can be found within the Woodland Caribou Recovery Strategy. Within the strategy, the target habitat protection (65% undisturbed habitat) is set where a local caribou population has a 60% probability of being self-sustaining (Environment Canada 2011a). It seems that while economic considerations are not explicitly included or calculated within the process of setting the conservation objective, some sort of consideration of economics played a role and has impeded the setting of a much stricter conservation objective. For example, the same study used to set the conservation targets also found that a greater than 90% probability of survival could be achieved if habitat disturbance was reduced to 10% or less (Environment Canada 2011b).

inclusion of economic costs earlier within the conservation planning process could ensure that the habitat protection and recovery actions outlined within an action plan are feasible, cost-effective and allocate resources to the best use.

1.2.1 The Potential Benefits of Multi-species Conservation Area Planning

The Canada-Saskatchewan Agreement on Species at Risk states that “ecosystem, landscape and multi-species approaches will be used when appropriate for the protection and recovery of species at risk” (subsection 2.7), and Saskatchewan’s Wildlife Act states that a recovery plan may include provisions for respecting one or more designated species as well as ecosystem management (subsection 50(3)). Despite these legal provisions for multi-species planning, species are generally considered individually within SARA despite numerous cases where multiple species share overlapping habitat.[10] In contrast to Canada’s slow adoption of multi-species plans, the United States’ Endangered Species Act (ESA) has employed many multi-species plans starting in the 1980s (Tear *et al.* 1995).

Multi-species conservation planning provides both practical and conceptual appeal. There is a belief that multi-species plans can speed up the recovery planning process for the large number of species requiring action plans by offering time and cost efficiencies during the planning and implementation stages (Tear *et al.* 1995; Scott *et al.* 1991; Shaffer 1992). However, multi-species plans add an additional layer of biological, management and political complexity which can limit the effectiveness of the plan (Tear *et al.* 1995), and a study of multi-species conservation on private lands suggested that multi-species plans are more time-consuming and expensive to prepare and do not necessarily improve recovery success (Langpap and Kerkvliet 2011).

[10] Habitat has been defined in the biological literature as the resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism (Hall *et al.* 1997). Using this definition, habitat implies more than habitat type which refers only to the vegetation association (Hall *et al.* 1997). Appendix A contains detailed information on the habitat requirements for the species at risk included in this thesis; however, within the body of the thesis, habitat refers to habitat type. In the case of the species at risk in the South of the Divide, habitat type means native grassland. In turn, within this thesis, habitat protection refers to the protection and/or restoration of native grasslands within the region.

Conceptually, the benefits of multi-species planning relates to the idea that "the whole is more than the sum of its parts." The principle of suboptimization states that optimizing subsystems independently will not, in general, lead to a system optimum if there are interconnections between the subsystems (Heylighen 1992). Within this analysis, individual species can be thought of as subsystems, and the entire species complex, or ecosystem, can be thought of as a system. In the case of Canada's mixed grass prairie which is home to several species at risk, the principle of suboptimization would suggest that selecting protected habitat areas for each species at risk individually will not, in general, lead to an optimal solution for the prairie ecosystem as a whole (Heylighen 1992). However, considering all species simultaneously will improve the optimization solution (Heylighen 1992). This simple, yet powerful, insight has resulted in a move toward conservation plans that simultaneously consider numerous individual species or use biodiversity indices (see Ando *et al.* 1998 and Polasky *et al.* 2001; Polasky *et al.* 2005; Cabez and Moilanen 2003; Montgomery *et al.* 1999; and Nicholson *et al*. 2006 among many others). If the magnitude of cost-savings (i.e. efficiency gains) achieved by multi-species plans is large enough, these plans could provide greater efficiencies than individual species plans despite their higher transaction and administration costs.

In summary, the overarching objectives of this thesis are (a) to measure costs associated with various conservation actions in the South of the Divide region, including the proposed critical habitat designations, (b) to develop estimates of cost-effective conservation area plans and create habitat protection cost curves, (c) to compare the cost-effective plans to the biology-based critical habitat assessments, (d) to assess the improvements in efficiency associated with multi-species plans relative to single species plans, and (e) to compare cost-effective plans that maximize grassland habitat patches to those without any habitat patch size requirements.

1.3 The South of the Divide Action Plan

The federal government (Canadian Wildlife Service, Parks Canada, Agriculture and Agri-Food Canada) and the Saskatchewan provincial government (Ministries of Agriculture, Energy and Environment, the Saskatchewan Watershed Authority) are working together to protect species at risk within Saskatchewan's Milk River Watershed. Currently as many as 22 species at risk (see Appendix A) reside within the Milk River Watershed.[11] A multi-species plan – formally known as the South of the Divide Action Plan – has been initiated to help protect and recover the species at risk within the region. This particular plan is unlike the majority of species at risk plans conducted under the guidance of SARA because it contains a large number of species at risk within a defined geographic region, and it includes a large amount of privately owned and managed land within the proposed critical habitat designations. A total of eight species have been tentatively selected to represent the region within the South of the Divide action plan's economic analysis, and, as such, those same eight species will be considered in this thesis. A multi-species approach has been selected for the region because multiple species within the region share similar habitat[12] and threats (Kirk and Pearce 2009). However, despite the eight species' common habitat and the multi-species nature of the action plan, critical habitat designations for these eight species were completed independently of each other.[13]

The South of the Divide region of Saskatchewan – as delineated by the Montana border to the south, Alberta border to the west, and the Milk River Watershed boundary to the north and east – is an area rich in native grassland habitat and the species at risk associated with those grasslands. The region contains 39% of Saskatchewan's federally listed (schedule 1) species at risk (Government of Canada 2011), and as much as 50% of the region still remains as native grasslands compared to an average of 20% across the province as a whole (Hammermeister *et al*. 2011). History has shown that many species whose ranges consist of primarily agricultural land never recover from their threatened status (Kerr and Deguise 2004), and as a result, a sound multi-species conservation plan for the region is vital if species at risk within the region are to persist and recover.

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[11] Two additional species – Grizzly Bear and Greater Prairie Chicken – are listed on SARA's schedule 1 but remain extirpated from the region.

[12] As mentioned previously, within this thesis habitat refers to native grasslands.

[13] While 3 of the eight species share a critical habitat polygon (Mountain Plover, Black-footed Ferret and Burrowing Owl) this is likely driven more by their co-occurrence than a purposeful attempt to coordinate critical habitat designations.

1.3.1 Methods/Approaches Used

A free access software program named Marxan (Ball *et al*. 2009; Watts *et al*. 2009) – which uses linear programming and a simulated annealing algorithm to optimize spatial conservation area planning problems (also known as reserve site selection models) – was used to determine cost-effective habitat protection designs and species' habitat protection cost curves for the South of the Divide region. The Marxan program is a simple reserve-site selection model that selects sites (i.e. parcels of land) for protection such that those sites minimize the cost[14] of habitat protection subject to meeting habitat protection targets. Habitat protection targets were varied between 5% and 100% of species' historical habitat for each model.

Habitat protection cost curves were calculated for each species individually and all species simultaneously. When species are considered individually, the percentage of their historical habitat protected must at a minimum equal the selected habitat target. The individual species models mimic the species-by-species approach that has been used in the region to select species at risk critical habitat polygons. When multiple species are considered simultaneously, the percentage of every species' historical habitat protected must at a minimum equal the habitat target. The multiple species model is better able to take advantage of species' habitat commonalities and overlap when designing the habitat protection areas.

The cost of protecting the proposed critical habitat designations for each species was also calculated. Habitat cost curves were calculated when habitat patch sizes were maximized by minimizing the number of exposed planning unit boundaries as well as when the model had a larger suite of conservation activities to choose from for the protection of habitat.

The reserve site selection models provided answers to several questions. The answers included information on the shape and magnitude of the cost curves for cost-effective species at risk habitat protection, the cost difference between protecting the proposed

[14] The costs considered within the Marxan models include the opportunity cost of removing oil, gas and agricultural production in the region as well as the cost (opportunity and direct) of implementing beneficial management practices, such as restoring native grasslands, improving grazing management, and planting buffer strips and shelterbelts, in the region.

critical habitat areas and an equivalent amount of habitat selected using the Marxan optimization model, the magnitude of cost-savings achieved by considering multiple species within one optimization model, the effect of habitat patch size on habitat protection costs, the effect that greater flexibility in a model has on habitat protection cost curves, and the selection and location of conservation activities as habitat protection targets change.

1.4 Overview of the Results

This study's results illustrate the role that economic analysis can play when it is included early within the conservation area planning process required by the Species at Risk Act. It specifically examines the benefits of including several species simultaneously within a single habitat protection optimization model.

The habitat protection cost curves within the region were non-linear within many of the models for the eight species which suggests that costs are spatially heterogeneous and that substantial habitat protection could occur for many of the species for very low cost.[15] For three of the eight species at risk considered in the analysis, protection of land designated as proposed critical habitat was substantially more expensive than protecting an equivalent amount of grassland habitat selected through the reserve site selection model. This finding suggest that the inclusion of cost considerations in the design of critical habitat could improve efficiency (i.e. reduce costs).[16] The remaining five species had such small parcels of land designated as proposed critical habitat that the cost of protection was minimal; however, the cost curves indicate that larger amounts of habitat could potentially be protected for the same or very little additional cost. The cost-savings of including all eight species simultaneously within a single optimization model is in the millions and tens of millions of dollars suggesting that selection of critical habitat on a species-by-species basis in an area with many different species at risk may not be optimal. Considering all species simultaneously can also

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[15] As little as 10% of the region's net present value to protect all, or almost all, habitat for several of the species at risk

[16] For insight into what may be driving these results, see section 3.3.3 for a discussion on the differences between the areas selected as proposed critical habitat and the areas selected by the reserve site selection model.

greatly reduce the added cost of acquiring larger habitat patches and in some cases can even completely compensate for the added costs of larger habitat patches. In general, habitat protection cost curves were lower when a greater number of conservation activities were available to protect habitat within the optimization models.

1.5 Chapter Summary

The advantages of including economic considerations in conservation area planning are well known (Ando *et al*. 1998; Naidoo *et al*. 2006; Carwardine *et al*. 2008); however, the South of the Divide Action Plan provides a unique opportunity to provide empirical measures of the value of including economic considerations within species at risk conservation area planning in Canada. Species recovery strategies and action plans have often include economics in a limited or secondary manner. However, there may be large losses to society – either as higher costs of habitat protection, or foregone habitat protection – when economics is not included in the species at risk management process. Using the Marxan conservation planning software, optimal protected area designs for the South of the Divide region and habitat protection cost curves were created which show the value of including economic considerations and multiple species planning within the management process.

Five sections follow this introduction: a literature review, an introduction to the study area, an overview of the methods and analysis, a summary of the results and findings, and finally a conclusion section to wrap up the thesis. The literature review focuses on the history of conservation planning and the current growth in systematic conservation plans that include economic considerations within the design process. The study area section provides an overview of the South of the Divide region including information on land-use and the species at risk. The methods section presents the conservation activity costs calculated for the region as well as a discussion on the reserve site selection models that use those activity costs as an input to design cost-effective habitat protection plans. The results section provides information on the magnitude of efficiencies gained by including economic considerations and multiple species in the conservation area planning process. Finally the conclusion section summarizes the research contributions, study limitations and potential for future research.

2 Literature Review: Cost-Effective Conservation Area Planning

This chapter presents a progression of conservation planning. Conservation area planning, a subset of conservation planning that focuses on protecting land areas or habitat in order to meet ecological goals and objectives, is a common form of conservation planning. It is this particular form of conservation planning that is the focus of this thesis. As a result, this chapter primarily uses concepts from conservation area planning to highlight conservation planning's shift from an unsystematic endeavour into a systematic process that recognizes the advantages of including economic considerations.

Areas of the world have been set aside to protect natural values (recreation, hunting, scenery, etc.), biodiversity, and ecological goods and services (food production, water and air quality, etc.). Unfortunately, historically, biological reserves have often failed to systematically protect biological capital or properly include economic considerations within the planning problem. Large numbers of protected areas have been designated on remote, unproductive parcels of land that require minimal economic and ecological trade-offs (Margules and Pressey 2000). However, conservation planners have begun to systematically plan the protection of biologically representative areas.

The protection of representative parcels of land are included within conservation areas results in a greater number of economic and ecological trade-offs having to be considered. The requirement to consider trade-offs between economic development and ecological protection has resulted in the growth of systematic, cost-effective conservation area planning (Naidoo *et al*. 2006). This new and fast-growing field has begun to revolutionize the manner in which conservation areas are designed. There have been advances in the calculation of trade-offs between conservation and development, in the movement from of single-species to multiple-species conservation areas, and in the inclusion of biological and economic dynamics in conservation planning.

2.1 Biology-based Conservation Area Planning

The protection of natural values – hunting, recreational or scenic sites – is a historic and widespread human phenomenon (Margules and Pressey 2000). Recently, protecting areas that provide ecosystem services – clean water and timber for example – and biodiversity has become commonplace (Margules and Pressey 2000; Anon 1992; Ando *et al.*1998).

The most basic role of any biological reserve or protected area is to separate the elements of biodiversity it is designed to protect from the activities and processes that threaten their survival outside of the protected areas (Margules and Pressey 2000). The effectiveness of a biological reserve's ability to protect biological diversity is determined by both the reserve's representativeness as well as its persistence (Margules and Pressey 2000). In order to meet these two objectives, from a biological perspective, conservation planning must consider a reserve's location, size, connectivity, replication, and alignment of boundaries (Shafer 1999; Peres and Terborgh 1995).

A biological reserve has a greater chance of effectively meeting protection and representation goals if it is created through a method of systematic conservation planning (Margules and Pressey 2000).Unfortunately, conservation planning has historically failed to be systematic and has resulted in a lack of representative legally protected biological reserves (Margules and Pressey 2000; Pressey *et al.*1996). This is because it is far easier to concentrate reserves on land that is remote, relatively unproductive, and does not require difficult decisions to be made regarding the trade-offs between economic production and biological protection (Margules and Pressey 2000; Terborgh 1999). Approximately 1.5% of the world's land and 0.5% of the oceans are now protected within reserves (WDPA 2003). However, these areas do not provide sufficient protection for the world's biodiversity, especially the species and ecosystems that are most imperiled (Andelman and Willig 2003; Rodrigues *et al.*2004; Meir *et al.*2004).

The past 30 years has witnessed a focus on the designation of systematic conservation areas (Klein *et al.*2008). Systematic conservation area planning can be defined as the identification of priority areas that comprehensively, adequately, and efficiently protect representative samples of biodiversity (Possingham *et al.*2006; Klein *et al.*2008; Margules and Pressey 2000). Conservation goals can be set as a target percentage of original extent (i.e. historical habitat or range)[17], a target population size for each species, or the persistence of biodiversity (Klein *et al.*2008). Systematic conservation area planning was developed by biologists, and, as such, the collection and inclusion of economic data within conservation area designs has historically been neglected (Naidoo *et al.*2006; Carwardine *et al.*2008).

2.2 The Advantages of Economics in Systematic Conservation Area Planning

It has been historically, and commonly, believed that conservation goals could be systematically and efficiently achieved by selecting biological hot spots (as indicated by high biodiversity or species richness) for protection (Ando *et al*. 1998). These approaches to conservation area design almost entirely excluded the consideration of economic costs (Wilson *et al.*2007). In fact, a well-cited article on systematic conservation area planning provides the following six steps as the guide to systematic conservation planning: (1) compile data on the biodiversity of the planning region, (2) identifying conservation goals for the planning region, (3) review existing conservation areas, (4) select additional conservation areas, (5) implement conservation actions, and (6) maintain the required values of conservation areas (Margules and Pressey 2000). Nowhere in that list is economics accounted for. However, it's becoming increasingly recognized that all conservation problems have scientific, social, political and economic aspects (Polasky *et al.*2005; Stewart and Possingham 2005).

Stewart and Possingham (2005) found numerous instances that suggest a legally protected reserve's success or failure depends primarily on socio-economic aspects, regardless of how sound the ecological science. Transparent inclusion of socio-economic factors can result in trade-offs and compromises being made early in the decision process (Stewart and Possingham 2005); the result is a streamlined design of systematic conservation areas, and ultimately a quicker and more effective protection of biodiversity. Thus, systematic conservation area planning would benefit from the inclusion of economics. The benefits and costs, including their spatial and temporal

[17] The conservation goal used within this thesis is the percentage of original extent. While protected areas can be designed to meet other targets such as population targets or a species' probability of persistence, the biological information available for this region limited the analysis to extent of historical occurrence. Please see section 4.1.1.2 for a discussion on the limitations associated with protected area planning based on extent of original/historical habitat.

distributions, of conservation plans should be considered in a systematic conservation planning framework as well questions of where, when, how much, and on what funds should be spent (Wilson *et al.*2007; Naidoo *et al*. 2006). In practice, effective systematic conservation area planning becomes the attempt to solve cost-effectiveness problems: how to achieve a given conservation target (on all land bases regardless of their production potential) at least cost – i.e. how to achieve the most conservation given limited resources (Naidoo *et al.*2006). Proper definitions of objectives in conservation area planning include not only defining the biological targets but also the actions used to conserve the targets and their associated costs (Carwardine *et al.*2008).

The design and location of systematic conservation areas can be accomplished through the use of a decision theory framework, ecological, spatial and socio-economic information, and mathematical algorithms (Stewart *et al.*2003; Margules and Pressey 2000; Stewart *et al.*2003). The power of mathematical algorithms in the field of systematic reserve design comes also from their ability to incorporate spatial data such as adjacent land uses, economic costs, boundary lengths, connectivity and minimum patch size (Stewart *et al.*2003).

2.3 Incorporating Economic Costs into Conservation Area Planning

Limited resource availability for biological conservation has resulted in the need to strategically allocate investments (Naidoo and Ricketts 2006; Margules and Pressey 2000; Csuti *et al.*1997). While the bulk of conservation planning literature focuses on the biological benefits of conservation plans, consideration of the cost side of conservation planning offers significant opportunities to achieve efficient conservation objectives in a world of limited conservation resources (Naidoo *et al.*2006; Stewart and Possingham 2005).

The most recent advances in the conservation planning literature suggests that benefits, costs and threats should all be used in an integrated approach (Naidoo *et al.*2006), and a thorough economic analysis of a conservation area design would include a full accounting of both the economic benefits and costs of protecting a range of biological targets. By calculating the costs and benefits of several conservation targets, the optimal target can easily be selected by directly comparing the costs and benefits and selecting the target that maximizes net benefits (Campbell and Brown 2003). This is known as a cost-benefit analysis. However, cost-benefit analyses are rarely done in conservation area planning due to the difficulty of quantifying the economic benefits of conservation in monetary units. As such, conservation planning problems often rely instead on cost-effectiveness analyses and consider only costs. Cost-effectiveness analysis is a useful economic approach used in the case that the benefits of a project or program are difficult to explicitly measure (James 1994). The technique involves setting a goal – such as a habitat protection target – and finding the least-cost way of achieving that goal (James 1994). In this case, the benefits are not specified explicitly in economic terms but, rather, are left in biological terms.

Unlike cost-benefit analysis, cost-effectiveness analyses cannot provide the answer of where the biological target should be set. However, recent studies have begun to show the substantial gains in efficiency that can result from the inclusion of economic costs in the design of conservation areas (Naidoo *et al.*2006; Naidoo and Ricketts 2006; Carwardine *et al.*2008). Along with the increase in efficiency, there is also an ability to mitigate or avoid conflicts that arise as a result of conservation planning in the absence of socio-economic considerations (Stewart and Possingham 2005). Another advantage of including costs into conservation planning is the ability to show the trade-offs between obtaining conservation targets and costs (Naidoo *et al.*2006). The result of these trade-offs is the creation of cost curves (Arthur *et al.*2004). A common pattern for cost curves is that moderate levels of conservation are relatively inexpensive and only very high levels of protection become quite expensive (Naidoo *et al.*2006; Schneider *et al.* 2011). These cost curves can provide valuable information for decision makers despite their lack of ability to indicate an optimal biological target.

Costs may often be excluded from conservation planning due to the difficulty of obtaining adequate cost data as well as the fact that cost data is often fraught with uncertainty (Carwardine *et al.*2008; Carwardine *et al.*2010). While using inaccurate cost data may limit the efficiency gains of conservation planning, the inclusion of uncertain cost data still results in more efficient results than ignoring costs altogether (Carwardine *et al.*2010). Thus, despite the realistic possibility of uncertainty within cost measurements, the inclusion of costs still improves the efficiency of conservation planning.

2.3.1 Homogeneous Costs and Cost Proxies

Most conservation plans focus the largest amount of attention on the biological aspect of the problem and incorporate economic costs simplistically (Naidoo *et al.*2006). Within the literature, the conservation planning goal is often to minimize simple cost proxies such as total conservation area or total number of planning units subject to meeting conservation targets (Naidoo *et al.*2006; Ando *et al.*1998). It is relatively simple to design a model that minimizes the number of sites or total area included within a conservation plan (simply set the cost of all planning units equal to 1, or to their area, respectively) (Stewart *et al.*2003). This is a simplified form of the reserve site selection problem where costs are assumed to be homogeneous; all area units or planning units are assigned the same value. The result is that costs are no longer used in a meaningful manner within the planning process, and the selection of sites within a reserve network is driven only by biological considerations and so-called biological “hot spots” (Ando *et al.*1998; Dobson *et al.*1997). In reality land values and conservation costs are spatially heterogeneous, and as a result, efficiencies are lost due to the “one size fits all” calculation and assignment of these homogeneous conservation area costs (Naidoo *et al.*2006; Ando *et al.*1998; Rodrigues *et al.*2004; Polasky *et al.*2001). Other cost proxies that have been used in conservation planning include distance to road or population density (Naidoo *et al.*2006); however, these measures also carry distinct disadvantages. The use of threat or vulnerability classifications as a correlate to cost can inform the importance of selecting particularly vulnerable areas for conservation, but these measures should be used in association with costs grounded in economic theory, and not as a substitute for those same costs (Naidoo *et al.*2006).

2.3.2 Spatially Heterogeneous Costs

Heterogeneity in costs is especially powerful when costs can be spatially applied to the landscape (Naidoo *et al.*2006; Schneider *et al.* 2011). Since conservation area planning is inherently spatial in nature, spatial cost and biological information is necessary to properly inform the process. Carwardine *et al.*(2008) found that conservation area planning with homogeneous costs (area as a proxy of cost) was unable to minimize the costs of land acquisition and stewardship; however, spatially variable costs were able to minimize both cost and area. Realistic, spatially-applied costs grounded in economic theory surpass homogeneous proxies for cost. Cost heterogeneity also opens the door to different mechanisms for habitat protection such as market based instruments (e.g. payments for ecosystem goods and services) which can target locations for habitat protection, illicit better estimates of conservation costs, and likely reduce overall conservation costs in the long run.

2.3.3 Relevant Costs for Conservation Area Design

Numerous costs are associated with the creation of protected areas. All conservation interventions or activities have associated costs which can include acquisition costs, opportunity costs, damage costs, management costs, and transaction costs (Naidoo *et al.*2006). A brief discussion of each type of cost is taken from Naidoo *et al.*(2006). Acquisition costs include the cost of acquiring total rights (outright purchase) or partial rights (conservation easements, or other contracts) to a parcel of land. Opportunity costs are the costs of foregone opportunities, or alternatively they are a measure of what could have been gained via the next best use of a resource had it not been put into conservation. Opportunity costs can reflect the value of foregone extractive or productive use (for example, oil and gas extraction, fishery harvest, or agricultural production). The purchase price of land or conservation easements reflects the value of lost production opportunities to private landowners. Opportunity costs are important to include so that the full cost of conservation planning can be considered. Management costs are the variable or fixed costs associated with the management of a conservation program. Management costs can include the costs of a wide diversity of activities including, but not limited to, implementing monitoring programs, running educational programs, or even controlling predators, improving habitat, or introducting additional individuals of a species. Transaction costs are the costs associated with negotiating an economic exchange. Damage costs are the costs associated with damages to economic activities arising from conservation programs. These can include damages to crops or livestock as a result of wildlife residing in protected areas. Acquisition costs or management costs are often paid directly by either government or conservation organizations while some costs – opportunity costs or transaction costs – are internalized by society and/or industry (Naidoo *et al.*2006).

While the inclusion of economic costs in conservation planning remains limited, costs are becoming more commonly included in the beginning stages of systematic conservation planning. Land values or the value of economic commodities – fisheries, agriculture, forestry, and oil and gas – have been used to estimate the opportunity cost of setting land aside for conservation objectives (Stewart and Possingham 2005; Polasky *et al.*2005; Hauer *et al.*2011; Ando *et al.*1998; Polasky *et al.*2001). While complete removal of production is often assumed in conservation areas, there are also instances where habitat restoration or other management costs (predator control, re-introduction of individuals, monitoring programs, etc.) may be the more appropriate interventions. Regardless of what the most appropriate course of action may be, it is vital that a clear specification of conservation objectives and actions is indicated at the outset of a project (Carwardine *et al.*2008).

2.3.4 The Mutual Exclusivity of Production and Conservation Areas

Reserve site selection models, and conservation area planning in general, often assume that lands in protected areas only contribute to biological objectives and land outside protected areas only contribute to economic objectives (Polasky *et al.* 2005). The commonly used Marxan software (Ball *et al.*2009) follows the standard reserve-site selection model; however, the Marxan with Zones software (Watts *et al.* 2009) allows a much greater flexibility in relationships between land-use and habitat provision. Marxan with Zones allows a number of varying land-uses to be specified. Each land-use has its own ability to contribute to habitat (i.e. native grassland) protection. Each land-use can also have targets set for its inclusion within the conservation areas.

However, things are often not so black and white and economic production and conservation objectives are not necessarily mutually exclusive (Polasky *et al.*2005). Polasky *et al.*(2005) found that when economically productive land is still allowed to provide habitat (even if at a reduced quality which is accounted for in the model), there is a less marked trade-off between economic and ecological objectives. Additional examples of the relaxing of the assumption of mutual exclusivity between production and conservation are shown by Montgomery *et al.* (1999) and Cabez and Moilanen (2003). Montgomery *et al.*(1999) maximized the value of land (commercial, residential, agricultural, and conservation) under different biological diversity goals where all land types contributed to biological diversity at levels relative to their ability to support species' populations. Cabez and Moilanen (2003) used a spatiotemporal dynamic population model to compare the impact on species persistence of land outside of reserve networks.

2.4 Incorporating Dynamics into Conservation Area Design

This thesis, like the majority of current conservation area planning projects (Meir *et al.*2004; Lichtenstein and Montgomery 2003), treats both biodiversity and economic systems as static. The result is a failure to account for dynamics in biodiversity abundance (population dynamics) as well as the dynamics in the actual creation and implementation of a conservation area (McDonald-Madden *et al.*2008). While this is a recognized weakness of the analysis, a dynamic model was not employed largely due to lack of sufficient data. Nonetheless, a brief discussion of the value of including dynamics in conservation area planning is included below.

Conservation planning, like any planning process, is dynamic in nature. Conservation area planning is made a dynamic process by the dynamic nature of biodiversity, conservation costs and land tenures (McDonald-Madden *et al.*2008). In practice, implementing a reserve network is a sequential process that can take up to several decades and in the meantime biodiversity is lost and the landscape changes (Meir *et al.*2004). As such, explicitly including dynamics into reserve network planning makes the process more realistic and can result in more effective and efficient conservation networks.

Population dynamics are often unknown for many species within the scale of the conservation planning area and the result is that explicit criteria for species persistence often fails to be considered within reserve-selection models (Araujo *et al.*2002). However, a few papers in the literature have attempted to model population dynamics. Within these papers, population dynamics as a result of forestry activity within the landscape are the most commonly used example (Calkin *et al.*2002; Lichtenstein and Montgomery 2003; Nalle *et al.*2004). Calkin *et al.*(2002) modeled the trade-offs between species persistence and timber harvest values when species persistence is dependent upon the harvesting (and conservation) activities on the landscape. Nalle *et* *al.* (2004) spatially modeled two species' populations as a function of vegetation cover, adjacency to suitable breeding habitat, and proximity to suitable hunting/foraging habitat within a working forestry landscape. Lichtenstein and Montgomery (2003) in an attempt to extend single-species dynamic models, built upon the model of Montgomery *et al.*(1999) to maximize timber profits through time with constraints on biodiversity (species persistence) which in turn is affected by timber production. Conrad and Finseth (n.d.) provide both deterministic and stochastic (non-spatial) models for the cost-effective recovery of an endangered woodpecker using translocations and habitat (tree cavities) creation.

Not only can dynamics be included in the biological component of a conservation plan, but also within the economic component. Net present value (NPV) calculations inherently account for time in their use of extraction paths, harvesting schedules and profit discounting[18] (Hauer *et al.*2011; Hauer *et al.*2010a; Nalle *et al.*2004; Calkin *et al.*2002; Lichtenstein and Montgomery 2003; Schneider *et al.* 2011). However, the calculation of one final NPV value that is used in a conservation area model inhibits the flexibility of the model to adjust harvest and extraction paths throughout time. Hauer *et al.*(2011) present information on the opportunity costs of oil, gas and forestry development resulting from the protection of woodland caribou in Alberta. Capacity constraints that improve the realism of the oil, gas and forestry NPVs were included within the dynamic model of caribou protection (Hauer *et al.*2011). Hauer *et al.*(2010a) also created a dynamic forestry harvesting model that then allowed trade-offs between avian abundance and timber harvest schedules.

2.5 Multiple Species Conservation Area Planning

Cost-effective conservation studies have faced an evolutionary process. One set of studies within the conservation planning literature considered trade-offs for single species. Often these studies used a dynamic biological model in an optimization

[18] Extraction paths refer to the development or extraction schedules that are used in the management of natural resources through time. Discounting refers to the adjustment of revenue streams through time to account for the opportunity cost of investing in resource development at the present time as well as society's preference to receive benefits in the present rather than in the future.

framework to relate wildlife population size and probability of persistence to resource development (Lichtenstein and Montgomery 2003). Production possibility frontiers relating resource NPVs and species persistence were the desired output of these studies (see Calkin *et al.*2002 for an example). Nalle *et al.*(2004) then used two species with varying habitat needs to develop production possibility frontiers between each species and resource NPV, and between the two species. Eventually, another set of studies began to show the trade-off between species persistence and resource development NPVs. These studies investigated the ability to use biodiversity persistence (as a function of land-use, species populations, etc.) rather than single-species persistence within the trade-offs modeled (Montgomery *et al.*1999; Lichtenstein and Montgomery 2003).

Another approach to expand upon the single-species methods and include a larger suite of species is the use of a reserve site selection model. These models select a system of reserve sites (i.e. parcels of land set aside for conservation) that achieve a target level of species' habitat protection at a minimum cost (see Ando *et al.*1998 and Polasky *et al.*2001). These studies include biodiversity in a simplistic manner (species richness, i.e. the presence or absence of species in a patch) and implicitly assume that meeting a minimum level of habitat protection for each species will ensure the species' persistence. A drawback with earlier models of this type is the assumption that land in protected areas only contribute to biological objectives and land outside protected areas only contribute to economic objectives (Lichtenstein and Montgomery 2003; see section 2.3.4). However, some studies have begun to consider the importance of non-reserve land to the conservation of biodiversity (Polasky *et al.*2005; Cabez and Moilanen 2003; Montgomery *et al.*1999).

The inclusion of multiple-species dimensions (either as a suite of threatened or endangered species, species in general, or as a biodiversity index) has become increasingly prevalent in cost-effective conservation models (Ando *et al.*1998; Polasky *et al.*2001; Polasky *et al.*2005; Lichtenstein and Montgomery 2003; Montgomery *et al.*1999; Hauer *et al.*2010a).The inclusion of multiple species and biodiversity goals in conservation planning is in-line with the primary goal of systematic conservation planning – the persistence of biodiversity (Nicholson and Possingham 2006). However, it remains undecided how to properly represent biological objectives for multiple species and how to integrate these objectives into optimization models that include the cost of land-use and land-use changes (Nicholson and Possingham 2006). Nicholson and Possingham (2006) suggest the best approach is not a minimum set problem where costs are minimized subject to conservation targets, but rather biodiversity or multiple species persistence should be maximized subject to budget constraints. The belief is that a minimum set problem (which often assumes multiple-species persistence after a particular habitat target is met) may not be as effective.

2.5.1 The Potential Efficiencies of Multiple-species Conservation Planning

There has been criticism of the species-by-species approach used by government for the conservation of species at risk, and multi-species or landscape level approaches have been presented as alternative options (Tear *et al.*1995). In their literature review on the strengths and weaknesses of multi-species planning (32 journal articles and grey literature reports as well as 31 multi-species plans from Canada, the United States, and Australia), Kirk and Pearce (2009) found that widespread support was given to multi-species plans in the 1990s and early 2000s because of their perceived benefits. The primary benefit of a multi-species plan is obvious: to simultaneously address the requirements of many species (Kirk and Pearce 2009).

A multi-species approach has the potential to provide efficiencies. Kirk and Pearce (2009) found that the top three reasons for choosing a multi-species approach include the co-occurrence of species, the existence of common threats, and the shared benefit of recovery actions (i.e. efficient use of resources). The number one reason was the ability to improve the efficiency of available resources (Kirk and Pearce 2009). Multi-species plans are attractive because they have the potential to reduce conservation costs (largely management and transaction costs, but also opportunity and acquisition costs) by concentrating conservation efforts on areas with the largest shared biological benefit to species. Time efficiencies in the conservation process (recovery strategies and action plans) could help governments meet the conservation planning needs of the large number of at risk in Canada and the United States (Tear *et al.*1995). Multi-species plans also make biological sense since the inclusion of multiple species is likely to create an effective conservation reserve design (select cost-effective areas that provide biological benefits to multiple species) and improve the comprehensiveness of conservation actions (Langpap and Kerkvliet 2011). Multi-species planning allow species, for which there is insufficient data for recovery planning, to piggy-back on species with sufficient data and similar life histories or habitat requirements (Kirk and Pearce 2009).

2.5.2 The Realization of Multiple-species Conservation Planning Efficiencies

Kirk and Pearce (2009) formulated a list that outlines the features of successful and unsuccessful multi-species plans. They found that the top four features of a successful multi-species plan (planning success, but not necessarily recovery success) are the composition and size of the recovery team, the inclusion of stakeholders (the need to include private landowners), the consideration of costs throughout the planning process, and using quantifiable metrics to measure recovery success. A recovery plan with economically realistic goals that are within the scope of available resources is crucial to a plan's success regardless of how well thought out and comprehensive the plan; however, cost information is not detailed in most Canadian multi-species recovery plans (Kirk and Pearce 2009). The top reasons found in the literature for a multi-species plan's failure is the lack of species-specific data and a poor understanding and/or identification of threats (Kirk and Pearce 2009). Tear *et al.*(1995) acknowledge that a multi-species approach – if carried out effectively – can improve cost-effectiveness and success through an increase in the scope of a recovery plan; however, they also recognize that the inefficiencies and lack of success in single species approaches must first be addressed before recovery planning should shift its focus to multi-species plans.

While there are many theoretical benefits to multi-species plans, these benefits may not always be realized. Multi-species plans add an additional layer of biological and political complexity (Tear *et al.*1995), often requires additional time and expense (Langpap and Kerkvliet 2011), and have been shown to provide little to no biological benefit over single-species plans (Clark and Harvey 2002; Langpap and Kerkvliet 2011). Multi-species plans provide efficiencies in theory, but the realization of these efficiencies seem to be elusive.

2.6 Additional Topics in Conservation Area Planning

There have been additional extension to conservation area planning and the elucidation of the trade-offs between species or biodiversity persistence and economic costs (opportunity costs in particular). Newburn *et al.* (2005) used a land conservation model that included the probability of land-use change. This may be particularly important when land cannot instantly be included within a legally protected reserve network (as in Meir *et al.*2004 or McDonald-Madden 2008). Hauer *et al*. (2010a) included a range of natural variation within their model that presented the trade-offs between avian abundance and timber harvests. The biological natural variation provided a guideline for setting conservation targets. Arthur *et al.* (2002) used probabilities of species presence to design an optimization approach – the expected coverage approach – that maximizes the expected number of species covered.[19] Arthur *et al.* (2004) expand the discussion on species occurrence uncertainty to include trade-offs between biological objectives: maximize the number of species covered versus maximize the number of species at risk covered. Arthur *et al.*(2004) also accounted for uncertainty in cost estimates which has been done by only a few site selection models (see Carwardine *et al.*2010 for a further discussion). Wilson *et al.*(2007) developed conservation action investment schedules (fire regimes, exotic plant management and habitat conversion/restoration) that maximize the total number of species conserved given a fixed annual budget, and they found that their method provides better outcomes for biodiversity conservation than simple land acquisition models. These studies are a small collection of the interesting extensions to conservation planning.

2.7 Cost-effective Conservation Area Planning in the South of the Divide: A Minimum Set Reserve Site Selection Model

Due to the large remnant tracts of native prairie located within the South of the Divide region, the area is a species at risk "hot spot". As such, biological objectives were the primary driver for the investigation into the creation of protected habitat areas within the South of the Divide region. Within the area, proposed or legally defined critical habitat has been designated for eight species at risk; for several of the species, this region contains the only critical habitat (either legally defined or proposed) designated across Canada. While "it is generally considered to be the socio-economic aspects that

[19] Their approach – in comparison to counting a species as present if the probability of its occurrence is greater than a specified threshold (e.g. 90%) – is a more sophisticated inclusion of the probability of species occurrence within a reserve site selection model.

ultimately determine a reserve's success or failure, regardless of how sound it is scientifically" (Stewart and Possingham 2005), socio-economic considerations are not legally required in the designation of critical habitat for species at risk in Canada. As such, the proposed critical habitat designations consider only biological data and are modeled based on species occurrence data and biological models (Stephen Davis, pers. comm).

Neither the selection of the South of the Divide region for protection nor the selection of the proposed critical habitat took into account any socio-economic considerations[20]. Assessments of socio-economic factors have predominantly been used to evaluate conservation areas rather than being included in the process of conservation planning itself (Stewart and Possingham 2005). This is indeed the case for all critical habitat designated within Canada under the Species at Risk Act (SARA); the South of the Divide is no different. The government requires a socio-economic assessment to meet legislative requirements, but the assessment is merely a post-hoc assessment of the costs associated with already-selected areas and is not used to inform the designation of critical habitat areas.

Information from the region was used to create a reserve site selection optimization model which minimizes the cost of habitat protection and restoration while still meeting all habitat protection requirements[21]. While proposed critical habitat areas had already been located within the region, the modeling exercise is not without merit. The model can test several questions related to conservation area planning and potentially initiate a discussion regarding the inclusion of socio-economic considerations within the SARA critical habitat designation process. The optimization model can provide information on the cost associated with different combinations of conservation activities, whether or

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[20] Since this area has a relatively high level of intact grassland habitat, it may have been more useful to model habitat protection and restoration in a region where grassland habitat is rarer and in greater need of protection and restoration.

[21] Again, the conservation actions, conservation costs and reserve site selection model are not indicative of the actions that will be carried out by either the provincial or federal governments. This thesis presents only one of many possible management scenarios that could be used in the South of the Divide region.

not the proposed critical habitat areas are economically efficient, whether or not there are economic benefits to multi-species planning in the region, and the spatial allocation of land in the region to different conservation activities. The in-depth consideration of several costs (oil and gas development, agricultural land values, and the cost of beneficial management practices) allows the creation of cost-effective conservation designs that go beyond the protection of the proposed critical habitat designations (moving into the realm of habitat stewardship possibilities). The result is the combination of two different philosophies forming the design of the conservation reserve network within the South of the Divide region. While conservation planning may be constrained by species at risk legislation, the use of economic optimization modeling can help to inform the conservation planning process as well as the species at risk legislative process.

The optimization framework used for the reserve site selection model minimizes the cost of the selected conservation area subject to meeting habitat targets. Within the model, species persistence is assumed at a level of habitat protection equal to or beyond the amount recommended to become legally designated as critical habitat by federal agencies. The assumption of species persistence stems from the definition of critical habitat, which is "the habitat necessary for the survival or recovery of a listed endangered, threatened or extirpated species" (Subsection 2(1) of the Species at Risk Act). In this manner, habitat protection can be equated with species persistence.[22] The costs of several different conservation actions – agricultural land acquisition, foregone oil and gas net present values, as well as different beneficial management practices including improved grazing management, the planting of shelterbelts, and the planting of buffer strips – are considered for the region. All costs were calculated into perpetuity so that the costs of the protected habitat areas reflect the total cost of the project into the future. Land that remains in productive uses (livestock grazing, oil and gas extraction, and annual crop production) are still capable of providing species habitat within a subset of the optimization models. In one model (the Marxan with Zones

[22] The use of target habitat area protection rather than some measure of persistence allows the optimization model to parallel the current legal requirements of critical habitat designation. The closer the two processes remain, the more likely the results and suggestions from the optimization model are transferable to actual policy.

model), each land-use type is given a weighting factor that can be interpreted or used in two ways: the weight indicates the quality of the land-use type as habitat for the species, or the probability that a species will be found in that land-use. The optimization model also allows the inclusion of spatial connectivity between habitat patches. In this way, spatial contiguity can be included within the model. The optimization model includes no species dynamics or dynamics to account for interactions between species responses and the spatial inclusion of habitat parcels or the application of conservation activities.

2.8 Chapter Summary

There has been an evolution toward and within systematic conservation planning. The concept of systematic planning is innovative in itself, and until recently the tools and theory required to carry out systematic conservation planning were lacking. Historically, the field of conservation planning was unable to inform questions regarding the distribution of funds between regions, or questions regarding when or on what the funds should be spent (Wilson *et al.*2007). Recent advances in the theory of systematic conservation planning, however, has resulted in the increased prevalence of cost considerations and dynamics in the decision of where, when and how much resources should be invested in conservation (Wilson *et al.*2007). While there is still work to be done in the field of systematic conservation planning, the field is growing in popularity and new extensions of old questions have begun to emerge.

This study provides both theoretical and application values. This study adds to the systematic conservation planning literature by testing the theory of multi-species planning efficiencies and the added cost of larger habitat patches. It also tests long held findings regarding conservation efficiency gains achieved by including economic costs in conservation planning. Extensions of the standard reserve site selection models are the inclusion management costs as well as acquisition and opportunity costs. Also, land currently in productive uses (livestock grazing, oil and gas extraction, and annual crop production) is allowed to provide species habitat within several of the optimization models.

3 The Study Area: The South of the Divide

This chapter provides additional background information on Saskatchewan's Milk River Watershed, or, more specifically, the South of the Divide study area that is contained within the watershed. The South of the Divide provided the geographical location for which all conservation activity costs were calculated and reserve site selection models were run. Within this chapter, information on the region's current land use is discussed as well as the importance of the region to species at risk and landowner perceptions of species at risk. Species specific information (historical ranges, habitat needs, threats to recovery, legally defined and proposed critical habitat designations) and information on practices that will assist in the protection and recovery of species at risk are also presented for a subset of the species within the region.

3.1 The Geographical Location

The South of the Divide study region is located in the only portion of Saskatchewan that is south of the continental divide (all water in the region flows to the Mississippi River and ultimately the Gulf of Mexico). The region is located within the mixed grassland and Cypress upland ecoregions of the Canadian prairie ecozone. The area is delineated by the Milk River Watershed to the north and east, Alberta to the west, and Montana to the south (Figure 3.1). Lands that intersected the watershed basin boundary were also included within the South of the Divide study area. As a result, the Nekaneet Cree Nation Indian Reserve, Birch and Maple Grazing Co-op Ltd., Piapot and Bear Grazing Co-op Ltd., Black Hills Grazing Co-op Association, Scotsguard Grazing Co-op Ltd, Beaver Valley Community Pasture, Auvergne-Wise Creek Community Pasture, Mankota Community Pasture and any bordering quarter sections with partial inclusion in the basin were encompassed within the South of the Divide study area (Kirk and Pearce 2009). The result is a total study area of 14, 923 square kilometers of dry mixed grass, mixed grass and Cypress upland prairie is included in the study region. A total of 21 532 quarter sections were included within the final analysis (13,871 square kilometers).

Figure 3.1. The geographic location of the South of the Divide study area within Saskatchewan's Milk River Watershed.

The study region is located in a rural and agriculture-rich corner of the province of Saskatchewan. The region contains 15 rural municipalities (8 of which are only partially included) and several small communities. There are no towns over 1000 within the study area. Overall, the region has a very low population density and falls primarily into Canada's land area that contains less than 1% of the country's population (Natural Resources Canada 2005).

3.2 The Region's Land-use and Importance to Species at Risk

The primary land uses within the South of the Divide region are agriculture (ranching and farming) and oil and gas development. The current allocation of land within the region to each agricultural land-use, soil classification, and range ecosite was determined using spatial information provided by the Canadian Wildlife Service and the

Saskatchewan Ministry of Environment. Within the region, approximately 42% of the area is privately owned farmland, 30% is provincial crown lease land, 17% is federal and provincial community pastures, 4% is Grasslands National Park, 3% is grazing cooperatives, and the remaining 4% is divided up amongst ‘other’ land uses including wildlife areas, irrigation project land, Indian reserve land, conservation easements and town sites. Annual cropland, hay fields and tame pastures, and native grasslands cover 23%, 13% and 53% of the region, respectively (Figure 3.2). Land classification ratings in the region range from Class 3 (moderately severe limitations to crops) to Class 6 (incapable of supporting annual cropland and limited to the production of native or tame perennial species). Class 3, 4, 5, and 6 lands make up 54%, 36%, 0.07%, and 10% of the study area’s land base, respectively. Loam and overflow are the most common ecosites (66% of land base), saline and solonetiz ecosites come in second (15% of the land base), and badlands and thin soils come in third (10% of the land base). Less common ecosites include clay, gravel, wet and dry meadows, and marsh ecosites.

Approximately 83% of the Earth’s surface has been modified by humans (Sanderson *et al.*2002), and Saskatchewan’s grasslands are not far off the global average. Only 20% of Saskatchewan’s native prairie ecozone remains intact and in areas of prime cropland, as little as 2% of the native prairie grasslands remain (Hammermeister, Gauthier and McGovern 2001). However, with approximately 53% of the region remaining as native prairie southwest Saskatchewan has much higher levels of remaining native grasslands. Only the very central portion of the study area has a high level of cropland development and little remaining native grasslands (Figure 3.2). The high occurrence of remnant grasslands is commonly attributed to the poor land productivity of the region and the high level of public ownership of land (whether in national parks, provincial parks, federal pastures, provincial pastures, or provincial crown land that is leased to the public; Figure 3.3).

Regardless of the reason behind the low agricultural disturbance in the region, it’s undeniable that the remnant grasslands in the region are essential habitat for several grassland species at risk (Kirk and Pearce 2009). Not only does the region have a high quantity of remaining native prairie, but the remaining grasslands are also high in quality. The mixed grass prairies have often benefited from conscientious management and are some of the best condition – as measured through range health assessments (plant community composition, invasive species, erosion, litter, etc.) – grasslands in the prairie ecozone (Hammermeister, Gauthier and McGovern 2001).

As a result of the high quality and quantity of suitable grassland habitat located within Saskatchewan's Milk River Watershed, as many as 24 species (see Appendix A for the list of species) currently listed on the federal species at risk public registry have all or part of their historic range located within the watershed. Species endemic to the prairies, including both permanent residents and migratory species, use the Milk River Watershed as their breeding grounds (Kirk and Pearce 2009). The success of these species is tied to the continued provision of healthy, well-managed native grasslands.

Given that the South of the Divide region has relatively little agricultural disturbance relative to other parts of Saskatchewan's grasslands that also provide habitat for species at risk, one important question is whether or not the South of the Divide is the best location for conservation planning. There are two supporting arguments for selecting the South of the Divide within this thesis. The first is that due to the high density of species at risk that currently occur in the area this area has been selected as the location of a species at risk action plan by the federal and provincial governments. As such, conservation planning is required in this particular region. The second is that while economic conservation area planning models can prioritize conservation and restoration based on biological benefits and conservation costs, high quality conservation cost and biological benefit data is required for the models. Within Saskatchewan, there is a lack of the biological data required (especially at the scale required) to provide quantitative measures of the increased benefits to species at risk of protecting higher disturbance areas. As long as extent of historical range is the biological goal used within the conservation planning models, an area with less agricultural disturbance can provide the same biological goal at lower cost. Therefore, focusing conservation efforts in the South of the Divide region is consistent with cost-effective conservation planning as applied in this thesis.

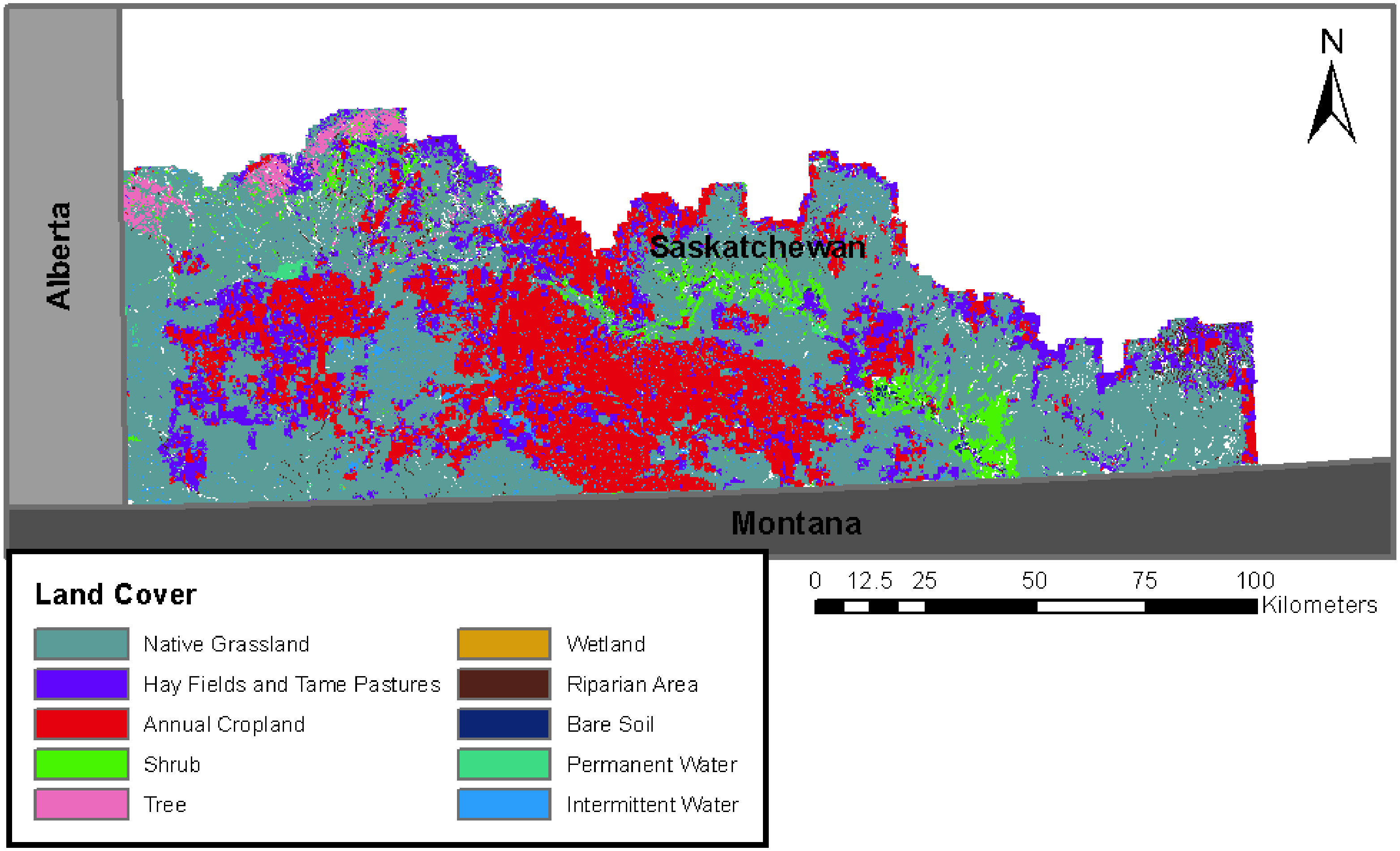

Figure 3.2 The distribution of landcover types within the South of the Divide study area.

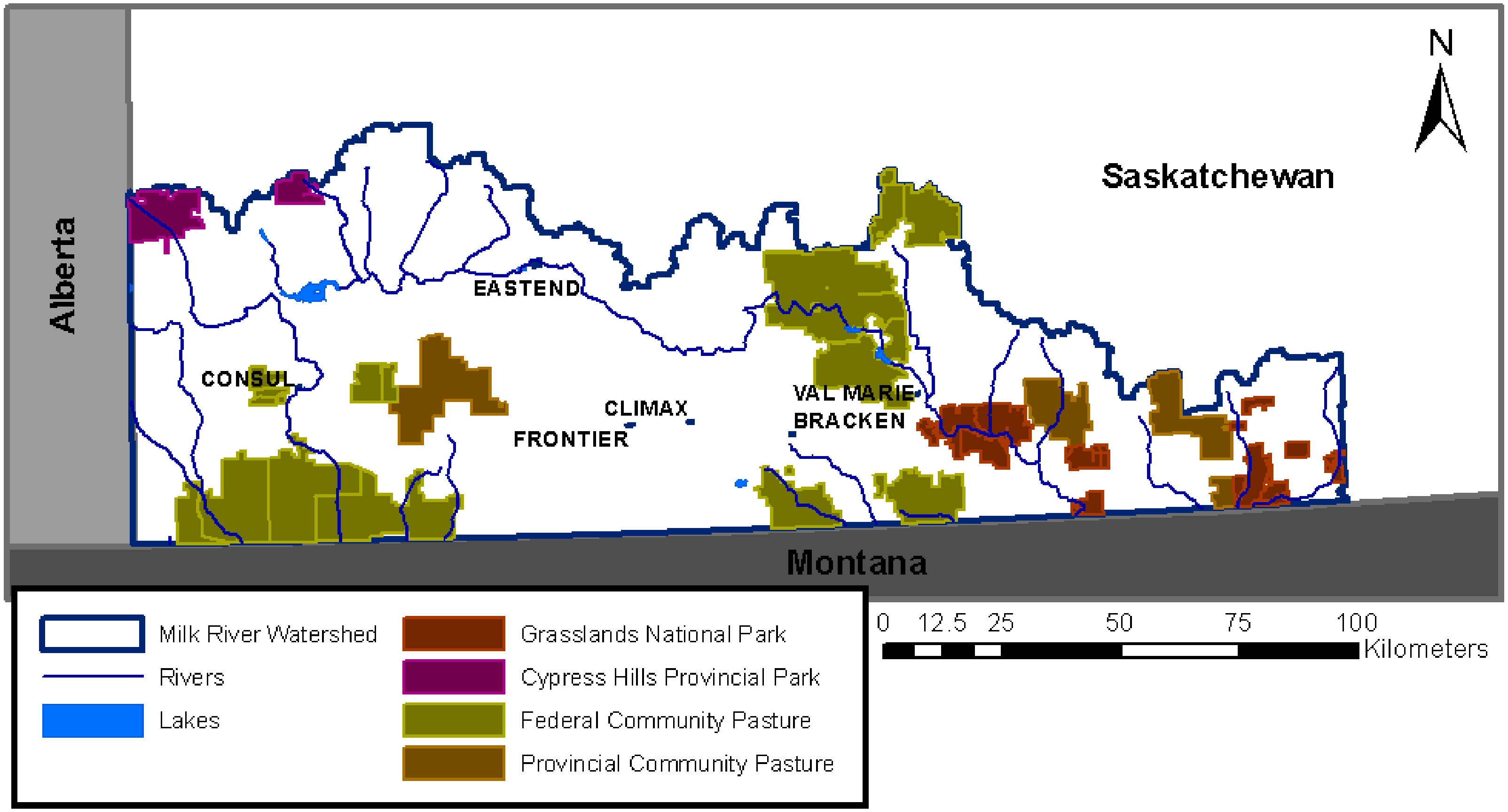

Figure 3.3 The distribution of government parks and community pastures within the South of the Divide study area.

3.2.1 Landowners and Species at Risk Management

The reserve site selection model presented in this thesis examined conservation actions on private land, and as such, it was important to address the question of the willingness of landowners to participate in conservation initiatives. Henderson (2009) interviewed land managers of native prairie within the South of the Divide. The interviews provided information on the culture of agriculture in the area and its relevance to the management of species at risk. Often land managers stated they had a strong tie to the land regardless of whether that land is privately owned or leased on long term contract from the provincial government (Henderson 2009). However, owners and managers feel it has become more and more challenging to run a profitable farming operation and believe they are required to push the land to its limits. The result is that there is little management flexibility left for conserving wildlife (Henderson 2009). As a result, Henderson (2009) found that any conservation plan supporting species at risk through changes in land management will likely have to recognize the economic obligations of landowners and potentially include compensation in order to be effective.

3.3 The Species of the Study Area

The large number of species at risk located in the South of the Divide region – as many as 24 species listed as special concern, threatened, endangered, or extirpated – makes a multi-species conservation plan attractive. Accordingly, the Saskatchewan provincial government and the federal government have teamed up to create a multi-species action plan for the region. However, managing multiple species at risk adds an additional layer of complexity to the design of an economically and biologically efficient conservation area plan (Kirk and Pearce 2009). Species at risk have different habitat and management requirements, and particular actions on the landscape may aid one species and hinder another. In order to design a conservation reserve network that will achieve the goals set out by policy makers and species' biologists, there must be a full understanding of the species' habitat and management needs.

While managing multiple species may be difficult, the common habitat requirements of many of the species at risk within the South of the Divide may make management easier in this region. All of the species at risk considered in this thesis, at the broadest level, require native grassland habitat (Kirk and Pearce 2009).[23]

A total of eight species were included within the conservation planning models for the South of the Divide. These species either had detailed assessment reports or recovery strategies that were posted on the SARA registry. They all also have legally designated or proposed critical habitat polygons that are partially or entirely located within the South of the Divide region (see Appendix A for additional information on the species).

The eight species selected for inclusion in the economic analysis – Burrowing Owl (*Athene cunicularia*), Loggerhead Shrike (*Lanius ludovicianus excubitorides*), Sprague's Pipit (*Anthus spragueii*), Swift Fox (*Vulpes velox*), Greater Sage-Grouse (*Centrocercus urophasianus urophasianus*), Eastern Yellow-bellied Racer (*Coluber constrictor flaviventris*), Black-footed Ferret (*Mustela nigripes*), and Mountain Plover (*Charadrius montanus*) – will be used to design the least-cost habitat protection scheme that will, in effect, provide native grassland habitat for all the other species at risk within the region. The following sections outline the species' habitat ranges, habitat requirements, and threats to survival or recovery as well as the management practices that will aid in their success – and the subsequent success of all species in the region.

3.3.1 The Habitats and Historic Ranges of the Species at Risk

In general, Canadian prairie species at risk are found in native grasslands, riparian areas, wetlands, tame pastures and haylands (Environment Canada 2011c). Only a few species at risk are found in summerfallow, winter crops and shelterbelts. The presence of species at risk is generally an indicator of healthy biological communities and responsible agricultural management (Environment Canada 2011c). See Appendix A for a detailed presentation of habitat requirements for each of the eight species.

The historic ranges of the grassland species were provided by the Saskatchewan Ministry of the Environment. Of the eight species considered in the conservation

[23] The only potential exceptions are Loggerhead Shrike and Greater Sage-Grouse that require shrubland for nesting and foraging. However, if it is assumed that conserved and restored grasslands will undergo a certain level of natural succession, those areas that historically supported shrubland will ultimately once again provide shrubland plant communities.

planning models, there are three that historically covered the entire study region: Burrowing Owl, Loggerhead Shrike and Sprague's Pipit (Figure 3.4). Swift Fox historically covered a large portion of the region and only the north-central portion of the study area would originally have lacked the small cat-sized foxes (Figure 3.4). Eastern Yellow-bellied Racers, Black-footed Ferrets and Mountain Plovers were all historically found in similar locations near what is now Grasslands National Park. Greater Sage-Grouse had pockets and stretches of habitat scattered throughout the entire region (Figure 3.4).

The historical species' range information allowed the creation of a historic species richness map (Figure 3.5). This map highlights key areas that would provide the largest biological benefit if they were protected. The yellow, orange and red sections of the map have the highest species diversity historically. While selecting these biological hotspots would result in multi-species conservation targets being met with minimal area having to be managed, this approach does not considered the heterogeneity of conservation costs across the landscape. By including spatially heterogeneous costs into an ecological-economic conservation planning model, large cost-savings are possible (Ando *et al*. 1998).

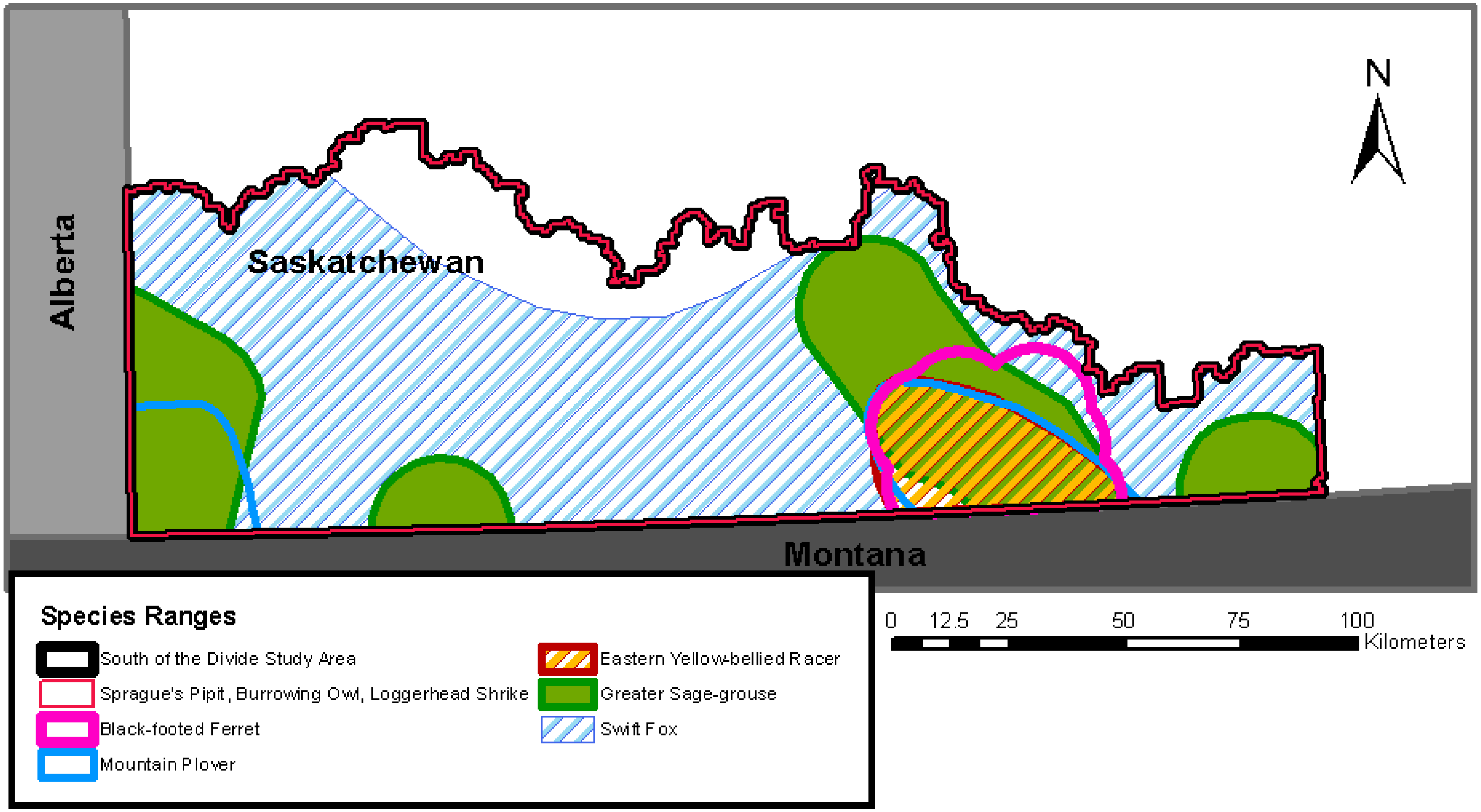

Figure 3.4. The historical ranges of species at risk within the South of the Divide study area boundary.

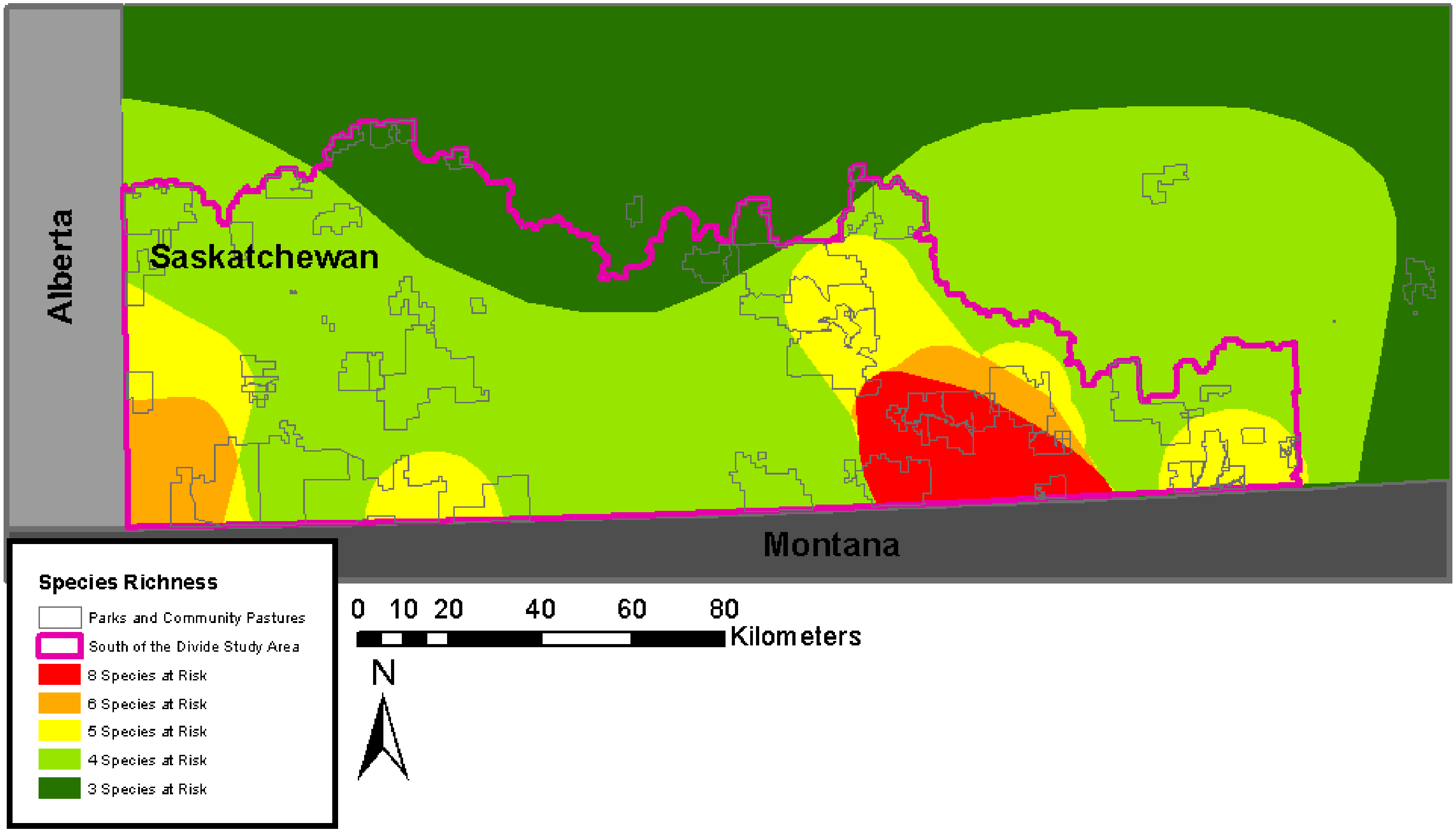

Figure 3.5. A map of historical species richness within the southwest corner of Saskatchewan and the South of the Divide study area.

3.3.2 Threats to Species at Risk and their Habitat

Habitat loss is often considered the primary cause of species declines (Brooks *et al.*2002; Pimm and Raven 2000; Ceballos and Ehrlich 2002). Within Canada, the primary cause for the decline of species is the loss of habitat, and agriculture is the primary cause of habitat declines (Kerr and Cihlar 2004). Land use changes that continue to threaten Saskatchewan's native prairie habitat include cultivation, invasive species, woody species encroachment, resource development, urban sprawl, and poor grazing management (Riemer *et al.*1997; Kirk and Pearce 2009).

The primary threats to species at risk within the South of the Divide are loss of habitat, habitat fragmentation and habitat degradation (Kirk and Pearce 2009; Kerr and Cihlar 2004; Kerr and Deguise 2004). Other threats include environmental stochasticity, invasive species, altered hydrologic patterns, increased predation, direct human-caused mortality and threats in over-wintering ranges outside the study area (Kirk and Pearce 2009). Often these other threats are directly or indirectly caused as a result of the activities that have resulted in habitat loss, fragmentation and degradation. Appendix A contains detailed threat information for the eight species.

3.3.3 Species at Risk Critical Habitat

Parks Canada and Environment Canada (Canadian Wildlife Service Division) are required to identify and designate areas of land as critical habitat for all species listed in Schedule 1 under the Species at Risk Act (SARA). Under SARA, critical habitat is defined as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (Subsection 2(1) of the Species at Risk Act). Critical habitat is largely a legal term which results in considerable difficulty in the selection of critical areas for species at risk (Hall *et al.* 1997). Nonetheless, the identification of critical habitat – which may be commonly associated with a species' high quality habitat (Hall *et al.* 1997) – is legally required (SARA 2003).

Critical habitat polygons were delineated individually for each of the eight species at risk included within the cost-effectiveness analysis. The polygons were provided by the

Canadian Wildlife Service and the Parks Canada Agency.[24] For all eight species, the critical habitat provided is the most recent draft – as of October, 2011 – that the federal government has for the species within the South of the Divide (Stephen Davis, pers. comm). For some species the critical habitat is the same as the critical habitat published in the species' recovery strategies, for others, the newly proposed critical habitat designation have been expanded, updated or created for the Milk River Watershed and the South of the Divide Action Plan.

Critical habitat locations were ultimately selected for each of the eight species independently using a combination of field data and modeling techniques that account for species occurrence as well as the amounts, locations and attributes of habitat required for a species survival and recovery. Species with smaller critical habitat polygons (Burrowing Owl, Black-footed Ferret, Mountain Plover, Eastern Yellow-bellied Racer and Loggerhead Shrike) have had their habitat polygons delineated largely by selecting areas with high species densities. For other species, like Sprague's Pipit, Greater Sage-Grouse and Swift Fox, critical habitat polygons have been delineated using a combination of species occurrence and density information as well as habitat information (vegetation, topography, etc.).

Critical habitat is often designated in areas that are already managed in a manner that promotes species at risk such as national parks, provincial parks, protected areas, federally owned land etc. It is less common for critical habitat to be located on private land or on land where species at risk management is likely to conflict with current or future land use. For example, the critical habitat designated areas for Burrowing Owl, Black-footed Ferret, Mountain Plover, and Eastern Yellow-bellied Racer, are all contained within Grasslands National Park and on provincial of federal community pastures. However, the critical habitat designations in the Milk River Watershed have in some instances challenged this trend. While Loggerhead Shrike critical habitat is primarily located in Grasslands National Park and federal community pastures, there is a

[24] Stephen K. Davis, of the Canadian Wildlife Service's Prairie and Northern Region office in Regina Saskatchewan is the head of the Critical Habitat task group for the South of the Divide Action Plan. All legally designated and proposed critical habitat polygons were supplied by Stephen Davis out of the Canadian Wildlife Service office in Regina, SK.

small proportion of the critical habitat located on provincial lease land and privately owned land. Notably, Greater Sage-Grouse, Swift Fox and Sprague's Pipit all have critical habitat polygons that make up a substantial portion of the South of the Divide Action Plan's region and are located on a mix of federal, provincial and private land. Figure 3.6 displays a map of the entire critical habitat area that has been proposed within the South of the Divide planning region. Maps for each species' individual critical habitat designations are included in Appendix A.

Critical habitat clearly differs from historical range data. There is a potential divide between the ability of the two different definitions of habitat to provide the necessary requirements for the survival and recovery of species at risk within the South of the Divide region. Designating a parcel of land as critical habitat implies that biologists believe species either currently occur or have a high probability of occurring on that parcel of land, and that the parcel of land provides the habitat necessary to support the persistence of the species. In comparison, historical range data shows parcels of land that were historically capable of supporting the species. In theory, if a species' historical range was restored (if necessary), the area would have the potential to provide habitat for the species.

The divide in habitat quality between critical habitat and restored historical range differs amongst the species in the region. The divide is likely largest in the case where critical habitat polygons are selected solely on species occurrence and density data (e.g. Burrowing Owl, Black-footed Ferret, Mountain Plover, Eastern Yellow-bellied Racer). When habitat models have been used to select a species' critical habitat polygons, the difference between native grassland habitat located within a critical habitat polygon and native grassland habitat located more generally within the species' historical range may not be as large. Thus, in the case of Sprague's Pipit, Greater Sage-Grouse and Swift Fox, there is the possibility that the selection of native grassland habitat outside the critical habitat polygons will provide similar benefits to the species as the selection of native grasslands inside the critical habitat polygons. Regardless, the true disparity in biological benefits resulting from the selection of these different grasslands is unknown due to the lack of the necessary biological information. However, within the conservation area planning models, the areas are assumed, perhaps erroneously, to have identical biological benefits. This assumption allows direct comparisons between the costs of protecting the species' critical habitat polygons and the cost of protecting an equivalent amount of the species' historical range that has been selected using the conservation optimization model.[25]

[25] This is an important assumption to consider when interpreting the results (presented in section 5.3.2.1.1) that compare the costs between critical habitat polygons and cost-effective habitat designs using species' historical ranges.

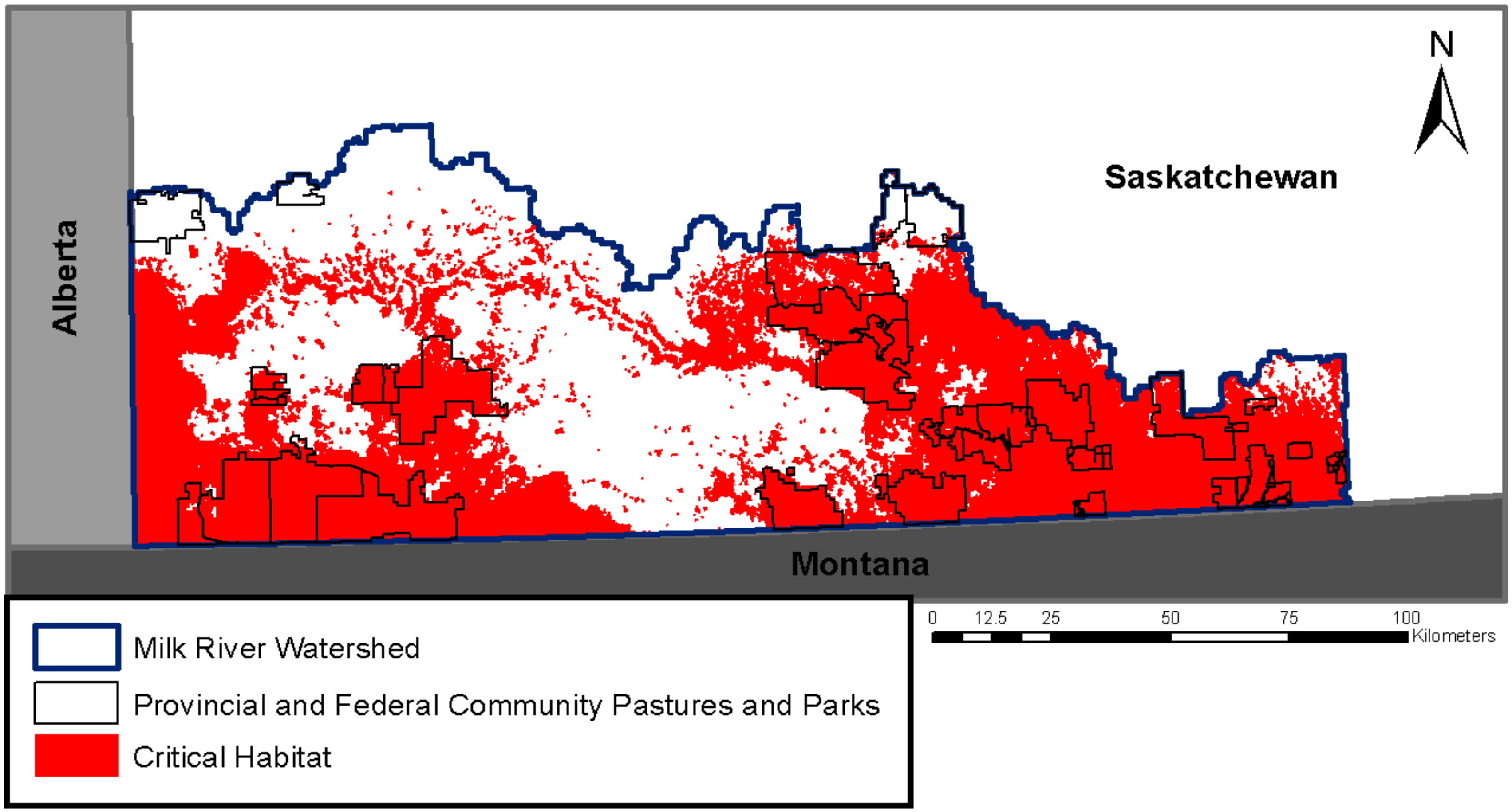

Figure 3.6. The critical habitat boundaries for all eight species considered together.

3.3.4 Beneficial Management Practices (BMPs)

Within the South of the Divide region, the primary economic activities include agriculture – farming and ranching – and oil and gas extraction. Many of the threats listed in the above section are related to these two primary activities. Habitat loss, fragmentation and degradation result from agricultural and resource development destroying or degrading native grasslands. Agriculture and subsurface resource extraction result in numerous issues: invasive species increase due to seeding lease sites, tame pastures, and roadways; altered hydrologic patterns occur from the digging of dugouts and roadways (especially with improper culvert installation); increased predation occurs due to the introduction of fences and buildings that provide avian predator roosts and the creation of roadways and other linear features that assist predator movement; direct human mortality occurs on roadways, lease sites, and in crops and pastures as a result of heavy machinery operation.

The Environment Canada (2011) publication on beneficial management practices (BMPs) along with each species' recovery strategy were used to create BMP suggestions for land owners and land managers that can help promote the recovery of species at risk on their lands. The BMPs provided by Environment Canada (2011) were integral in the selection of the activities – and associated costs – that would be included within the reserve site selection (i.e. conservation area planning) model used to calculate the cost of habitat protection in the South of the Divide. The BMPs that have been included in this study's cost-effectiveness model include:

1) Protecting existing native grasslands
2) Converting cultivated lands to perennial cover (where native grasslands are preferred to tame pasture or hay fields)
3) Grazing at the recommended stocking rates for each ecosite and ecoregion in order to promote grassland health
4) Leaving buffer strips within hay fields and planting buffer strips of perennial cover in cropland

5) Planting shelterbelts in already modified landscapes such as cropland or tame hay fields or pastures. [26]

Detailed BMP information for each species and data source information are included in Appendix A.

3.4 Chapter Summary

The Milk River Watershed is a region that contains an uncommonly high percentage of remaining native grasslands that are still in a condition capable of supporting at risk grassland species. The higher proportion of federal and provincial land has limited the cultivation and fragmentation of the native prairie landscape. Species in this region, however, are still at risk due to potential activities both inside and outside the region. The largest threats under human control within the region are the destruction and fragmentation of habitat by oil and gas extraction and agricultural development. Restricting oil and gas activity and protecting current native grasslands can prevent additional habitat losses. However, beneficial management practices such as planting native prairie on cropland, grazing pastures at recommended stocking rates, leaving buffer strips in fields and planting shelterbelts can help to improve habitat beyond that which currently exists in the region.

[26] Shelterbelts were used in the management of only 1 of the 8 species at risk: Loggerhead Shrike. For all other species, shelterbelts can provide perching areas for avian predators and may be detrimental to the survival of the species.

4 Methods

There are two primary components to this project. The first is the calculation of costs associated with conservation actions that benefit species at risk. The costs calculated represent both foregone production costs from oil, natural gas and agricultural developments (opportunity costs) as well as the costs to implement beneficial management practices on the landscape (opportunity costs of lost production as well as the direct costs of implementation). These costs are calculated and presented spatially for the South of the Divide planning region (from this point forward, the study area is referred to as the South of the Divide study region or study area).

The second stage of the analysis combines the spatial information on costs with spatial information on species at risk in the region in order to run several conservation planning optimization models. The optimization models select parcels of land that together create reserve networks that meet conservation goals – expressed as a percentage of habitat protected – for minimum cost. The models provide information on the trade-offs between the costs and benefits of habitat protection, the possible benefits of multiple species planning, and the additional costs of protecting larger habitat patches. The spatial models can also provide information on the optimal locations for habitat protection under the presence and absence of a habitat patch size term in the model's objective function. This chapter begins with a discussion of the overall optimization framework, moves into a discussion of the models' economic and biological inputs and finishes with a discussion of the particular models designed and run for the South of the Divide region.

4.1 Linear Programming

Linear programming (also known as linear optimization) is a method used to solve the optimization of a linear objective function subject to linear constraints. The constraints can be equality or inequality equations that taken together define the feasible set of solutions that would simultaneously satisfy all the constraints and provide a value for the objective function. The optimization process searches for a point in the feasible set that results in the objective function having the largest (or smallest) value possible.

Linear programming has been applied to many fields of study within economics, and one of its many possible applications is conservation planning. Within conservation planning, the application of linear programming in its most basic form is commonly known as the reserve site selection problem (Ando *et al.*1998). There are two versions of the site selection problem that dominate the literature (Ando *et al.*1998). The first is the minimum set problem where the objective is to minimize a loss function (which can either be the number of selected sites or the cost of selected sites) subject to species coverage (or some other biological measure) constraints. The second version is the maximum coverage problem where the objective is to maximize species coverage (or some other biological measure) subject to loss constraints (which may again be the number of selected sites or the cost of selected sites). There are numerous optimization software programs capable of solving such problems (Ando *et al.*1998). However, Marxan is a freely available and widely used program that solves the minimum set problem. As such, Marxan (Ball *et al*. 2009; Watts *et al*. 2009) is the program that was used to run the reserve site selection models for the South of the Divide region.

4.1.1 Marxan: Creating Optimal Conservation Area Networks

Marxan is a software package designed to answer the minimum set problem of reserve site selection, and, as such, it is commonly used in conservation area planning. It uses linear integer programming in combination with spatial inputs to create a powerful conservation planning tool. The program provides reserve planners with a tool to facilitate the creation of systematic reserve systems that account for biological, economic and social considerations (Ball *et al.* 2009).

The program was initially designed by Dr. Ian Ball as part of his PhD at The University of Adelaide, Australia. Marxan (MArine Reserve design using spatially eXplicit ANnealing) was funded by Environment Australia, the Great Barrier Reef Marine Park Authority in Australia, and the US National Marine Fisheries Service (Ball *et al.* 2009). While the name implies the reserve planning program is for marine reserves, the program is just as applicable to terrestrial conservation planning programs (Ball *et al.* 2009).

The quality, quantity and type of data available influence the questions that can be answered with the software; however, Marxan offers valuable attributes beyond the traditional linear programming software programs. Similar to traditional linear programming, the ecologic and economic value (relative or absolute) of each site is calculated and a reserve can be created that minimizes total cost while meeting conservation targets. The additional mechanisms capable in Marxan are the allocation or restriction of specific spatially located sites to particular conservation actions (or inaction) and the ability to place more or less emphasis on the spatial relationships (i.e. habitat patch size) between planning units (Ball *et al.*2009). Marxan has the ability to (1) identify areas that meet biodiversity targets for minimum cost, (2) systematically select reserve sites (also known as planning units) that complement the reserve network as a whole, (3) meet spatial requirements such as larger habitat patches, (4) identify trade-offs between conservation and socio-economic objectives, and (5) generate a suite of good reserve network solutions (University of Queensland 2008).

4.1.1.1 The Optimization Problem

Marxan's goal is to minimize the sum of the conservation[27] and connectivity costs of the planning units included in a reserve system subject to the constraint that all the conservation features reach their predetermined target levels within the reserve system (Ball *et al.* 2009). The mathematical optimization program that the traditional Marxan program solves is outlined in the following three equations (Ball *et al.*2009; Watts *et al.*2009):

Equation 4-1 $$minimize \sum_{i=1}^{m} c_i x_i + b \sum_{i1=1}^{m} \sum_{i2=1}^{m} x_{i1}(1 - x_{i2}) cv_{i1,i2}$$

Equation 4-2 $$subject\ to \sum_{i=1}^{m} a_{ij} x_i \geq t_j \quad \forall j$$

Equation 4-3 $$and\ x_i \in \{0, 1\} \ \forall i$$

Where

m = the total number of planning units within the study area;

x_i = the control variable which equals 1 if planning unit i is selected and equals 0 if planning unit i is not selected (Equation 4-3);

c_i = the cost of selecting planning unit i;

b = the connectivity weighting factor – also known as the boundary length modifier – that weights the importance of planning unit connectivity (you can remove this term from the objective function thereby removing the importance of connectivity by setting b = 0);

[27] Conservation costs here refer to all of the conservation and restoration costs (both opportunity costs and direct costs) associated with the conservation activities included within each model. Table 5.3 provides a summary of the conservation activities included within the models.

$cv_{i1,i2}$ = the connectivity cost associated with having planning unit i1 selected and i2 not selected. The connectivity cost can be monetary costs, distances, or other values associated with reserve boundaries or edges. The connectivity cost is only included if one unit is selected and not the other (i.e. no cost is paid if both are selected, or alternatively if neither are selected);

a_{ij} = the amount of conservation feature j held in each planning unit i; and

t_j = the amount of each conservation feature j that must be reserved.

The first term in Equation 4-1 is the sum of all selected planning units' conservation costs. The second term of Equation 4-1 is a weighted connectivity cost of the reserve system's spatial design. This connectivity cost term can be easily removed from the objective function by setting b equal to zero (this may be appropriate when larger habitat patches are not a priority). Equation 4-2 is a conservation target constraint, and Equation 4-3 defines the control variable. Equation 4-1 and Equation 4-2 together create the linear program that Marxan solves.

The set of equations presented above indicates that choosing planning units is a binary process – they are either selected, or not selected, for a particular conservation activity. There is no flexibility in the type of conservation activity that a planning unit can be assigned. Marxan with Zones designed by Matthew Watts at the University of Queensland, Australia provided this additional functionality to the Marxan software. The Marxan with Zones software creates a zone configuration that minimizes the sum of planning unit and connectivity costs while meeting representation and zone targets (Watts *et al.*2009). The problem is formally defined as follows:

Equation 4-4 $$\boldsymbol{minimize \sum_{i=1}^{m}\sum_{k=1}^{p} c_{ik}x_{ik} + b\sum_{i1=1}^{m}\sum_{i2=1}^{m}\sum_{k1=1}^{p}\sum_{k2=2}^{p} cv_{i1,i2,k1,k2}x_{i1,k1}x_{i2,k2}}$$

Equation 4-5 $$\boldsymbol{subject\ to \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij}ca_{jk}x_{ik} \geq t1_j\ \forall j}$$

Equation 4-6 $$\boldsymbol{and \sum_{i=1}^{m} a_{ij}x_{ik} \geq t2_{jk}\ \forall j\ and\ \forall k}$$

Equation 4-7 $$\boldsymbol{and \sum_{k=1}^{p} x_{ik} = 1\ \forall i}$$

Equation 4-8 $$\boldsymbol{and\ x_{ik} \in \{0, 1\}\ \forall i}$$

Where

m = the total number of planning units within the study area;

p= the number of zones within the conservation plan;

x_{ik} = the control variable which equals 1 if planning unit i is selected into zone k and equals 0 if planning unit i is not selected into zone k (Equation 4-8);

c_{ik} = the cost of placing planning unit i within zone k;

b = the connectivity weighting factor – also known as the boundary length modifier – that weights the importance of planning unit connectivity (you can remove this term from the objective function thereby removing the importance of connectivity by setting b = 0);

$cv_{i1,i2,k1,k2}$ = the connectivity cost associated with having planning unit i1 selected and i2 not selected[28];

a_{ij} = the amount of conservation feature j held in each planning unit i;

ca_{jk} = the proportion of planning unit x_{ik} that contributes to the conservation of feature j when it is placed in zone k;

$t1_j$ = the amount of each conservation feature j that must be reserved; and

$t2_{jk}$= the amount of conservation feature j that must be captured in zone k.

The first term in Equation 4-4 is the sum of all selected planning units' conservation costs when each planning unit is assigned to a particular zone. The second term of Equation 4-1 is a weighted connectivity cost of the reserve system's spatial design (again, this term can be removed by setting b equal to zero). Equation 4-5 is a conservation target constraint weighted by the contribution that zone k provides for the habitat protection of conservation feature j. Equation 4-6 is a zone target constraint that requires a certain level of conservation feature j to be represented in zone k. Equation 4-5 and Equation 4-6 can be used simultaneously, but care must be taken to ensure that both constraints can be met (i.e. a feasible set can be found) or the algorithm will be unable to find an answer (Watts *et al.*2009). Equation 4-7 states that all planning units can only be placed into one zone (i.e. zones are mutually exclusive).

[28] The connectivity cost can be modified by zone. For example to planning units that are both included can still have a connectivity cost applied if they are selected into different zones. In this way, not only can larger conservation patches be selected, but also larger patches of the same zone.

4.1.1.1.1 The Complete Objective Function

The previous section outlines the optimization setup for the Marxan and Marxan with Zones models. While these models are designed using an objective function and constraints like a traditional linear programming model, in practice, Marxan solves the conservation design problem by placing the objective function and the constraints together in the objective function by transforming the constraint(s) into a penalty term that is minimized within the objective function. The inclusion of the constraint into the objective function allows a value to be assigned to reserve systems that do not meet all of their conservation targets. This is useful within the annealing process. The final Marxan objective function is presented in Equation 4-9 and the final Marxan with Zones objective function is presented in Equation 4-10. See Appendix B for a detailed discussion on the transformation of the constraints into the final form included within the objective function.

Equation 4-9

$$\sum_{i=1}^{m} c_i x_i + b \sum_{i1=1}^{m} \sum_{i2=1}^{m} x_{i1}(1 - x_{i2})\, cv_{i1,i2} + \sum_{j=1}^{n} FPF_j FR_j H(s) \left(\frac{s}{t_j}\right)$$

Equation 4-10

$$\sum_{i=1}^{m} \sum_{k=1}^{p} c_{ik} x_{ik} + b \sum_{i1=1}^{m} \sum_{i2=1}^{m} \sum_{k1=1}^{p} \sum_{k2=2}^{p} cv_{i1,i2,k1,k2} x_{i1,k1} x_{i2,k2} + \sum_{j=1}^{n} FPF_j FR_j \left(H(s1) \left(\frac{s1}{t1_j}\right) + \sum_{k}^{p} H(s2) \left(\frac{s2}{t2_{jk}}\right) \right)$$

Within the Marxan handbooks, the objective function is simplified into Equation 4-11. Where PUs are the planning units within the study area, BLM is the boundary length modifier, Boundary is some measure of planning unit connectivity costs, ConFea are the conservation features to be protected within the reserve, SPF is the species penalty factor, and Penalty is the penalty for failing to meet a conservation feature's target level.

Equation 4-11

$$\sum_{PUs} Cost + BLM\left[\sum_{PUs} Boundary\right] + \sum_{ConFea} (SPF \times Penalty)$$

4.1.1.2 The Strengths and Weaknesses of Marxan

While Marxan is a relatively new software program, it has begun to revolutionize systematic conservation planning around the world. The popularity and functionality of the Marxan software programs are its greatest strengths because it allows conservation planners to share, discuss, and improve upon each other's methods. As a combination of free conservation planning programs and GIS platforms, Marxan has begun to change a field whose work has historically been non-systematic, opportunistic and uncoordinated (Ando *et al.*1998; University of Queensland 2008; Margules and Pressey 2000). Historically, reserves failed to contribute efficiently or effectively to the representation of biodiversity (University of Queensland 2008; Margules and Pressey 2000). However, with the introduction of Marxan – which provides a framework through which explicit conservation goals can be attained by allowing reserve planners the ability to make informed choices between alternative management actions (University of Queensland 2008) – high quality conservation area designs are within grasp of most planners.

The second greatest strength of the Marxan models is the integration of spatial inputs and outputs within the models. The ability to create larger, contiguous conservation areas, to lock certain planning units in or out of a conservation design, to restrict specific planning units to certain conservation activities, to assign separate costs to each planning unit, and to know the frequency with which each particular planning unit is included within a reserve network are all strengths of the model that result from its spatial nature. A regular linear programming model would be indifferent in the selection between two planning units with the same cost and same contribution to a conservation feature; however, the Marxan models would be further informed by the spatial location of the planning units relative to other planning units. Thus, while some flexibility is given up when using Marxan over a linear programming model, having spatial outputs to highlight priority areas within the landscape is extremely useful for planning purposes as well as communicating the plan to other stakeholders.

The powerful optimization technique of simulated annealing also allows Marxan to generate many near-optimal solutions quickly, even with hundreds of thousands of planning units (Ball *et al.* 2009). Marxan, unlike traditional integer programming, does not provide one optimal solution, but rather provides a large number of very good solutions to each problem. Ball *et al.*(2009) argue that there are two ways that Marxan's simulated annealing algorithm are superior over the classical linear programming. The first is that Marxan is able to successfully solve extremely large problems, and the second is that finding the one 'best' solution is not always that useful when working with conservation planning where negotiations and choices are often required. There is also the argument regarding how good the one 'best' solution is, given the uncertainty present in most biological and economic data.

The largest limitation of the Marxan software programs are the underlying assumptions of the simplistic standard reserve site selection model that it runs. The Marxan models assume that land inside the reserve contributes only to biodiversity, land outside the reserve contributes only to production[29], that species persistence is implicit in habitat targets, that the presence or absence of species at each site is known with certainty (i.e. probability of 1 if the quarter section is within the species range, and a probability of 0 if the quarter section is outside the species range) and that a reserve network is built instantaneously. The models are unable to account for risk or uncertainty, are static in nature and do not facilitate dynamics or multi-period planning. As such, the conservation reserves created are based on information provided at a snapshot in time.

Any changes to the assumptions of the standard reserve site selection model must be included as modifications to the input data and cannot be explicitly included in the Marxan software due to its simplistic and rigid format. Thus, as is the case in any modeling exercise, the quality of data can limit the quality of output achieved by the Marxan models and the easy accessibility of the software can open up the opportunity of misuse by people not properly educated in the field of conservation planning.

The importance of high quality model inputs for high quality outputs raises some issues for the study in the South of the Divide region. Historic ranges are a low resolution source of species habitat information which oversimplifies the issue of selecting sufficient, suitable habitat for species at risk. Historical ranges are provide no information on the density of species' occurrence or the distribution of species across the landscape. Range data in essence assumes density (i.e. biological benefit) is constant across the historical range. In reality species are unlikely to make use of all the quarter sections within their range (some quarter sections will have unsuitable habitat); however, the Marxan models assume that species will occur in every quarter section of

[29] The Marxan with Zones model, however, allows parcels of land to be allocated amongst a number of different conservation zones. Each zone can contribute a unique proportion of its area to effective habitat protection while still providing varying levels of economic activity to continue within the zone. These zones can thereby provide both economic and biological value.

their historic range and that protecting any quarter section within the species range will protect habitat and ultimately the species.[30] Relaxing these assumptions may result in very different conservation area designs.[31,] Historic ranges are also static in nature and there is no guarantee that protecting a certain percentage of a species historic range will equate into a particular level of population persistence or growth.[32]

4.2 The Input Data Required

The Marxan models require spatial cost and biological data. The biological data were provided by Environment Canada (Canadian Wildlife Service division), Parks Canada, and the Saskatchewan Ministry of Environment.[33] The cost data were calculated using secondary data sources, and the methods and results of the cost calculations are presented in the following sections. Table 4.1 contains a summary of the spatial data that will be presented in the following sections. The biological data are discussed first, followed by a discussion on costs. Biological data included historical range data as well as the legally designated and proposed critical habitat (as of October 2011) for all eight species at risk included in the analysis. The costs include two broad categories: land values and beneficial management practices. Land values were calculated for subsurface resources and agriculture and represent the foregone value of oil, gas and agriculture in the region if land is removed from production. Beneficial management practices included in the reserve design were land use conversion, buffer strips, shelterbelts, and

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[30] Density information was not used within this thesis because it was unavailable for the species at risk in the South of the Divide.

[31] Conservation costs and biological benefits (habitat) are measured on a per unit basis. If density data was available, costs and benefits could be adjusted to reflect per species individual measures. An area of land with high species density would have a lower cost/individual relative to its costs/area. Planning units with high costs/area have a low likelihood of being included in the reserve network using the current model set-up; however, if the biological target was number of individuals and the planning unit was known to support a very high species density, the area's cost/individual may warrant its inclusion in the reserve network.

[32] A goal of species persistence might be better served by protecting the species' critical habitat designation (see section 3.3.3 for a discussion of critical habitat).

[33] As mentioned in section 3.3.1 and section 3.3.3, historical range data for species at risk came from the Saskatchewan Ministry of Environment while current critical habitat designations came from the Canadian Wildlife Service and Parks Canada Agency.

grazing management changes. The costs of the beneficial management practices include any opportunity costs resulting from lost production as well as any additional implementation costs required. The calculation and collection of this information is presented in Section 4.2.2 below, and the design of the Marxan models is discussed and presented in Section 4.3.

Table 4.1. Summary of the spatial information created and collected in this project for use within the final Marxan models.

Spatial Biological Data	Spatial Cost Data	
	Opportunity Costs	**Direct Costs**
Historic ranges; Proposed and legally designated critical habitat	Halt current and future oil development; Halt current and future natural gas development; Halt current and future agricultural development including cropping, haying and grazing; Align stocking rates with the recommended rates for the region	Convert modified landscapes into native grasslands by re-vegetating with native species Plant, establish and maintain shelterbelts on modified landscapes

4.2.1 The Biological Information

See section 3.3 for a complete discussion of the species at risk included in the model including information on historic ranges, threats, habitat requirements, and proposed critical habitat designations.

4.2.1.1 The Biological Data: Species' historical ranges

Species' historic ranges (Figure 3.4) were used within the Marxan opportunity cost model.[34] This allowed the freedom to select optimal, cost-effective areas of land for protection and/or improvement. The activities included within the model (land conversions, buffer strips, shelterbelts, etc.) allow land that is currently poor habitat to

[34] The range of the Black-footed Ferret was not included in the database provided by Saskatchewan Environment. However, the range of the Black-tailed Prairie Dog was used to represent the range of the Black-footed Ferret because Black-footed Ferrets are specialists on prairie dogs (they prey only on prairie dogs and use the burrows of the prairie dogs as their homes; Tuckwell and Everest 2009).

be converted into suitable habitat. Thus, limiting potential habitat to currently suitable habitat – or restricting it even more severely to land designated as critical habitat – reduces the value of the model's output. By including a larger area, greater flexibility in the location of activities is possible, thereby, allowing for more informative outcomes to be found.

4.2.1.2 The Biological Data: Species' Critical Habitat

Species' critical habitats were used to calculate and compare the cost of protecting the proposed critical habitat area to the cost of protecting an equivalent amount of a species' historical range that was optimally selected for conservation using the Marxan optimization model. The government is required to legally protect the critical habitat of species at risk and ensure it remains capable of supporting the existence and recovery of the species. Thus, in reality there is no flexibility in which quarter sections are included in a protected area after critical habitat has already been designated. However, it is of interest to determine the level of efficiency lost due to the lack of consideration of costs in the original designation of critical habitat and the species-by-species nature of critical habitat designations.

4.2.2 The Spatial Cost Information

The calculation of oil, natural gas, and agricultural land values as well as the calculation of the costs of beneficial management practices (land conversion, stocking rate changes, buffer strips, and shelterbelts) are presented in this section. Each section provides a brief outline of the methods used to calculate the costs, and the final results of the calculations for the entire study region. The methods used to calculate the cost values sometimes contain numerous steps, and as a result a more thorough discussion detailing the calculation of each cost category is provided in Appendices C - H. References to the appropriate appendix will be made throughout the sections.

4.2.2.1 Oil and Natural Gas Net Present Values

Oil and natural gas net present values were used in the Marxan models to represent the foregone value of oil and gas development if oil and gas development were to be removed from the South of the Divide landscape. The method used to calculate the oil and gas net present values for the South of the Divide Region followed the methods of the 2010 Project Report 'A Net Present Value Model of Natural Gas Exploitation in

Northern Alberta: An Analysis of Land Values in Woodland Caribou Ranges' written by Hauer *et al.* (2010b). The net present value (NPV) model calculates the value of subsurface resources while accounting for remaining resources, costs of exploration and drilling, and the probability of (un)successful exploration and drilling.

Information on Saskatchewan's marketable remaining ultimate potential natural gas reserves was collected from the National Energy Board and the Saskatchewan Ministry of Energy and Resources (ER/NEB 2008), and information on oil reserves was collected from the Saskatchewan Ministry of Energy and Resources (Saskatchewan Industry and Resources 2011; ER 2008). Information on current oil and gas wells was also collected from the Ministry of Energy and Resources (Saskatchewan Industry and Resource 2011). Additional information necessary to conduct the net present value analysis – including cost information, production profiles, well depths, etc. – came from Hauer *at el.* (2010b), Alberta Department of Energy (2007), the Petroleum Services Association of Canada (2007), and Saskatchewan Industry and Resource (2011). Costs, profits, royalties and taxes were all calculated in 2008 prices using the consumer price index (CPI). Detailed discussions of all inputs into the NPV model can be found in Appendix C.

4.2.2.1.1 Net Present Value (NPV) Model

There are 3 different NPV equations that were used in this analysis[35]. Quarter sections with resources currently being extracted by active wells use Equation 4-12, quarter sections with discovered resources that are not currently being extracted use Equation 4-13 (which accounts for the probability of successful drilling), and quarter sections with undiscovered future resources use Equation 4-14 (which accounts for the probabilities of successful exploration and drilling). A thorough discussion of all the inputs and parameters used within the NPV models, and the calculation of profits, royalties, and taxes is included in Appendix C.

[35] Each net present value equation also has two additional equations associated with it: one equation to calculate royalties and one to calculate taxes. Both these additional values are included within the opportunity cost model and detailed information on the calculation of royalties and taxes is located within Appendix C.

Equation 4-12

$$NPV = W^{s}\left(\sum_{t=1}^{L}\beta_t\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - T_t^{ax}\right]\right)$$

Equation 4-13

$$ENPV = P^{success}W^{s}\left(C^{drillcomp} + C^{tiein} + C^{equip} + \sum_{t=1}^{L}\beta_t\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - T_t^{ax}\right]\right) + P^{success}W^{sa}C^{drillabandon} + (1 - P^{success})W^{a}C^{drillabandon}$$

Equation 4-14

$$ENPV = C^{seis}\left[P^{success}(W^{s} + W^{sa}) + (1 - P^{success})W^{a}\right] + P^{seis}\Big[P^{success}W^{s}\Big(C^{drillcomp} + C^{tiein} + C^{equip} + \sum_{t=1}^{L}\beta_t\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - T_t^{ax}\right]\Big) + P^{success}W^{sa}C^{drillabandon} + (1 - P^{success})W^{a}C^{drillabandon}\Big]$$

Where

$\beta_t = \left[\frac{1}{1+r}\right]$ = a discount factor set to 0.96 which is equivalent to a 4% interest/discount rate;

V_t = volume of resource (natural gas, medium oil) extracted per well in year *t;*

P_t = price of resource (natural gas, medium oil) in year *t*;

T_t^{ax} = corporate taxes collected in year *t*;

C_t^{roy} = royalties collected on the resource (natural gas, medium oil) in year *t*;

C^{oper} = unit cost of operating a well;

C^{seis}= cost of seismic activities per well;

$C^{drillcomp}$ = cost of drilling and completing a well;

C^{tiein} = the cost of tying in the gas well to the pipeline gathering and processing system (not included in medium oil NPV equations)

C^{equip}= the cost of equipment used to extract the natural gas or medium oil;

$C^{drillabandon}$ = the cost of drilling and abandoning a well;

P^{seis} = the probability that seismic and/or other information indicate that resources are present in the quarter section;

$P^{success}$ = probability that drilling activity on the section will result in discovery of oil and/or gas;

W^{s}= the number of successful wells required to extract gas given successfully drilled quarter section (this is known for equation 1, and estimated for equations 2 and 3);

W^{sa} = the number of unsuccessful wells given that the quarter section has been successfully drilled;

W^{a} = the number of wells abandoned on a quarter section given that drilling has been unsuccessful; and

L = lifespan of a well.

4.2.2.1.2 The Results of the Oil and Gas NPV Models

Net present values of profits were calculated for each quarter section using Equation 4-12, Equation 4-13, and Equation 4-14 for natural gas resources, and using Equation 4-12 and Equation 4-13 for oil resources (for which no undiscovered reserve information was found). Setting the discount rate at 0.04 reflects a risk free real return on capital (Hauer *et al.*2010b). The result is that investing in oil and gas development has a higher return (i.e. higher net present values) than if risk was included through the use of a higher discount rate, which may be more representative of the rate used by oil and gas development companies.

The NPVs in this model are calculated under the assumption that initial investment proceeds immediately for all quarter sections in the area. This is an unrealistic assumption – due to the capacity and time constraints faced by energy producers. Two quarter sections with identical reserves and estimated NPVs would have different realized NPVs if they are developed at different times. The quarter section that is developed later would have a lower NPV due to discounting. In fact, Hauer *et al.*(2011) extend the work done in Hauer *et al.*(2010b) to include a 50 year planning horizon for oil and gas development with capacity constraints which resulted in lower estimated net present values for resource extraction.[36] Adamowicz *et al*. (2009) found that capacity constraints reduced oil and gas NPVs by 8 – 30%. Consequently, the oil and gas values provided here are an upper bound on the oil and gas NPVs within the South of the Divide region. However, the inclusion of low, mid and high estimates of gas values provides a sensitivity analysis showing the range of values possible for the region. While

[36] The areas of Alberta that had lower natural gas net present values were developed later in the 50 year planning horizon. The idea is that the wealthier deposits are exploited first and poorer reserves are developed after the wealthier reserves have been depleted. Interestingly, the regions with natural gas values similar to those found in the South of the Divide region were not exploited during the 50 year time horizon as a result of their low reserve values.

the values may be upper bound estimates, the NPV model output still provides information on the relative values of subsurface resources in the region and can provide valuable information on priority development or conservation areas (Hauer *et al.*2010b).

4.2.2.1.2.1 The Spatial Allocation of Oil and Gas NPV

Each quarter section had its total NPV (profits, taxes and royalties) summed to get the total oil and natural gas value. Land values for natural gas were calculated using the low, mid and high natural gas values and maps are presented for all three scenarios in Appendix C; however, only a map of the total values for the mid-point scenario is presented here (Figure 4.1). The relatively homogeneous total land values for natural gas are due to the homogeneous natural gas reserves in the region[37] (see Appendix C Figure C.3).Figure 4.2 is a map showing the total land values for oil reserves in the region.

[37] The natural gas values calculated for the South of the Divide (SoD) region can be put to test against the natural gas values calculated by Hauer *et al.* (2010b) for Alberta. The reserves in the SoD region are similar to reserves in northwest Alberta. They are low (in general <4 000 000 m^3/section or equivalently <1 000 000 m^3/quarter section) and primarily undiscovered. The resulting natural gas values are similar between the two regions and range from $2.5/acre to $500/acre. The values greater than $500/acre in the SoD are due to one of three reasons: the quarter section has a higher natural gas reserve potential (as much as 6 400 000 m^3/section in the western part of the region), the quarter section has 'discovered' reserves with a higher probability of success, or the quarter section already has active wells that no longer have to account for drilling and exploration costs. Natural gas values for southeast Alberta may not be the best indicator of gas values for southwest Saskatchewan because in general, natural gas formations are less developed in Saskatchewan than similar formations in Alberta (ER/NEB 2008). As a result, gas reserves are less explored in Saskatchewan and natural gas net present values may be lower than Alberta values because of greater levels of undiscovered reserves and higher levels of uncertainty.

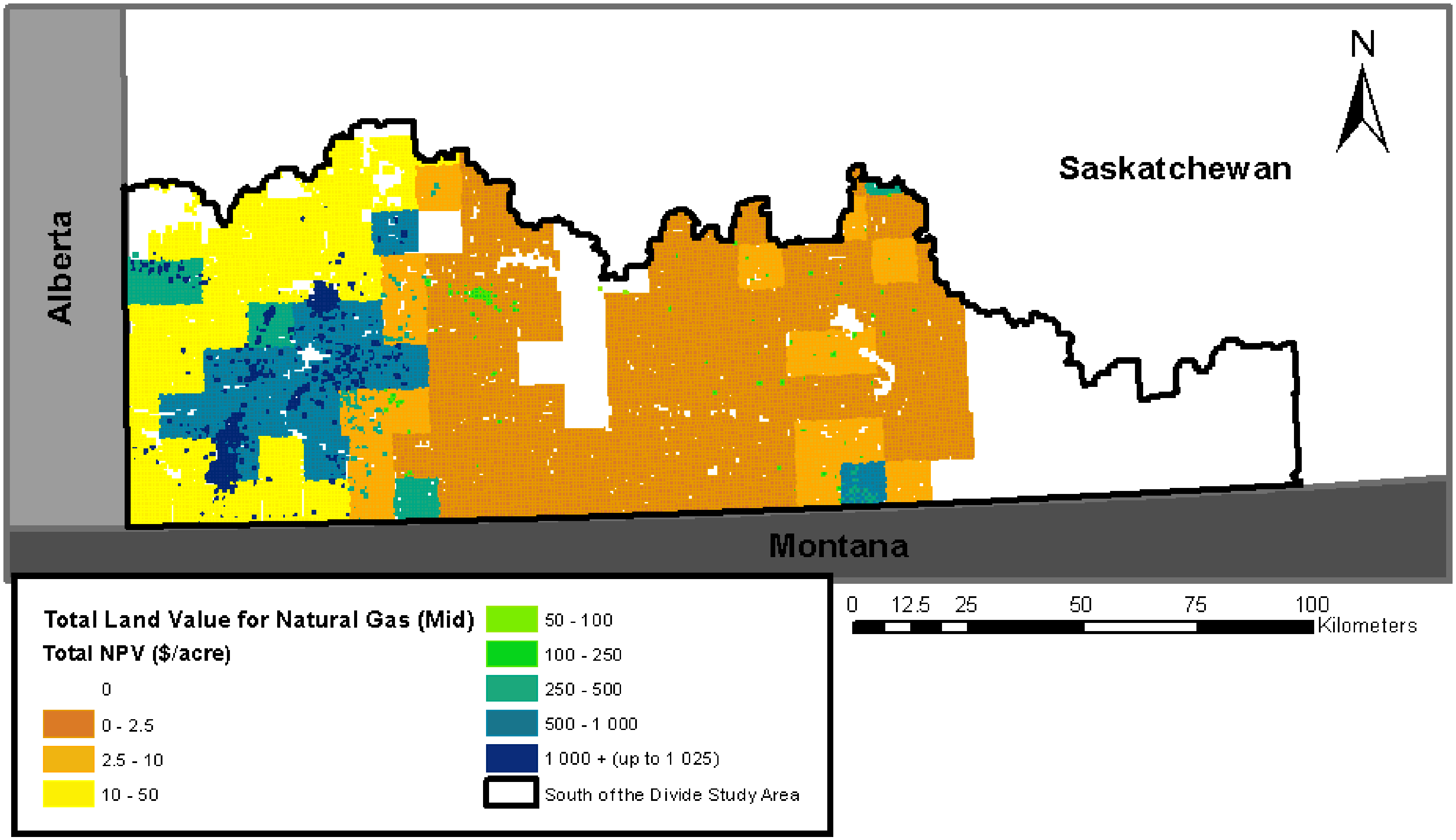

Figure 4.1. The South of the Divide natural gas land values for the midpoint of the estimated remaining ultimate potential reserves (2008 dollars).

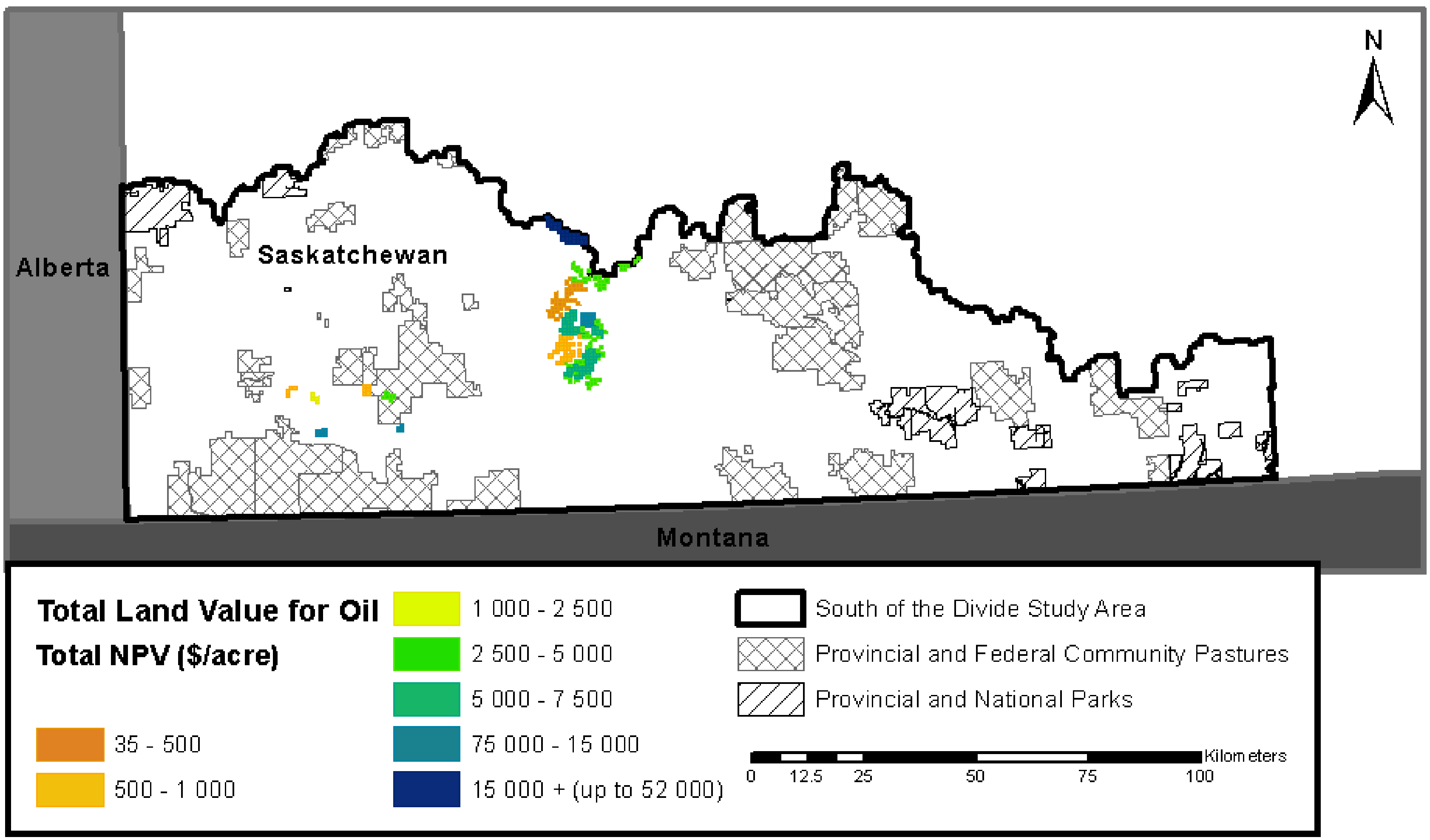

Figure 4.2. The South of the Divide oil land values shown for all oil pools in dollars per acre (2008 dollars).

4.2.2.1.2.2 The Allocation of Oil and Gas Land Values within Each Species Critical Habitat and Range

The net present value of oil and natural gas can be tallied within each species' range and proposed critical habitat to give an estimate of the relative value of resources in each species' habitat. Table 4.2 shows the NPVs for all wells (future and existing) in each species' range broken down by profits, royalties, and taxes. Total values are also reported. The NPVs are further broken down by resource – oil and natural gas – and by natural gas reserve levels – low, mid and high. Table 4.3 shows the same information for species' critical habitat. Table 4.4 and Table 4.5 show NPV/acre for each species' range and critical habitat, respectively. Species have been sorted in the tables so that the species with the largest values in the mid ultimate potential scenario appear first and the smallest value species appears last.

Table 4.2. Expected net present values (millions of 2008 dollars) of profits, royalties and taxes of all oil and natural gas wells (low, mid and high reserve levels) within each species' range.

	Millions of Dollars															
	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
Species Name	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Burrowing Owl	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Loggerhead Shrike	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Swift Fox	67	5	15	87	176	38	67	281	343	103	128	574	101	10	35	147
Greater Sage-Grouse	18	0	2	21	51	10	18	79	101	29	36	167	0	0	0	0
Mountain Plover	13	0	2	15	29	4	9	42	50	10	16	77	0	0	0	0
Eastern Yellow-bellied Racer	2	0	1	3	4	1	2	6	5	2	2	10	0	0	0	0
Black-Footed Ferret	1	0	1	2	3	1	1	4	4	1	2	7	0	0	0	0

Table 4.3. Expected net present values (millions of 2008 dollars) of profits, royalties and taxes of all oil and natural gas wells (low, mid and high reserve levels) within each species' critical habitat.

	Millions of Dollars															
	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
Species Name	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	41	3	9	54	102	22	38	162	196	59	73	327	31	6	11	49
Swift Fox	32	3	8	42	77	16	29	121	144	41	53	238	11	1	4	15
Greater Sage-Grouse	8	0	1	10	15	2	5	22	28	6	9	43	0	0	0	0
Eastern Yellow-bellied Racer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loggerhead Shrike	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burrowing Owl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mountain Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-Footed Ferret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The size of a species' range and critical habitat size is the largest driver for differences in total NPV values amongst the eight species. Loggerhead Shrike, Burrowing Owl, and Sprague's Pipit historical ranges cover the entire South of the Divide study area, and as such they have the largest oil and gas NPVs within their range. The remaining species listed by decreasing range sizes (and also decreasing oil and gas NPVs) are Swift Fox, Greater Sage-Grouse, Mountain Plover, Black-footed Ferret and Eastern Yellow-bellied Racer (Table 4.2). For half the species at risk included in this analysis, critical habitat has been designated or proposed almost entirely within Grasslands National Park. However, Sprague's Pipit, Swift Fox, Greater Sage-Grouse and Loggerhead Shrike have critical habitat designated outside the national park. The park's mineral rights are not available for development (Patrick Fargey, pers. comm.); nonetheless, natural gas land values within the park have been included in these tables to provide insight into the true opportunity cost of forgoing oil and natural gas exploration within these eight species' critical habitats and ranges[38]. Species listed from largest to smallest critical habitat area designated are Sprague's Pipit, Swift Fox, Greater Sage-Grouse, Loggerhead Shrike, Burrowing Owl, Mountain Plover, Black-footed Ferret, and Eastern Yellow-bellied Racer. Predictably, the order of NPVs for oil and natural gas land values closely follow the same order (Table 4.3). When NPV/acre is calculated, the location of ranges and critical habitat can also play a role in determining the most and least expensive species to protect. Mountain Plover's NPV/acre for its range is higher than Greater Sage-Grouse's NPV/acre which moves it up the list (Table 4.4).

[38]Table 5.1 and Table 5.2 present natural gas land values within each of the eight specie's historic ranges and critical habitats, respectively, when natural gas located within Grasslands National Park is excluded from the value calculations.

Table 4.4. Oil and natural gas (low, mid, and high reserve level) ENPVs (2008 dollars) per unit area ($/acre) for each species' range.

		NPV of Profits ($/acre)			NPV of Profits, Royalties and Taxes ($/acre)		
Species Name	Range Area (10,000 acres)	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil
Sprague's Pipit	343	79	112	162	144	202	290
Burrowing Owl	343	79	112	162	144	202	290
Loggerhead Shrike	343	79	112	162	144	202	290
Swift Fox	304	55	91	146	77	141	237
Mountain Plover	41	31	73	124	36	103	190
Greater Sage-Grouse	95	19	54	106	22	83	175
Eastern Yellow-bellied Racer	26	6	14	21	11	24	37
Black Footed Ferret	36	3	7	11	6	12	19

Table 4.5. Oil and natural gas (low, mid, and high reserve level) ENPVs (2008 dollars) per unit area ($/acre) for each species' critical habitat.

Species Name	Range Area (1000 acres)	NPV of Profits ($/acre)			NPV of Profits, Royalties and Taxes ($/acre)		
		Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil
Sprague's Pipit	1515	48	88	150	68	139	248
Swift Fox	1004	42	87	154	57	136	253
Greater Sage-Grouse	662	12	23	42	15	34	65
Eastern Yellow-bellied Racer	1	1	2	4	1	5	10
Burrowing Owl	3	0	0	4	0	5	11
Mountain Plover	3	0	0	4	0	5	11
Black-footed Ferret	3	0	0	4	0	5	11
Loggerhead Shrike	33	0	0	2	0	3	6

There is the potential to mitigate some of the lost oil and gas revenues through alternative drilling practices (horizontal drilling, directional drilling and slant drilling), technological advancements in resource extraction, and an understanding of the relationships between resource extraction and species at risk. Subsurface resources can be extracted from areas adjacent to critical habitat location through the use of horizontal or directional drilling (ER/NEB 2008). Advancements in policy or technology may also be able to mitigate the harmful effects of oil and gas on species at risk and, therefore, reduce lost oil and gas revenues. For example, the creation of lease roads (linear disturbance) and the seeding of lease sites and roadways to non-native species such as crested wheatgrass are two of the major drivers behind the avoidance of natural gas well sites by Sprague's Pipits (Stephen Davis pers. comm.). Policies that promote multiple wells in one location and reseeding to native species would reduce linear disturbances and the presence of invasive species at a minimal cost compared to that associated with a total removal of subsurface resource development.

4.2.2.2 Agricultural Land Values

In competitive markets, the price of land equals the discounted sum of expected net returns obtained through the allocation of land to its highest valued use (Plantinga *et al.*2002). In this way, land prices reflect the value of current land uses, as wells as the value of potential land uses (Plantinga *et al.*2002). In the case of agricultural land, potential uses can include any number of land use changes including, but not limited to, urban development. As such, the market value of agricultural land can represent the opportunity cost of removing a parcel of land from any future productive use, regardless of what that use might be. Within the Marxan models, agricultural land market values are used to represent the foregone benefits when land is removed from production and placed into habitat protection.

4.2.2.2.1 Calculating Agricultural Land Values

Agricultural land is often valued on the real-estate market using a combination of historical land sales and the assessed values (Gord Larson, pers. comm.). Assessed values account for the productive capacity of land (see Appendix D.2) and the difference between the market value and the assessed value accounts for characteristics of the market at the time of sale and/or the buyers and sellers. A simple ratio is often calculated by dividing the price at which a quarter section was sold in an actual land transaction by the assessed value that the Saskatchewan Assessment Management Agency (SAMA) calculated for the quarter section. This ratio can then be multiplied by adjacent parcels of land's assessed values to adjust those quarter section's assessed value into their estimated market values (i.e. adjust their assessed values up or down using the sales data from a nearby land parcel). Using this method, the market value of a parcel of land reflects both its productive capability (i.e. its assessed value) and the current market conditions. Land transactions were purchased from the Farmland Security Board (FLSB) of Saskatchewan and assessment data were provided by SAMA. All sale and assessed values were moved into 2008 dollars using the consumer price index (CPI).

A hedonic land value model was also estimated using the transaction data purchased by the FLSB. The results of this model are less complete than the method discussed above because of the lack of equal representation of quarter sections within the sales data. However, detailed information on all of the input data used for both methods, the calculations carried out, and detailed discussions and presentations of results are included in Appendix D. Ultimately, the assessment method was used for the final agricultural land values in the Marxan model, and the results of the hedonic model are used in section 4.2.2.3 to provide information on the opportunity cost of land-use conversions in the region.

4.2.2.2.2 The Results of the Agricultural Land Value Calculations

Within the South of the divide region, a total of 21 532 quarter sections had their market values calculated using their assessed values and their nearest neighbour's land value ratio. The average land value ratio $(sale\ price/acre \div assessed\ value/acre)$ was 1.15 for the region (n = 3314), and the ratios were the highest for 'other' lands (1.20), and lowest for cultivated lands (1.10; see Table 4.6). The average distance between a quarter section without a land value ratio and a quarter section that with a land value ratio was furthest for hay and pasture lands (2.86 km), and shortest for cultivated lands (0.33 km). The very southwest corner of the study area contains the quarter sections that are the furthest distance from quarter sections with land value ratios. A total of 6 549 quarter sections were directly adjacent to a quarter with a land value ratio (i.e. a distance of zero meters).

On average, the estimated market value of quarter sections was $3500/quarter section ($20.57/acre) higher than their assessed values when they are adjusted using the transaction data of neighbouring quarter sections. The average market land value in the region is $30 836.91/quarter section when all 21 532 quarter sections are considered. Lands that were assessed as arable lands had a higher average market value than lands assessed as hay and pasture lands with market land values of $43 519.85/quarter section ($271.86/acre) and $23 783.21/quarter section ($148.67/acre), respectively (Table 4.6). Calculated market land values for each of the 21 532 quarter sections are spatially displayed in Figure 4.3.

Table 4.6. A summary of the land value ratios, distance between parcels of land with and without land value ratios, and the resulting land market values (2008 dollars) for quarter sections categorized by land-use.

	Arable Land	Hay and Pasture Land	Other Lands*	All Land Uses
Total Number of Quarter Sections	7 613	13 906	13	21 532
Mean Ratio	1.10	1.18	1.20	1.15
(Std. Deviation)	(0.46)	(0.85)	(0.40)	(0.74)
Mean Distance (m) to Ratio	328.86	2 865.01	850.41	1 967.09
(Std. Deviation)	(784.77)	(3064.11)	(743.20)	(2784.21)
Mean Market Value	43 519.85	23 783.21	148 789.47	30 836.91
(Std. Deviation)	(19 259.92)	(17 544.81)	(20 085.63)	(21 205.20)

*Commercial and Industrial land (n = 9) and mixed agricultural land (n = 4) make up the other category

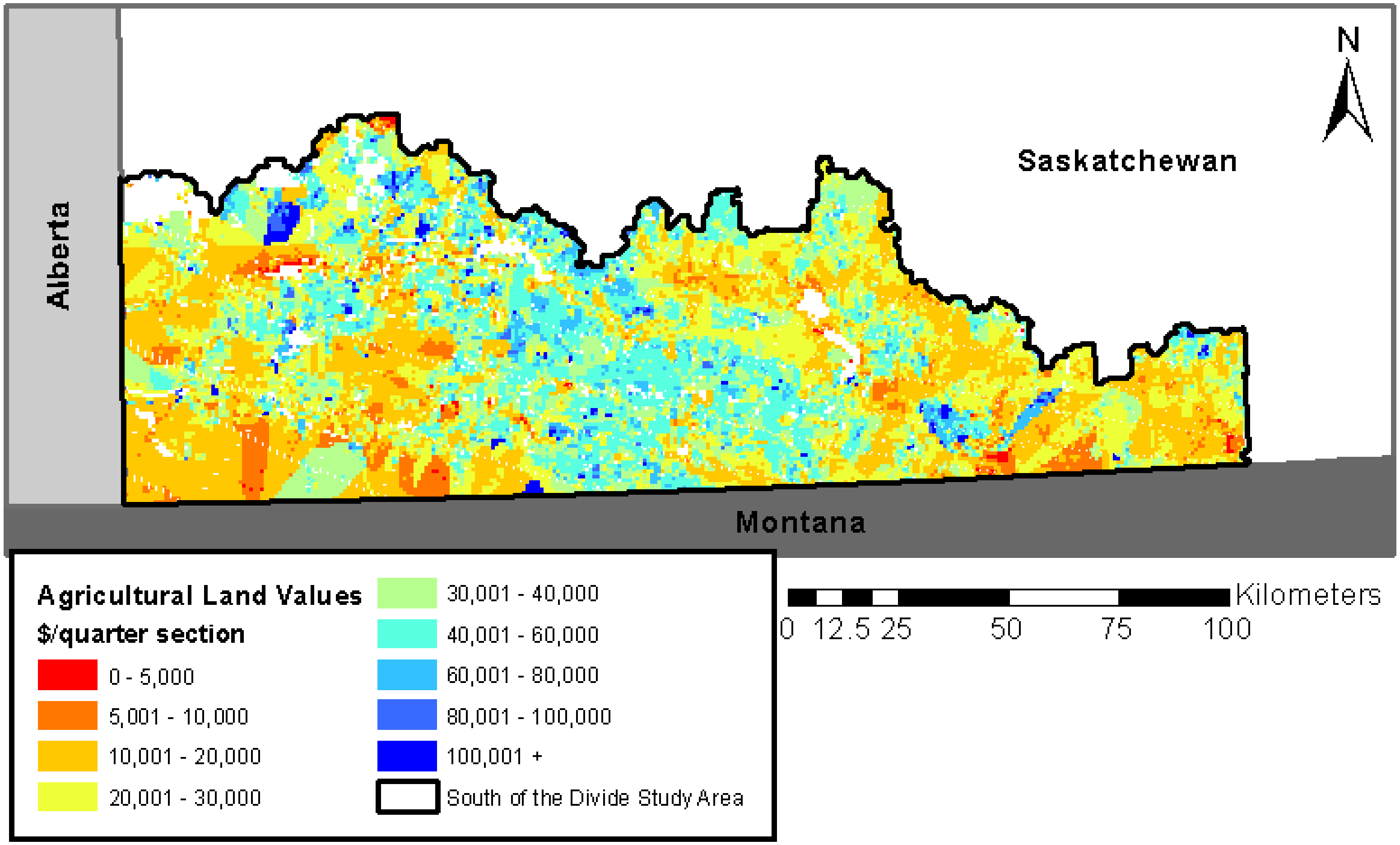

Figure 4.3. Agricultural land values (2008 dollars) calculated using sales transaction and assessment data.

4.2.2.3 Land Conversion Costs

Converting (or restoring) annual cropland and hay fields back to native grasslands can be viewed as a beneficial management practice (BMP) that will benefit species at risk in the South of the Divide region. As such, the cost of converting crop and hay fields into native pasture is considered within the possible conservation actions that will be implemented on the landscape. As mentioned in the previous section, the opportunity cost of removing agricultural land from production is equal to the land's market value. The hedonic land value model (Plantinga *et al.* 2002) presented in Appendix D, Section D.4 is able to provide information on land market values, but more importantly it can also provide information on the value of changes in individual characteristics of each parcel of land (Palmquist and Danielson 1989). In turn these values can inform the opportunity cost of altering land characteristics[39]. Implementation costs and opportunity costs of land conversion can be summed to provide a total cost of land conversion in the South of the Divide.

4.2.2.3.1 Land Conversion Opportunity Costs

Using a hedonic land model that includes land use characteristics (cropland, hay land or native grassland) as dummy variables, the change in a quarter section's market value can be observed when it changes from one land use to another (see Appendix E for a thorough discussion). The change in market value is equivalent to the opportunity cost of land conversion. The opportunity cost of converting cropland into native grassland in perpetuity was estimated to equal $71.03/acre, and the opportunity cost of converting hay or tame pasture into native grassland in perpetuity was estimated to be $50.29/acre.

Opportunity costs of land conversion were calculated for all quarter sections in the study area. The number of acres of cropland for each quarter section was multiplied by $71.03/acre to give the total opportunity cost of converting a quarter section from cropland to native grassland. The number of acres in hay and tame pasture for each quarter section was multiplied by $50.29/acre to give the total opportunity cost of

[39] It is likely that these opportunity costs are an upper bound (Palmquist and Danielson 1989; Freeman 1975; Lind 1975; see Appendix E).

converting a quarter section from hay and tame pasture to native grass. The total opportunity cost of converting a quarter section to native grass is the sum of the opportunity costs of converting the quarter section's cropland and hay and tame pasture acres to native grassland. Figure 4.4 shows the total opportunity cost of conversion to native grassland for all quarter sections in the study area.

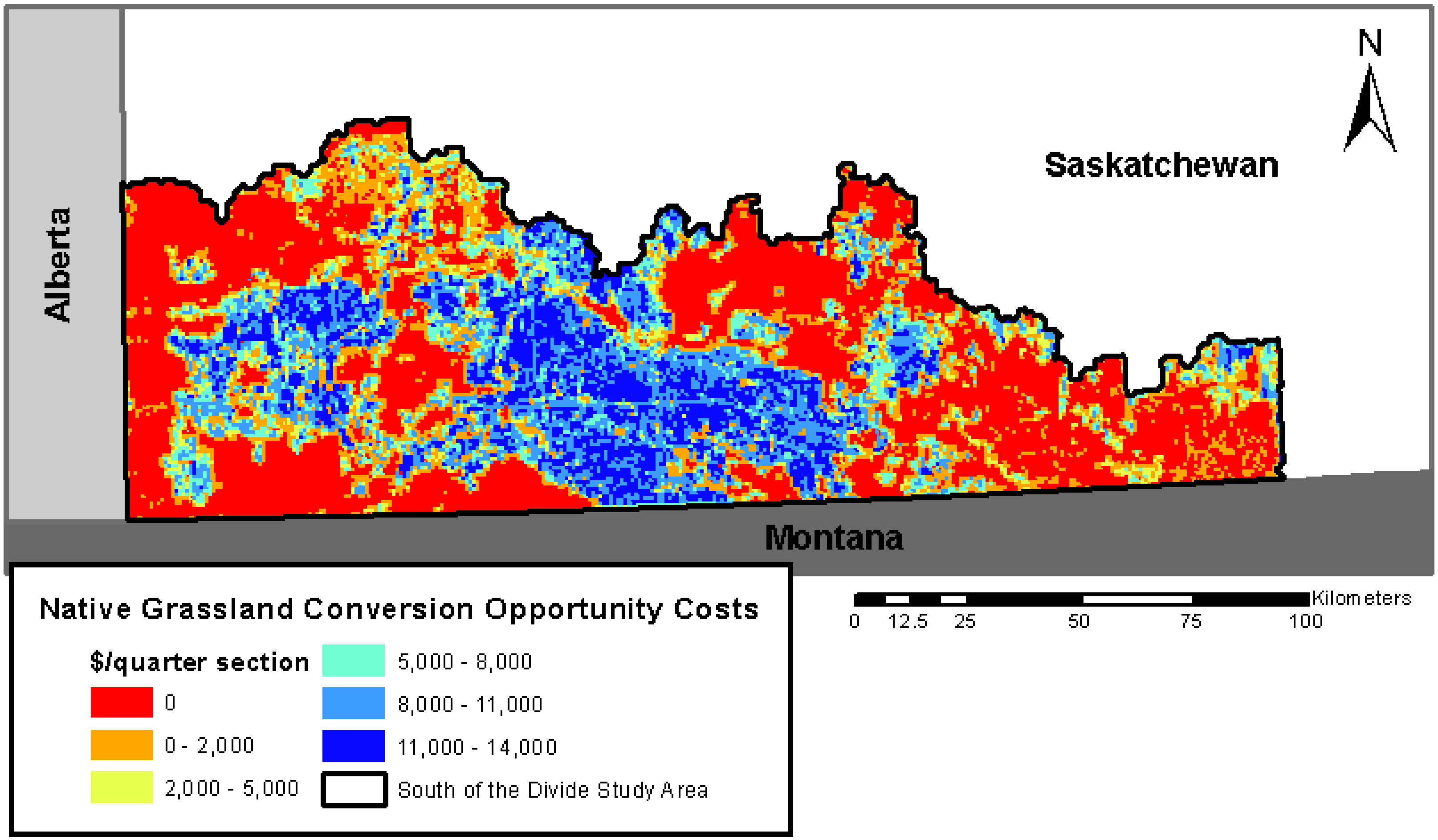

Figure 4.4. The opportunity cost (2008 dollars) of converting land from annual cropland and perennial forages (tame pasture or hay land) into native grasslands.

4.2.2.3.2 Land Conversion Establishment Costs

Conversion to native grasslands is much more expensive than seeding to tame grasslands. The larger expense is largely due to the higher price of seed (there are fewer producers due to lower demand). There is also the added expense of lower germination and establishment success which requires a heavier seeding rate and often reseeding. The following table (Table 4.7) highlights the potential direct cost per acre to return cropland into perennial cover.

Table 4.7. Direct costs of converting cropland into perennial cover.

	Cost ($/acre)	Cost (2008$/acre)	Source
Cropland to Native Pasture	$375/acre	$373.88/acre	Tannas 2009 (in Dollevoet 2010)
Tame Pasture or Hay to Native Pasture	$400/acre	$391.84/acre	Patrick Fargey pers comm.

4.2.2.3.3 The Total Cost of Land Conversion

The total cost of conversion used within the final conservation area planning model is the sum of direct costs and opportunity costs (Table 4.8). The total costs of converting cropland or hay land into native grasslands closely corresponds to the $421/acre value found by Dollevoet (2010) when farms in southeastern Saskatchewan convert cropland into tame hay.

Table 4.8. Total costs of converting between land uses within the South of the Divide region.

	Direct Cost ($/acre)*	Opportunity Cost ($/acre)	Total Cost ($/acre)
Cropland to Native Pasture	$373.88/acre	$71.03/acre	$444.91/acre
Tame Pasture or Hay to Native Pasture	$391.84/acre	$50.29/acre	$442.13/acre

*Costs in 2008 dollars

4.2.2.4 Grazing Management Opportunity Costs

Sustainable grazing management (i.e. grazing according to the recommended rates for the region) on native grasslands is a BMP that would benefit many species at risk located within the South of the Divide region. Optimally, grazing management would result in sustainable grazing over the long run and would also provide a heterogeneous grassland landscape. Heterogeneity would support species with tall, mid and short grass requirements. The problem lies in determining where this heterogeneity should be located, and what percentage of the landscape should be made up of each grassland type. The simplest way to tackle this issue is to assume that by following the provincial stocking guidelines, there will be a natural provision of heterogeneity due to topography, climate, soils, and livestock grazing preferences. Thus, this section will attempt to measure the opportunity cost of moving from current stocking rates within the region to the recommended stocking rates provided by the province (Thorpe 2007).

4.2.2.4.1 Calculating the Opportunity Cost of Stocking Rate Changes

The opportunity cost of stocking rate changes was calculated as the value of grazing that is foregone in perpetuity when stocking rates are reduced from current levels to match the levels recommended for the South of the Divide region. The current management of community pastures, grazing cooperatives, private lease land and privately owned land were determined through various sources and compared to the recommended management for the South of the Divide region[40]. Differences between current and recommended stocking rates (and the subsequent opportunity cost required to align the two rates) were calculated for all sixteen range ecosites located in both ecoregions (mixed grass prairie and cypress upland) within the study area. Opportunity costs were applied to the differences in stocking rates using a land rating system created by the Saskatchewan Assessment Management Agency (the detailed steps and calculation used to determine opportunity costs are outlined in Appendix F). Values were then spatially applied to the landscape using the decision tree outlined in Figure 4.5.

[40] Spatial variation was accounted for to the greatest extent possible by dividing the area into different ecoregions, ecosites and management types. Unfortunately, assumptions about average stocking rates for each management type were required since range health and stocking rate information was not available for the region.

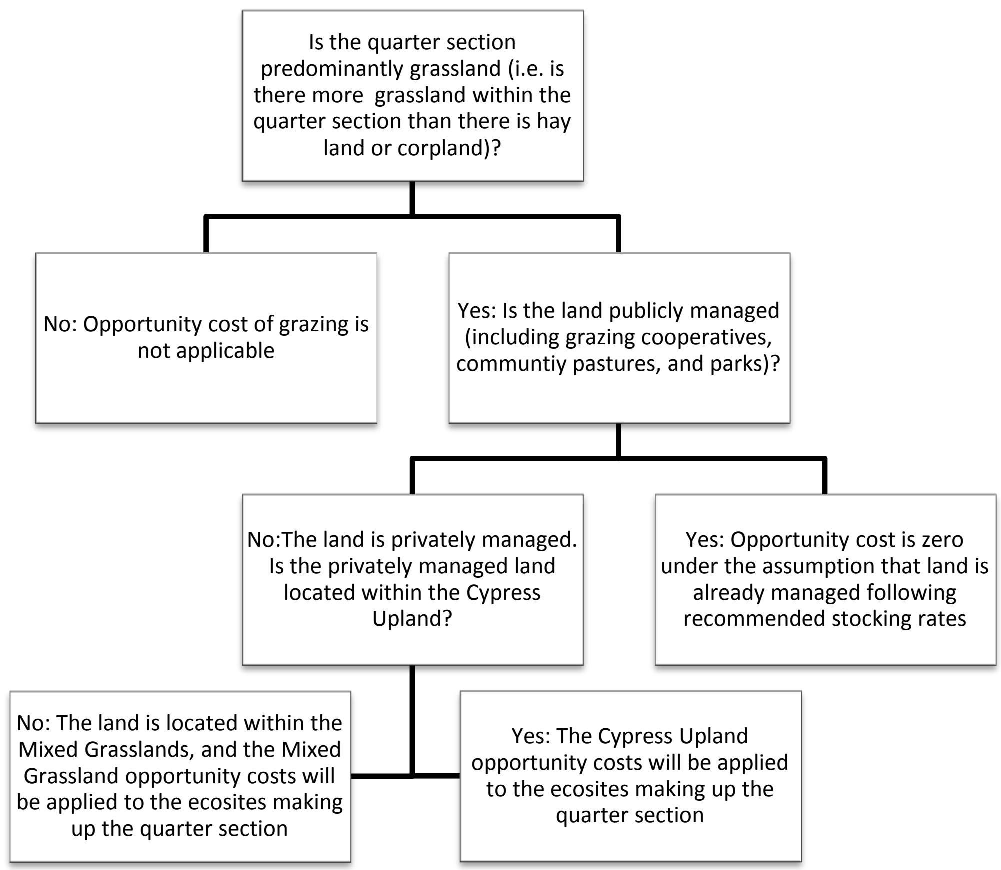

Figure 4.5. Decision tree showing how stocking rates were spatially applied to quarter sections within the South of the Divide study regions.

4.2.2.4.2 The Results of the Grazing Opportunity Cost Calculations

Opportunity costs of grazing were calculated for all 14,950 quarter sections with grassland as their primary land use. Information in Table 4.9 includes public and private land to provide a complete picture; however, in the final conservation area planning model, public land is assumed to have an opportunity cost of zero due to its current management being in line with recommended stocking rates for the region. The average quarter section size is very close to the commonly used value of 160 acres per quarter section. Within both samples, the minimum cost per acre is set by the lowest producing ecosites in the Mixed Grasslands, and the highest cost per acre is set by the highest producing ecosites in the Cypress Upland. The average costs per quarter section and per acre are lower when public land is included due to the high proportion of the Mixed Grassland – which has lower opportunity costs than the more productive Cypress Uplands – that is represented by public grazing lands.

Table 4.9. Summary statistics for grazing management opportunity costs (2008 dollars) in the South of the Divide region.

	Private Land	Public and Private Land
Number of Quarter Sections **(% of total quarters in region)**	9228 (40%)	14,950 (65%)
Mean Size of Quarter Sections (acres)	158.85	159.12
Mean Cost per Quarter Section **(Standard Deviation)**	8838.30 (3236.50)	8452.47 (3071.90)
Minimum Cost per Acre	30.06	30.06
Mean Cost per Acre **(Standard Deviation)**	55.79 (16.13)	53.24 (14.60)
Maximum Cost per Acre	174.35	174.35

Figure 4.6 displays the spatial distribution of grazing management opportunity costs for privately managed land within the South of the Divide. Values of zero arise on quarter sections that are predominantly cropland (not applicable for inclusion) and on areas that are predominantly grassland but already managed optimally as in the case of federally and provincially owned and managed grasslands. The highest opportunity costs arise in the Cypress Upland where land is more productive and the potential difference between actual grazing rates and recommended grazing rates are larger.

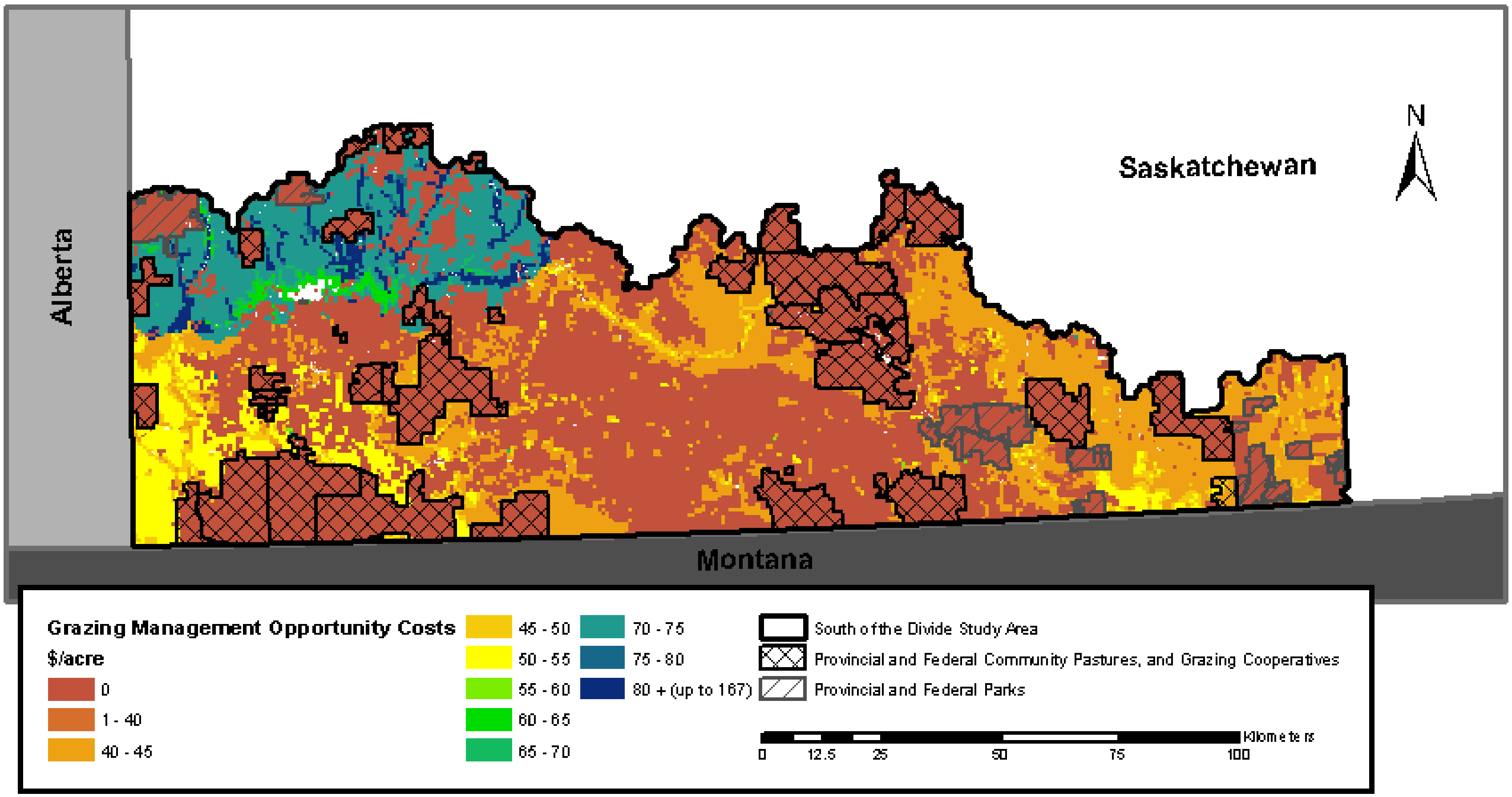

Figure 4.6. The spatial distribution of grazing management opportunity costs (2008 dollars) in the South of the Divide region.

4.2.2.5 Buffer Strips

Buffer strips are a common BMP on agricultural land. Often they are used to protect the quality of riparian areas and wetlands (Koeckhoven 2008); however, permanent vegetation cover can also provide habitat to grassland species at risk. In fact, the Canadian Wildlife Service suggest leaving strips of uncut hay in hay fields to provide shelter for bird species like Sprague's Pipits and Burrowing Owls (Environment Canada 2011c). There could also be a benefit to providing buffer strips of perennial cover around the outside perimeter of a quarter section of cropland. Providing strips of permanent cover around crop fields and leaving uncut vegetation strips in hay field is a lower cost option (compared to complete conversion to native grasslands) to provide habitat for species at risk on modified landscapes within the South of the Divide region.

4.2.2.5.1 The Cost of Buffer Strips

Calculating the cost of the buffer strip BMP was necessary in order to include them into the conservation area planning model. Buffer strip costs were calculated using the land conversion costs presented in section 4.2.2.3.1 (the opportunity cost of the land) and section 4.2.2.3.2 (the establishment cost of the perennial cover) as well as additional information collected on the value of standing hay. The total cost of establishing and maintaining a 12 m perimeter of native grassland around a quarter section of cropland in perpetuity is $6038.88 ($645.87/acre; 2008 dollars). The cost of leaving a pattern of uncut hay strips (Figure 4.7) within a quarter section in perpetuity would cost a total of $1736.80 ($440.81/acre; 2008 dollars). Detailed cost calculation information is presented in Appendix G. After costs were calculated, the applicable costs were spatially linked to all quarter sections that were either predominantly cropland or hay.

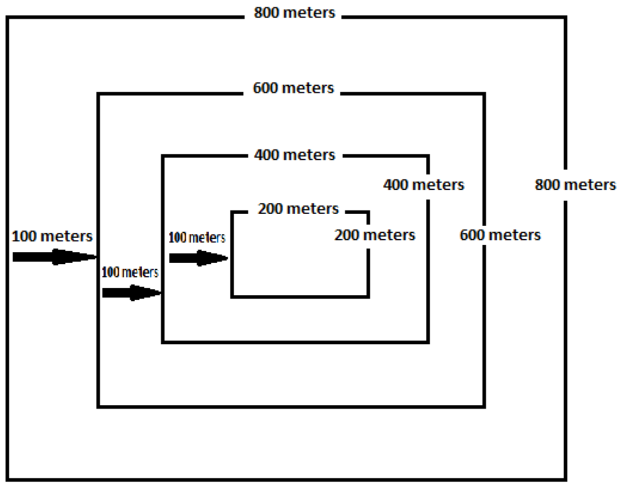

Figure 4.7.Diagram showing the buffer strips of remaining standing hay left on a quarter section.

4.2.2.6 Shelterbelts

Shelterbelts are a fairly common agricultural practice, especially within more arid farming regions. While shelterbelts are often cited to be detrimental to grassland species (as they provide perching spots for avian predators), Loggerhead Shrikes benefit from the nesting and foraging habitat provided by shelterbelts. As a result, shelterbelts are considered a possible BMP that would benefit Loggerhead Shrike populations on already modified agricultural land (i.e. cropland or hay fields).

4.2.2.6.1 The Cost of Shelterbelts

Information on the total cost (opportunity and establishment) of shelterbelts in cropland came from a Masters' thesis completed at the University of Alberta's Department of Resource Economics and Environmental Sociology. Trautman-Laslop (2011) investigated the costs of BMPs on representative Alberta farms. One of the BMPs was the planting of shelterbelts. The results of her thesis were adjusted to fit the South of the Divide region. Detailed cost calculations can be found in Appendix H. Shelterbelt costs were spatially applied to only those quarter sections that had either cropland or hay fields as their predominant cover type.

Within the South of the Divide region there were four different shelterbelt costs calculated. Two were calculated for cropland – one representing the mixed grass prairie and one representing the cypress upland. The values were found to be $5152.09/quarter section for the cypress upland and $7632.79/quarter section for the mixed grasslands. The remaining two values were for hay fields in the mixed grassland –

$5229.81/quarter section – and hay fields in the cypress upland – $6583.43/quarter section. These costs were spatially applied to the appropriate quarter sections in the study area.

4.2.2.7 Summary

In summary, inputs required for the Marxan model include spatial biological and spatial economic data. The biological and economic cost information was compiled into a single spatial layer and exported to Excel. Only quarter sections that had all of the required cost information – land values, oil and gas values, and BMP values – were included in the final Marxan models. As a result, a total of 21 532 quarter sections were included in the final analysis.

4.3 The Marxan Models

A total of four Marxan reserve site selection models were designed and run to determine the trade-off between the cost of habitat protection and the benefit of habitat protected for species at risk. The models minimize the cost of habitat protection while still meeting all habitat protection requirements.

The first three models use the traditional Marxan software where a binary decision is made for all quarter sections in the study area: protect or don't protect. 'Protection' is defined as a different set of conservation activities, and subsequently a different set of costs, for each of the three models. The degree of habitat protection within the three models varies from high to low, and so does the cost associated with the habitat protection. Each model had several scenarios run representing different habitat protection levels, different habitat patch size requirements, and different numbers of species included within the models. The three models provide information on the trade-offs between the amount of habitat protected and the costs of habitat protection, the spatial allocation of cost-effective habitat protection, the spatial allocation of cost-effective habitat when larger habitat patches are desired, the higher costs associated with larger habitat patches, and the efficiencies gained as a result of multiple-species planning.

The fourth Marxan model stands alone from the other three models. This fourth model makes use of the Marxan with Zones software which permits the optimization model to allocate quarter sections to a number of different conservation activities, land-uses, and costs. The model also allows different conservation activities and land-uses to contribute to habitat protection differently (i.e. can weight each land-use by the quality of habitat it provides or by the probability that a species will make use of that land-use type). The model allows large quantities of low quality habitat to provide the same amount of effective habitat that low quantities of high quality habitat provides. The Marxan with Zones model had several scenarios run representing different levels of habitat protection requirements, different habitat patch size requirements, and different numbers of species included within the model. The model provides information on the trade-offs between the amount of habitat protected and the costs of habitat protection, the spatial allocation of cost-effective habitat protection, the spatial allocation of cost-effective habitat when larger patches are desired, the higher costs associated with the protection of larger habitat patches, and the efficiencies gained as a result of multiple-species planning.

The four Marxan models generated optimal habitat conservation designs for each scenario. Scenarios were then compared in terms of their cost (including both opportunity costs of foregone production and the direct cost of implementing beneficial management practices). Costs for each of the scenarios were either reported and compared using costs per acre, or as a proportion of the model's total net present value (a technique that was first used by Schneider *et al.* 2011). The cost of protecting the quarter sections designated as proposed critical habitat within the South of the Divide was compared to the cost of the protecting the quarter sections selected using the Marxan conservation planning optimization models.

As discussed in section 2.1.1.2 Marxan does not provide the "best" design, but rather uses an iterative approach to find very good designs. A total of 100 iterations were run for each scenario. The set of three Marxan models is discussed first followed by a discussion on the fourth, Marxan with Zones, model.

4.3.1 The Three Marxan Models

The Marxan Models were designed to represent a gradient of habitat protection. While it is intuitive that higher levels of protection come at a higher price, running several models provides the answer of "how much more" higher protection would cost. Table

4.10 presents the three models. Model 1 was the highest cost model and allowed each quarter section to either maintain the status quo management (unprotected) or be completely removed from agricultural and oil and gas development (protected). Model 2 converted any crop or hay fields into native grasslands (on public or private land) and then implemented conservation easements on any privately owned land in the region (in this model full protection can occur on grazed grasslands). The cost of an easement was calculated as 20% of the agricultural land value for each quarter section (Fargey *et al.* 2004). Model 3 implemented the grazing management BMP on applicable native grasslands (i.e. applied to privately managed lands but not publicly managed lands) and the buffer strip BMP on all crop and hay fields (in this model full protection can occur on grazed, cropped, and hayed lands).

In all three models, quarter sections already protected in Grasslands National Park or other protected areas[41], were locked into the conservation area design cost.[42] All models were run for the eight species individually (1 species per optimization model for a total of 8 models) and simultaneously (all eight species run together in one optimization model). The individual species models independently minimized the conservation costs of meeting that particular species' habitat protection targets. The simultaneous species models minimized the costs of meeting the habitat protection targets for all species. Within the simultaneous models, all species had at least the minimum habitat target met. The models were run with habitat protection requirements ranging from 5% of the study area to 100% of the study area and with the presence and absence of the requirement to promote larger habitat patches (Table 4.10).

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[41] Fort Walsh, Chimney Coulee Historic Site, Fish and Wildlife Development Fund Land, National Wildlife Areas (10,11,14,15 and 16), and the Val Marie Migratory Bird Sanctuary (a total of 35 quarter sections) are all included into "other protected areas" and will be treated the same as Grasslands National Park (i.e. they will be locked into all conservation area designs).

[42] The cost of land conversion of current holdings in Grasslands National Park was estimated at $350,000 (Fargey *et al.*2004); however, in this study conversion costs were recalculated using GIS information and found to equal closer to $2 million for current and future holdings. The park owns the oil and gas rights within the park boundaries and, therefore, there will be no future oil and gas extraction within the park boundaries.

Table 4.10. Conservation design elements and their implementation in the Marxan optimization model.

Design Elements	Marxan Implementation	Marxan Objective
Species Historical Habitat Representation	• Represent all 8 species at risk's historical habitat individually • Represent all 8 species at risk's historical habitat simultaneously	5%; 10%; 25%, 50%, 75%, 100%[1]
Size of Habitat Patch	Promote larger habitat patches through a penalty (BLM[2]) on boundary length BLM = 0, 1000, 400, and 200[3]	Minimize: $BLM[\sum_{PUs} Boundary]$[4]
Costs **(Opportunity and Direct)**	Minimize NPVs of land values and beneficial management practices • Model 1: Petroleum Land Values, Agricultural Land Values, and Agricultural Conversion Costs • Model 2: Land Easements and Agricultural Conversion Costs • Model 3: Grazing Management and Buffer Strip Costs	Minimize: $\sum_{PUs} Cost$

[1] Numeric targets represent the percentage of the total area of the feature that is required to be represented in the conservation area system.
[2] BLM stands for Boundary Length Modifier and is the Marxan term for a penalty or weighting factor that can be applied to the boundary length to promote habitat clumping
[3] A BLM of zero results in no requirement to select adjacent quarter sections, whereas calibration techniques provided the ability to select BLMs of 1000, 400, and 100 to promote larger patch sizes in models 1, 2, and 3 respectively.
[4] This is never minimized on its own, but, rather, is minimized as a weighted sum with the total cost of all planning units. It is weighted by the BLM.

4.3.1.1 The Model Scenarios

Table 4.11 presents the entire suite of scenarios run for each of the Marxan models. The models were run under different combinations of parameters in order to explore the issues of multiple-species management and habitat patch size. As discussed before, one of the drawbacks of the Marxan optimization framework is that it is static in nature. As a result, several model runs are required for each cost curve. Each point on the cost curve is an individual model run under a very specific set of parameters.

Table 4.11. All of the scenarios run for the three Marxan models.

	Species Representation		Costs			
Experiments	**Individual**	**Simultaneous**	**Model 1**	**Model 2**	**Model 3**	**Contiguity**
Set 1	X		X			
Set 2	X		X			X
Set 3		X	X			
Set 4		X	X			X
Set 5	X			X		
Set 6	X			X		X
Set 7		X		X		
Set 8		X		X		X
Set 9	X				X	
Set 10	X				X	X
Set 11		X			X	
Set 12		X			X	X

4.3.1.2 Calibrating the Models

Simple calibrations for the Marxan input parameters (the weighting factors on the species target and boundary length terms in the objective function[43]) were run in Zonae Cogito (Watts *et al.*2010). Models 1, 2, and 3 were run with species penalty factors (SPFs) of 20, 40, and 130 and with BLMs of 1000, 400, and 100, respectively. See Appendix I for a more thorough discussion on choosing the BLMs and SPFs.

4.3.2 The Marxan with Zones Model

The Marxan with Zones optimization model was created to allow a greater level of flexibility in the assignment of conservation activities to the study area. While the overall model design and implementation are very similar to the three Marxan models discussed above, the difference lies in the flexibility of applying different conservation activities (and their associated costs) to quarter sections in the study region. Table 4.12

[43] The weighting factors on the species were selected so that all models met the habitat protection targets of all the species in the model. Boundary length modifiers were selected so that boundary length in the reserve network was minimized without having to bring additional planning units into the reserve to decrease the boundary length.

presents the model elements. Table 4.13 contains the information on which parcels of land can be assigned particular conservation activities – known as “zones” in the Marxan software – as well as the costs of each zone and the proportion of a zone’s area that can contribute to the overall conservation area. A total of 10 zones were considered in the model for the South of the Divide study area. Again, as is the case with the three models discussed above, current protected areas (including Grasslands National Park) are locked into the conservation design.

Table 4.12. Conservation design elements and their implementation in the Marxan with Zones optimization model.

Design Elements	Marxan Implementation	Marxan Objective
Species Historical Habitat Representation	• Represent all 8 species at risk’s historical habitat individually • Represent all 8 species at risk’s historical habitat simultaneously	5%; 10%; 25%, 50%, 75%, 100%[1]
Size of Habitat Patch	Promote larger habitat patches through a penalty (BLM[2]) on boundary length BLM = 0 and BLM = 20[3]	Minimize: $BLM[\sum_{PUs} Boundary]$[4]
Costs **(Opportunity and Direct)**	Minimize NPVs of land values and beneficial management practices (See **Table 4.13**)	Minimize: $\sum_{PUs} Cost$

[1] Numeric targets represent the percentage of the total area of the feature that is required to be represented in the conservation area system.

[2] BLM stands for Boundary Length Modifier and is the Marxan term for a penalty or weighting factor that can be applied to the boundary length to promote larger habitat patches.

[3] A BLM of zero results in no requirement to select adjacent quarter sections, whereas calibration techniques provided the ability to select a BLM of 20 to promote larger habitat patches.

[4] This is never minimized on its own, but, rather, is minimized as a weighted sum with the total cost of all planning units. It is weighted by the BLM.

Table 4.13. The zones, zone costs, and zone contribution levels as well as the land on which each zone can apply for the Marxan with Zones optimization model.

	Zone Name	Zone Cost	Lands On Which the Zone Can be Applied	Contribution to Species Habitat[1]
1	Grasslands National Park and Other Protected Areas*	No Additional Cost	Grasslands National Park, Fort Walsh Historic Site, Fish and Wildlife Development Fund Land, National Wildlife Areas, Val Marie Migratory Bird Sanctuary, etc.	100% for all species
2	Public Grasslands*	No Additional Cost	Community pastures, grazing cooperatives, and provincial lease land	70% for all species
3	Private Grasslands*	No Additional Cost	Privately owned grasslands	50% for all species
4	Community Pasture 'Reserves'	Oil and natural gas values; conversion (establishment + opportunity) costs	Community pastures[2]	100% for all species
5	Protected Areas	Oil and natural gas values; agricultural land values; conversion (opportunity) costs	Privately owned land and provincial lease land[3]	100% for all species
6	Conservation Easements*	20% of agricultural land values (new easements); no cost (current easements)	Current easements[4] and privately owned native grasslands	75% for all species
7	Healthy Grasslands	Stocking rate costs; conversion (establishment + opportunity) costs	Community pastures, privately owned land, and provincial lease land	75% for all species
8	Buffer Strips	Buffer (establishment + opportunity) costs	Privately owned hay or cropland	25% for all species
9	Shelterbelts	Shelterbelt (establishment + opportunity) costs	Privately owned hay or cropland	25% for Loggerhead Shrikes; 0% for all other species
10	Not Protected	No Additional Cost	Any land not included in the protected habitat area	0% for all species

* These zones are currently present within the area. In the case of zones 1,2, and 3, no additional quarter sections will be added to these zones; however, in the case of zone 7 – conservation easements – additional quarter sections will potentially be added as new easements. The other zones (4, 5, 6, 8, 9) are created through management actions (or the lack of management actions in the case of zone 10).

[1] This is the proportion of each acre in this zone that contributes to the total habitat target. The higher the values (bounded between 0 and 1), the better protection the zone provides.

[2] Old Man on His Back provincial lease land was re-categorized as "community pasture" to signify a higher level management and commitment to healthy grasslands than most provincial lease land would receive.

[3] Provincial lease lands are included with private land because land tenure is not secure (Michalsky, Mackenzie and Good 2010).

[4] Current easements were locked into the conservation easement zone with a cost of zero.

4.3.2.1 The Model Scenarios

The entire suite of scenarios run for the Marxan with Zones model is presented in Table 4.14. The model was run under the same combinations of parameters as the three Marxan models discussed above; however, this model also allowed a greater level of flexibility in the application of conservation activities on the landscape.

Table 4.14. All of the scenarios run for the Marxan with Zones Model.

	Species Representation (Habitat protection levels of 5 – 100%)		
Experiments	**Individual**	**Simultaneous**	**Contiguity**
Set 1	X		
Set 2	X		X
Set 3		X	
Set 4		X	X

4.3.2.2 Calibrating the Model

Zonae Cogito (Watts *et al.* 2010) was again used to calibrate the species penalty factor (SPF) and the boundary length modifier (BLM) prior to running the final model scenarios. The appropriate BLM was found to be 20 and the appropriate SPF is 50 (see Appendix I for a more thorough discussion).[44]

4.4 Chapter Summary

Linear programming – in the form of the Marxan reserve site selection conservation planning programs – was used to create cost curves for the South of the Divide region. The cost curves illustrate the trade-offs between economic values (oil, natural gas, and agriculture) and habitat protection. The costs considered in the cost curves include oil and gas net present values, agricultural land values, as well as the cost of numerous beneficial management practices (land conversions, grazing management, buffer strips and shelterbelts). A total of four models were used to provide insight into the cost of protecting cost-effective habitat under various combinations of conservation activities and objectives.

[44] The selection of the species' weights and boundary length modifiers used the same criteria as the three Marxan models discussed previously.

5 Results

This chapter reports and discusses the results from the Marxan linear optimization models created in the methods section (Section 4). First, however, a brief summary of the conservation activity costs and species biological data is presented. Following this summary, the results of each of the four Marxan models is displayed including the total cost of each model and cost curves for the species at risk within the South of the Divide region. The benefits of multiple species at risk planning are explored along with the potential increases in cost resulting from reserve networks with larger habitat patches. Finally, a brief look into the possible policy recommendations that the Marxan reserve site selection models can provide is presented.

5.1 Summary of the Biological and Cost Data

This section presents the results of the cost calculations outlined in the methods section (section 4.2.2). Results are broken down by species' ranges and critical habitat. Information on species historical ranges, critical habitat and current protected areas are also presented.

5.1.1 Range and Critical Habitat Areas

The proportion of the South of the Divide region that was historically covered by each species varies widely. Some species have only covered a small portion of the region and others once occupied the entire region. Burrowing Owls, Loggerhead Shrikes and Sprague's Pipit all have historical ranges that cover the entire South of the Divide. Swift Fox also historically covered a very large percentage (89%) of the region. Greater Sage-Grouse historically covered approximately one third (28%) of the region while other species like the Eastern Yellow-bellied Racer, Black-footed Ferret and Mountain Plover historically covered much smaller portions of the region (7%, 11% and 12%, respectively).

There are also large differences in the current protection of species at risk habitat within the South of the Divide region. Some species have large percentages of their proposed critical habitat and historical range protected within Grasslands National Park while other species have a much smaller percentage of their habitat currently protected. Figure 5.1 shows the area historically covered by each of the eight species at risk included in this analysis.[45] The area that each species currently has protected in Grasslands National Park or other protected areas (Fish and Wildlife Development Fund Land, National Wildlife Areas, Conservation Easements, etc.) as well as the area that each species has designated as proposed critical habitat is also shown in the figure. The species historically covering a smaller area have a larger proportion of their historical range protected. There are two reasons driving this higher percentage of coverage, the first is simply that these species' historical ranges are smaller and therefore any level of protection results in a proportionally higher level of protection, and the second is that these species' historical ranges have a high level of overlap with current protected areas, especially Grasslands National Park.

The critical habitat area included in Figure 5.1 is the proposed critical habitat designations as of October 2011 (Stephen Davis pers. comm.). Burrowing Owl, Black-footed Ferret and Mountain Plover critical habitat is entirely contained within current protected areas. High levels of protection are also already present for Eastern Yellow-bellied Racers (72% in Grasslands National Park and the remaining area in a Federal Community Pasture), and Loggerhead Shrike (47% located within Grasslands National Park and almost the entire remaining area within a Federal Community Pasture). Lower levels of protection are currently afforded to Greater Sage-Grouse, Swift Fox and Sprague's Pipit proposed critical habitat polygons.

[45] Previous sections discussed the drawbacks of using extent of historical occurrence as the biological goal within this analysis rather than species' population or density (see sections 3.3.3 and 4.1.1.2).

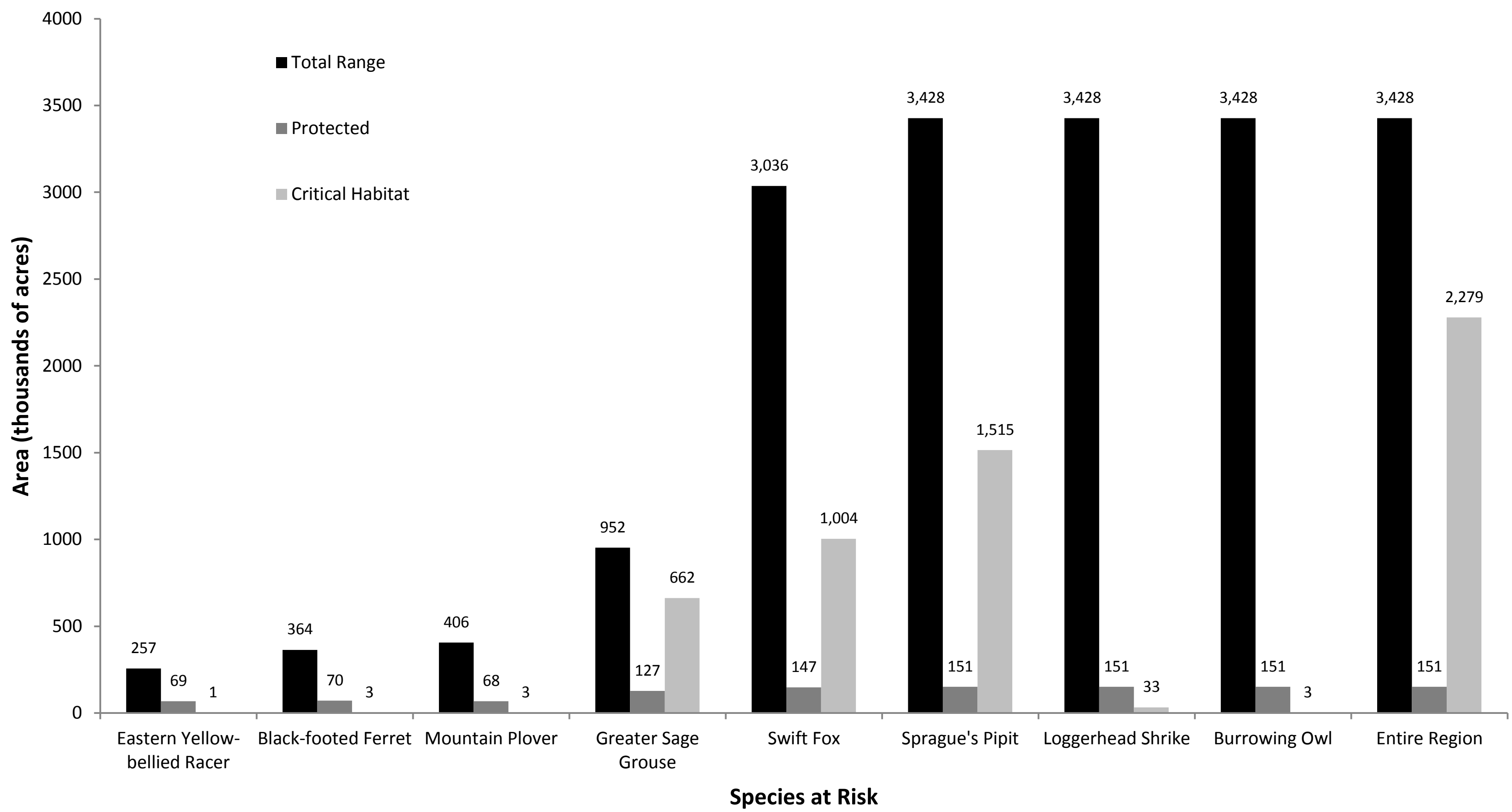

Figure 5.1. The total area (in thousands of acres) historically covered, currently protected and currently designated as proposed critical habitat for each species at risk.

5.1.2 Range and Critical Habitat Costs

Land values for oil, natural gas and agriculture were tallied for each species' historic range and critical habitat[46]. The costs of beneficial management practices were also tallied for each species. The results are presented in Table 5.1 and Table 5.2 below. Table 5.1 includes information for species ranges. These are the spatial biological inputs used within the Marxan models. Table 5.2 includes information for species proposed critical habitat. The total cost column is somewhat artificial in that all seven costs would not be applied to any one quarter section all at once since the beneficial management practices are mutually exclusive; however, it provides a picture of the relative cost of each species' range and critical habitat. The tables account for the fact that certain opportunity costs (oil, natural gas and agriculture) do not apply to Grasslands National Park and other protected areas because these areas have already been removed from production. While the opportunity costs of agriculture, oil and natural gas do not apply to Grasslands National Park, it is likely that the park will continue with its conversion of non-native grasslands into native grasslands. As such, estimated land conversion costs remained in the table under the land conversion column.

Within the tables, species are listed from highest cost per acre to lowest cost per acre and finally at the bottom of each table, the last row provides information on costs if all species' ranges or critical habitats were to be simultaneously considered. Four of the eight species at risk – Burrowing Owl, Loggerhead Shrike, Sprague's Pipit and Swift Fox- have oil resources located within their ranges, and only two – Sprague's Pipit and Swift Fox – have oil resources located within their designated critical habitat. Oil values have the ability to drive up the cost/acre for these species.

The species with the largest ranges have the highest costs simply because habitat protection costs are applied to a larger area. However, the species with the largest ranges also generally overlap high quality agricultural land – which has largely been converted to cropland – and as a result have high agricultural opportunity costs and

[46] Marxan is unable to select partial quarter sections. The costs of protecting species' ranges and proposed critical habitats (presented in Table 5.1 and Table 5.2, respectively) are, therefore, calculated for the entire quarter section intersected by a species' historical range or critical habitat polygon (and not just the portion of the quarter section included within the polygon).

conversion costs (Table 5.1). Several species – Burrowing Owl, Black-footed Ferret and Mountain Plover – have very low costs/ acre for their designated critical habitat. This is due to the location of their critical habitat within Grasslands National Park. The only costs considered for these species are potential management strategies (native grassland restoration, buffer strips and shelterbelts) for non-native parcels of land within the park.

Table 5.1.The expected net present land values and beneficial management costs (excluding agricultural land and oil and gas values for Grasslands National Park and other protected areas) associated with each species at risk's range within the South of the Divide region. Species are listed in descending order of cost per acre (2008 dollars).

	Costs in Millions of Dollars								
Species	**Oil**	**Gas**	**Agricultural Land**	**Land Conversion**	**Buffer Strip**	**Shelterbelt**	**Stocking Rate Change**	**Total Cost[1]**	**Cost per Acre**
Sprague's Pipit	404.6	287.8	641.1	470.6	42.2	37.9	77.5	1961.8	572
Loggerhead Shrike	404.6	287.8	641.1	470.6	42.2	37.9	77.5	1961.8	572
Burrowing Owl	404.6	287.8	641.1	470.6	42.2	37.9	77.5	1961.8	572
Swift Fox	146.5	280.9	549.6	414.2	37.2	32.9	65.5	1526.8	503
Mountain Plover	0.0	41.9	56.2	25.5	2.4	2.2	9.6	137.7	339
Greater Sage-Grouse	0.0	78.8	132.7	70.3	6.5	5.7	21.4	315.4	331
Eastern Yellow-bellied Racer	0.0	6.1	39.0	19.9	1.9	1.7	4.9	73.6	286
Black-footed Ferret	0.0	4.4	55.7	27.2	2.6	2.3	7.5	99.7	274
All Together	404.6	287.8	641.1	470.6	42.2	37.9	77.5	1961.8	572

[1] While several of the conservation activities are mutually exclusive, the total cost and cost per acre values are the sum of all seven conservation costs in the table. As a result, the total costs are somewhat artificial, but they still provide valuable information on relative costs between species.

Table 5.2. The expected net present land values and beneficial management costs (excluding land values for Grasslands National Park and other protected areas) associated with each species at risk's proposed critical habitat within the South of the Divide region. Species are listed in descending order of cost per acre (2008 dollars).

	Costs in Millions of Dollars								
Species	**Oil**	**Gas**	**Agricultural Land**	**Land Conversion**	**Buffer Strip**	**Shelterbelt**	**Stocking Rate Change**	**Total Cost[1]**	**Cost per Acre**
Sprague's Pipit	48.6	161.6	319.2	148.2	13.4	11.9	52.4	692.6	499
Swift Fox	15.0	121.4	128.6	34.0	3.0	2.7	22.9	303.0	326
Greater Sage-Grouse	0.0	22.3	80.0	28.7	2.6	2.3	13.4	134.1	225
Eastern Yellow-bellied Racer	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.3	222
Loggerhead Shrike	0.0	0.1	4.7	1.2	0.1	0.1	0.8	6.1	214
Burrowing Owl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	61
Black-footed Ferret	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	61
Mountain Plover	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	61
All Together	51.8	185.8	336.1	158.0	14.3	12.7	56.3	748.3	358

[1] While several of the conservation activities are mutually exclusive, the total cost and cost per acre values are the sum of all seven conservation costs in the table. As a result, the total costs are somewhat artificial, but they still provide valuable information on relative costs between species.

5.2 Using the Species' Ranges and the Conservation Costs within the Marxan Reserve Site Selection Models

The data summarized in the above sections are used in four reserve site selection models to find cost-effective habitat protection designs. The models minimize the cost of habitat protection (i.e. the sum of all conservation activity costs for all selected quarter sections) subject to meeting habitat targets (defined as a percentage of a species' historical range). The models provide information on the trade-offs between economic values (oil, natural gas, agriculture, and the cost of BMPs) and habitat protection. The following sections present the results of the models run for each species individually as well as all species simultaneously under both the presence and absence of habitat patch size requirements.

5.3 The Results of the Marxan Reserve Site Selection Modeling

Three of the four reserve site selection models were relatively inflexible in their ability to select conservation activities on the landscape. These models use the original Marxan software which allows a planning unit – in this case a quarter section in the South of the Divide region – to either be included or excluded from the reserve network and offers no freedom as to what level or form of protection (and associated cost) can be assigned to the included quarter sections (see section 4.1 for a complete discussion on the Marxan optimization process including its strengths and weaknesses). As a result, the three reserve site selection models were created to provide different levels of protection – through different management activities – and different levels of cost. The fourth model uses the relatively new Marxan with Zones software which allows a greater level of flexibility regarding the conservation activities – and their associated costs – that can be chosen within the design of a reserve network. Rather than have a quarter section included or not included into the reserve network with the pre-established conservation actions and costs, a quarter section can be assigned to any number of conservation activities each with their own cost. The following sections summarize the results of the reserve site selection models that were run to simulate different management scenarios and costs for the South of the Divide study area.

5.3.1 The Total Costs of Each Model

Table 5.3 below provides the total net present value of the entire South of the Divide region (i.e. assuming 100% protection) for each of the models as well as a summary of which conservation activities are included in each model.[47] Protection level and costs decrease sequentially from model 1 to model 3. Model 1 removes all land from any sort of agricultural or subsurface development and would cost approximately 1.7 billion dollars (2008 Canadian Dollars). Model 2 would result in the landscape being returned to native grasslands with conservation easements on all private land for a total cost of approximately half a billion dollars. Model 3 would result in improved grazing management strategies on privately managed native grasslands and beneficial management practices for species at risk on current cropland and hay land for a total cost of 119 million dollars (Table 5.3). The Marxan with Zones model has a greater level of flexibility with how it reaches different levels of habitat protection, but to reach 100% habitat protection the model converges into model 1 and results in a total NPV of 1.7 billion dollars.

The annual cost, calculated over the next 30 years, per Saskatchewan household of each program is presented in Table 5.4. The annual payments are presented under different discount rate scenarios. These annual costs are not equivalent to a tax payment as many of the costs within the model are simply the cost of foregone opportunities (opportunity costs) and not costs that require a direct monetary outlay. The result is that these estimated costs are much higher than any payment households would be expected to pay to protect and restore grassland habitat in the South of the Divide region.

[47] Table 5.3 presents only the costs of the conservation activities that were included within this thesis. There are several other conservation costs that would realistically apply on this landscape that have not been included. These costs could include, for example, the cost of reclaiming oil and gas lease roads, controlling predators, translocating species individuals, monitoring the species at risk populations, among others.

Table 5.3. The conservation activities associated with each of the four reserve site selection models, and the total cost (net present value) of applying the conservation activities of each model to the entire South of the Divide study region.

Conservation Activities	Marxan Model 1[1]	Marxan Model 2	Marxan Model 3	Marxan with Zones[2]
Remove/prevent oil and gas development	X			X
Remove agricultural land from production	X			X
Convert non-native grasslands back to native grasslands	X	X		X
Purchase conservation easements on private lands		X		X
Improve grazing management strategies on privately managed native grasslands			X	X
Plant or retain buffer strips on croplands and hay lands, respectively			X	X
Plant shelterbelts on croplands or hay lands				X
Total NPV (millions of dollars)	**1662.27**	**540.86**	**119.47**	**1662.27**

[1] A quarter section is either assigned all of the conservation activities listed for this model if it is included in the reserve network, or none of the conservation activities if it is not included in the reserve network. This holds for Marxan models 1, 2 and 3.
[2] A quarter section can be assigned any of a number of conservation activities and their associated costs if it is included in the reserve network, or none of the conservation activities if it is not included in the reserve network.

Table 5.4 The effective annual cost (2008 dollars) to each Saskatchewan household over the next 30 years to protect the entire study region within each of the four Marxan models under three discount rates.[48]

Discount Rate	Marxan Model 1	Marxan Model 2	Marxan Model 3	Marxan with Zones
4%	248.30	80.79	17.85	248.30
5%	279.31	90.88	20.07	279.31
10%	455.47	148.20	32.74	455.47

5.3.2 Cost Curves for Models 1 to 3

Information presented in this section includes the costs of each individual species' conservation, the potential cost-savings of including multiple species at risk within one conservation plan, and the additional costs required to create larger habitat patches (i.e. spatially contiguous habitat). The cost curves will also illustrate the potential for

[48] The number of Saskatchewan households in 2006 was 387 145 (Government of Saskatchewan, 2007), and the formula used to calculate annualized payment was:

$Annual\ Payment\ = \frac{NPV}{A_{t,r}}\ where\ A_{t,r} = \frac{1-{}^{1}/_{(1+r)^t}}{r}$ and *r* is the discount rate and *t* is the number of years over which payments will be made.

efficiency improvements when economic considerations are included in the process of designating critical habitat. The cost curves are presented either in terms of average price per acre or percentage of total NPV (Schneider *et al.* 2011) where total NPV is the value reported in Table 5.3 for each of the four models. For simplicity, species will be referred to in the cost curve figures using their 3 to 5 letter names (Black-footed Ferret = BFF; Eastern Yellow-bellied Racer = EYBR; Mountain Plover = MOPL; Greater Sage-Grouse = GRSG; Sprague's Pipit = SPPI; Loggerhead Shrike = LOSH; Burrowing Owl = BUOW; Swift Fox = SWFOX).

Species cost curves provide information on the cost associated with individually managing each of the eight species at risk within the South of the Divide region. There are large differences in the area historically covered by each species and the activities that are currently occurring within their historical ranges. As a result there are large differences in costs associated with their habitat protection. The species cost curves are presented in both average price per acre and percentage of total NPV. The cost curves using percentage of total NPV provide the ability to easily compare the relative costs of species' conservation within each model. Points indicating each species' proposed critical habitat as percentage of habitat protected and percentage of total NPV required for protection are also provided on each graph. The inclusion of these points provides information on whether or not the inclusion of costs in the process of designating critical habitat could result in cost-savings. The cost curves that present the average price per acre for each species' habitat conservation target are also included. These cost curves provide the ability to easily compare costs between models and will potentially inform the selection of economically feasible conservation actions for the region and species.

Marxan as a modeling tool is particularly valuable when spatial considerations are required in reserve planning. Through the use of a boundary length modifier, a spatial connectivity term is included within the objective function. The 'cost' of disconnected or fragmented habitat patches are therefore minimized resulting in larger, continuous habitat patches (see section 4.1.1 for a complete discussion on the integration of the boundary length modifier into the optimization model). Rather than including all the least cost quarter sections into the reserve network, a trade-off must be made between acquiring a lower cost quarter section that is not connected to any other already included quarter sections and acquiring a more expensive quarter section that is adjacent to an already included quarter section. The latter choice increases the size of an already existing habitat patch and helps to minimize the boundary length of the reserve network, but it comes at a higher cost. The minimization of boundary length in a reserve network design results in more expensive reserve networks with larger habitat patch sizes and less habitat edge. Cost curves displaying the difference in costs (as percentage of total NPV) with the presence and absence of the habitat patch size requirements provides information on just how costly larger habitat patches can be.

Simultaneously including all eight species within a single optimization model allowed the investigation of the benefits of multiple species planning. Currently, the policy goal is to manage the eight species at in a multiple species at risk action plan under the Species at Risk Act (SARA). The belief is that there are biological and economic benefits to be gained as a result of managing species at risk together. However, despite the desire for a multi-species plan, species' critical habitat designations were still selected individually. In order to address the cost of designing habitat protection based on species-by-species information, all species were considered individually within their own Marxan models as well as together in a single Marxan optimization model.

The results of the individual species' conservation planning models were joined in an ad-hoc manner where any quarter section selected as cost-effective habitat for at least one of the eight species was included in the final multi-species plan. Any quarter sections included in more than one species' reserve were only counted once in the final multi-species plan (i.e. there was no double counting of quarter sections or costs). Thus, after adding the results of all the individual species models together, all species would at least meet the habitat protection target while some might exceed the target. The benefits (cost-savings) of planning a multi-species plan within one optimization model versus the ad-hoc joining of eight individual species' plans were calculated and reported (as percentage of total NPV) for each of the models under both the presence and absence of habitat patch size requirements.

5.3.2.1 Species Cost Curves

The following sections discuss the resulting species cost curves for Marxan models 1, 2, and 3.

5.3.2.1.1 Species Conservation Costs (Percentage of Total Net Present Value)

Figure 5.2, Figure 5.3, and Figure 5.4 show each model's species cost curves – measured as percentage of total NPV – as a function of percentage of historical range (i.e. grassland habitat or just habitat) protected.[49] The same pattern emerges in all three figures, four species can be protected with a small proportion of the region's total net present value and four species – Loggerhead Shrike, Sprague's Pipit, Burrowing Owl and Swift Fox – are much costlier to protect. The higher total costs of protection associated with these four species is primarily driven by the large size of their historical ranges, but as shown in Table 5.1 above, their costs per acre are also higher as a result of the activities located within their range – specifically oil development and annual crop agriculture. It is oil resources that drive the large increase in percentage of total NPV at the highest protection levels for Swift Fox, Sprague's Pipit, Burrowing Owl and Loggerhead Shrike in model 1.

The cost curves for model two remain around zero until habitat targets become quite high because there are large areas of publicly owned native grasslands that would not require conservation easements or native grassland conversions. In this model, these current productive land-uses are able to provide sufficient habitat for species at risk, and until all these zero cost quarters are selected as habitat, no conservation easements or land conversions would take place. The large spike in cost for Swift Fox, Sprague's Pipit, Burrowing Owl and Loggerhead shrike in Figure 5.3 is due the high costs of converting annual cropland into native grasslands (establishment costs per acre alone are almost twice the value of agricultural land in the region). The lands requiring conversion would only be selected after habitat protection constraints become strict enough to require it.

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[49] Within these figures, abbreviations are used to represent the species. These are the abbreviations: Eastern Yellow-bellied Racer = EYBR; Black-footed Ferret = BFF; Mountain Plover = MOPL; Burrowing Owl = BUOW; Loggerhead Shrike = LOSH; Sprague's Pipit = SPPI; Greater Sage-Grouse = GRSG; Swift Fox = SWFOX.

Model 3, while having a total cost lower than that of model 2, cannot provide as much land at zero cost as model 2. This is because in this model, beneficial management practices are applied to privately leased provincial crown land (that would not require an easement in model 2) in the form of stocking rate changes. As a result, cost curves rise faster than in model 2. The spike in costs as habitat protection increases is likely due to the need to include land with high cost grazing management changes, and the need to include large volumes of annual cropland and hayfields requiring buffer strip management.

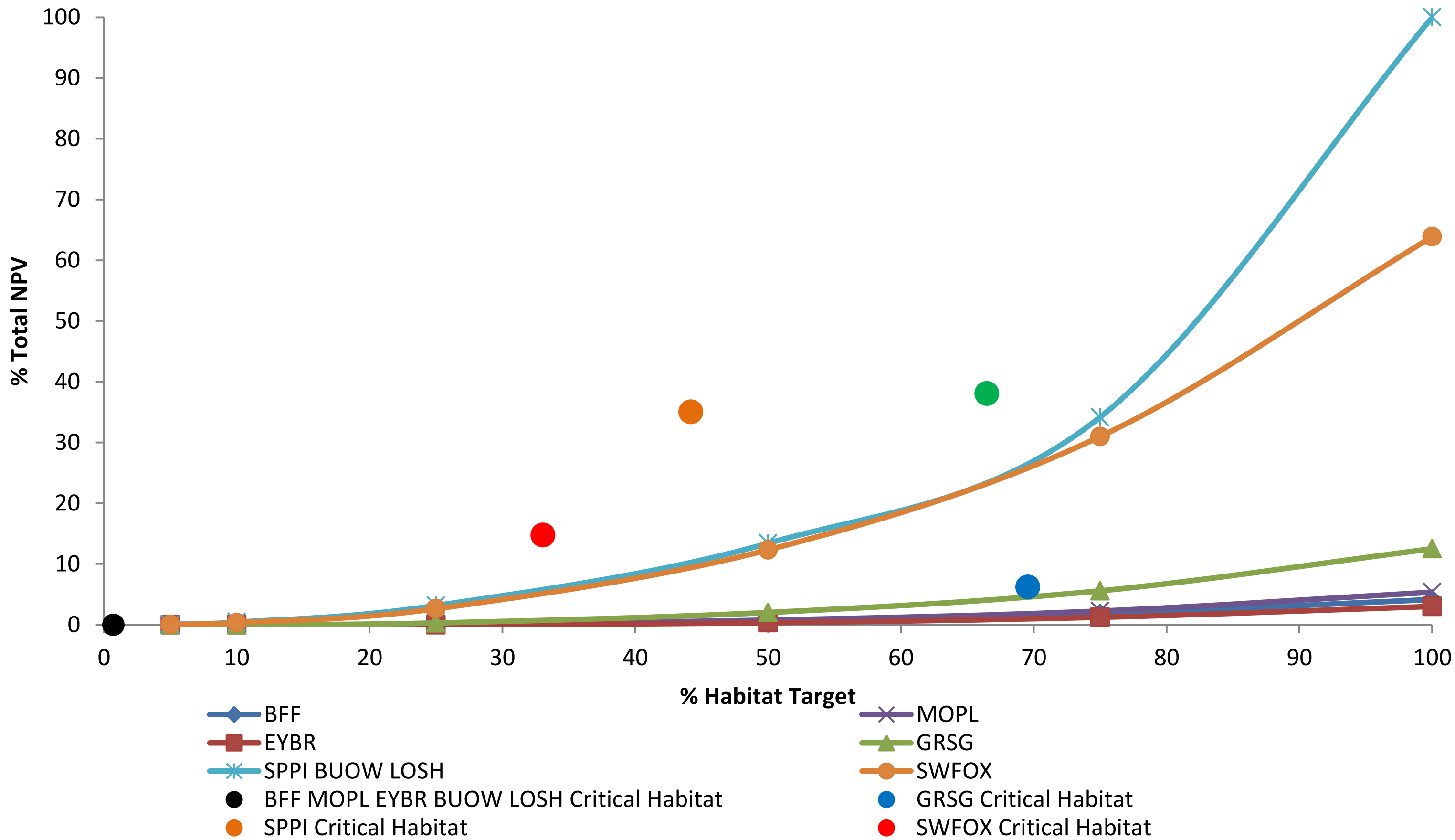

Figure 5.2. Model 1 species' cost curves shown as percentage of total NPV for each habitat protection level. The cost of 100% habitat protection is $207 million (12.5% of total NPV) for Greater Sage-Grouse, $90 million (5.4% of total NPV) for Mountain Plover, $68 million (4.1% of total NPV) for Black-footed Ferret, $50 million (3.0% of total NPV) for Eastern Yellow-bellied Racer, $1.06 billion (64% of total NPV) for Swift Fox, and $1.66 billion (100% of total NPV) for Sprague's Pipit, Loggerhead Shrike and Burrowing Owl.

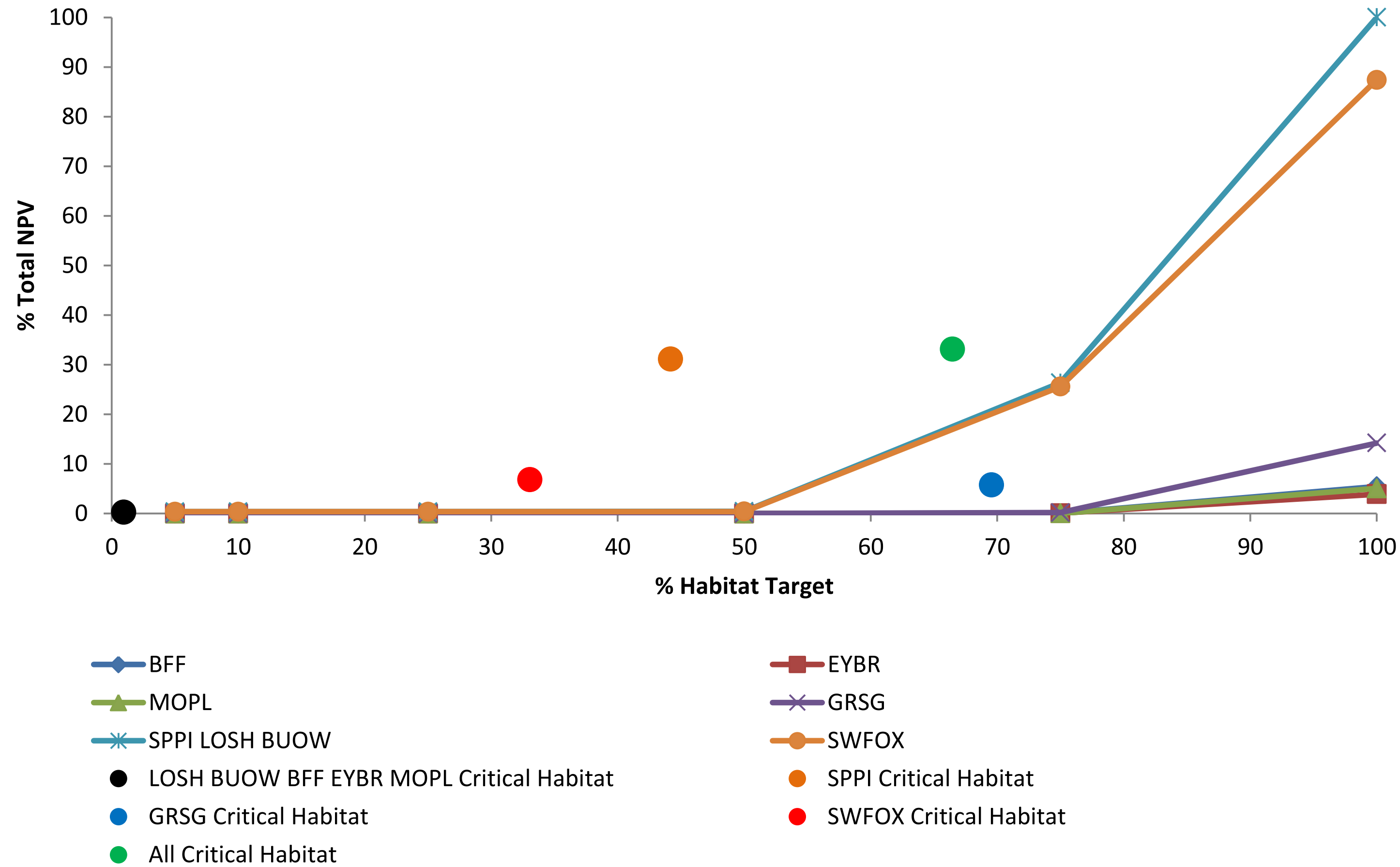

Figure 5.3. Model 2 species' cost curves shown as percentage of total NPV for each habitat protection level. The cost of 100% habitat protection is $30 million (5.5% of total NPV) for Black-footed Ferret, $21 million (3.9% of total NPV) for Eastern Yellow-bellied Racer, $77 million (14.2% of total NPV) for Greater Sage-Grouse, $27 million (5.1% of total NPV) for Mountain Plover, $473 million (87.4% of total NPV) for Swift Fox, and $541 million (100% of total NPV) for Sprague's Pipit, Loggerhead Shrike and Burrowing Owl.

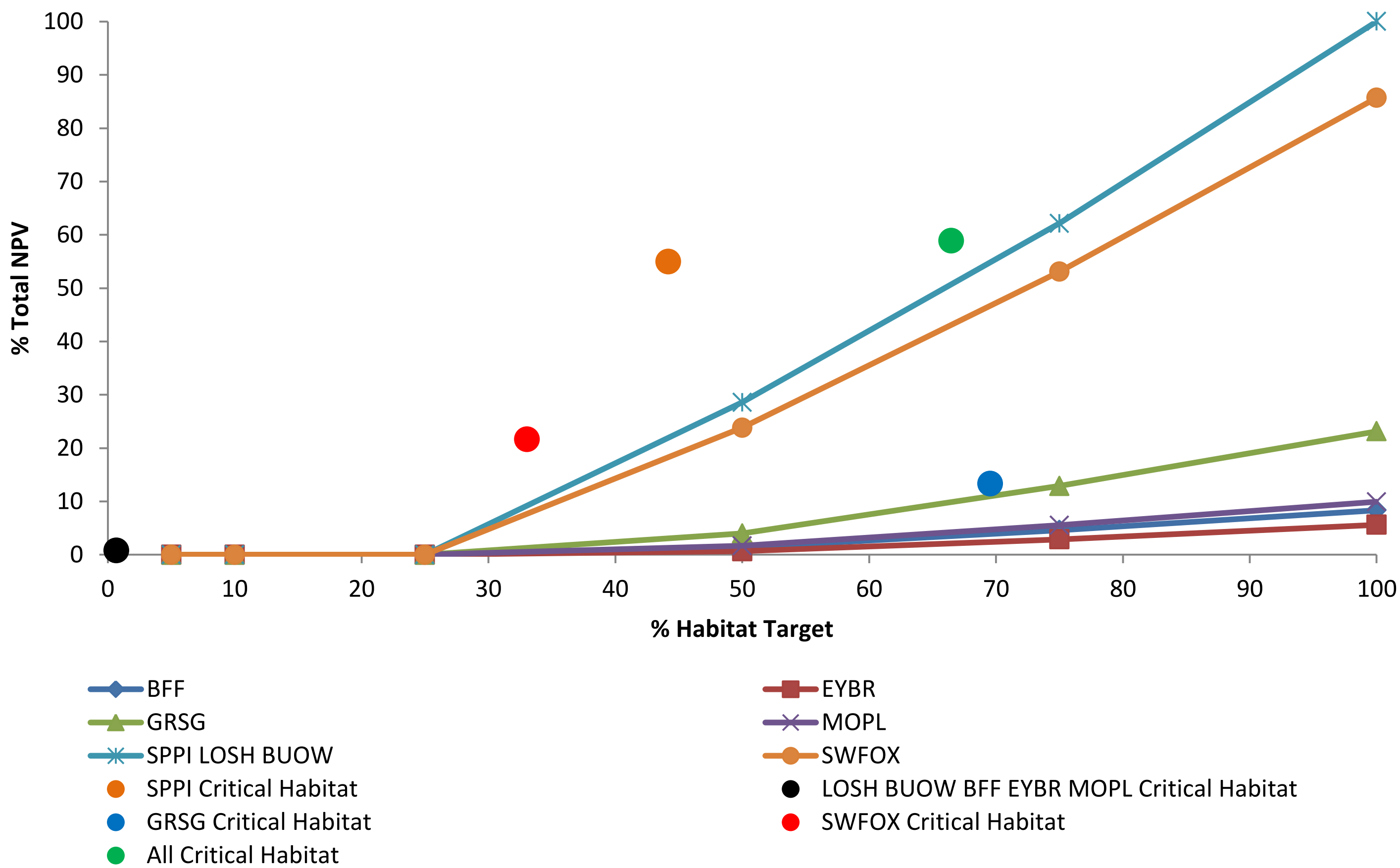

Figure 5.4. Model 3 species' cost curves shown as percentage of total NPV for each habitat protection level. The cost of 100% of habitat protection is $10 million (8.3% of total NPV) for Black-footed Ferret, $7 million (5.6% of total NPV) for Eastern Yellow-bellied Racer, $28 million (23.2% of total NPV) for Greater Sage-Grouse, $12 million (9.9% of total NPV) for Mountain Plover, $102 million (85.7% of total NPV) for Swift Fox, and $119 million (100% of total NPV) for Sprague's Pipit, Loggerhead Shrike and Burrowing Owl.

5.3.2.1.1.1 Proposed Critical Habitat and the Cost Curves

Proposed critical habitat is designated on areas where species currently occur, or have a high probability of occurring according to biological models. These quarter sections are treated differently by biologists and conservation planners than other quarter sections in the region. However, our models treat all quarter sections within a species' historic range as biologically equal. If the conservation actions included within the model can indeed turn lower quality habitat into more desirable grassland habitat (which seems possible in the case of native grassland restoration), there should little issue comparing the costs of protecting the critical habitat polygons to the costs of protecting the cost-effective reserve network designs. However, if the conservation actions included within the models are unable to make habitat outside the critical habitat polygons equivalent to the habitat inside the critical habitat polygons, the costs should not be directly compared. Rather, the costs should be adjusted in some manner to reflect the higher biological benefits of the critical habitat quarter sections. This section compares conservation costs under the assumption that protected critical habitat is biologically equivalent to protected/restored historical range.

With critical habitat areas of 2 546 acres for Black-footed Ferret, Mountain Plover and Burrowing Owl (0.69%, 0.62%, and 0.07% of their historical ranges, respectively); 1 218 acres for Eastern Yellow-bellied Racer (0.47% of its historical range); and 32 750 acres for Loggerhead Shrike (0.96% of its historical range) all these species' proposed critical habitat points are located in the very bottom corner of the species curve graphs (Figure 5.2, Figure 5.3, and Figure 5.4).[50] The small cost of proposed critical habitat protection for these species is amplified by the fact that almost all of the proposed critical habitat for these species is contained within Grasslands National Park and are already afforded protection from oil, natural gas, and agricultural development.

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[50] The cost of each species' proposed critical habitat designation is the sum of the appropriate conservation costs within each model for all quarter sections intersected by the species' critical habitat polygon. The cost is calculated for the entire quarter section regardless of whether critical habitat is only designated on a portion of the quarter section. This allows comparisons to be made with the Marxan models that can only select complete quarter sections.

Greater Sage-Grouse, Sprague's Pipit and Swift Fox have larger areas of proposed critical habitat designated in the region. Greater Sage-Grouse critical habitat makes up approximately 70% of the historical range. In models 1 to 3, Greater Sage-Grouse critical habitat costs a total of $100 million (approximately 6% of total NPV), $31 million (approximately 6% of total NPV), and $16 million (approximately 13% of total NPV), respectively. These values are higher than the cost-effective habitat protection curves of models 1, 2 and 3 by $19 million (1.12% of total NPV), $30 million (5.9% of total NPV), and $2.5 million (2% of total NPV), respectively. Swift Fox critical habitat (covering 33% of the study area) costs $244 million (15% of total NPV), $37 million (6.8% of total NPV), and $26 million (21.6% of total NPV) using the conservation actions of models 1, 2 and 3, respectively. The same area could be protected for $96 million, $40,000, and $9.1 million by using models 1, 2 and 3, respectively. Sprague's Pipit critical habitat (covering 44% of the study area) costs $581 million (36% of total NPV), $168 million (31.1% of total NPV) and $66 million (54.9% of total NPV) for models 1, 2 and 3 respectively. Using the cost curves; however, the same area could be protected in models 1, 2 and 3 for $180 million, $74,000 and $26 million, respectively.

There are substantial savings possible if costs are taken into account during the designation of critical habitat. These savings are potentially due to the flexibility to choose potentially lower quality habitat (i.e. habitat outside a species' critical habitat polygon) as if it is equivalent to potentially higher quality habitat (i.e. habitat inside a species' critical habitat polygon). However, if it is the case that the conservation actions would result in the quarter sections outside of the critical habitat polygons being capable of providing the same quality of habitat and supporting the same density of species individuals (after restoration of native grasslands, proper grassland management, etc.), the costs are comparable and conservation cost-savings are realistically achievable.

5.3.2.1.2 Species Conservation Costs (Average Cost per Acre)

For each model and all eight species, the average price per acre for varying habitat protection targets is shown (Figure 5.5, Figure 5.6, and Figure 5.7). For the same reasons discussed above – the location of species ranges relative to oil resources and productive agricultural land – some species have higher cost of habitat protection than others. In model 1, 25% of the study area can be protected for a cost of approximately $81/acre. In model 2, for less than $1/acre, on average, 50% of the total study region and 50% of all species' historical ranges can be protected. In order to move protection up to 75% of the study region, the average cost per acre becomes approximately $63/acre and a total of 2.6 million acres can be protected. In fact, the entire study area can be protected for an amount less than the average cost of an acre of agricultural land in the region. In model 3, protecting 50% of the total study region and 50% of all species' historical ranges can be done for an average cost less than $20/acre. As much as 75% of the region can be protected for an average cost of $30/acre.

Again, the points on the graphs (Figure 5.5, Figure 5.6, and Figure 5.7) represent the average cost per acre for the proposed critical habitat in the study region. The location of all the points above their respective species cost curves indicates that there is the potential to decrease habitat protection costs if economic considerations are taken into account when designing critical habitat.

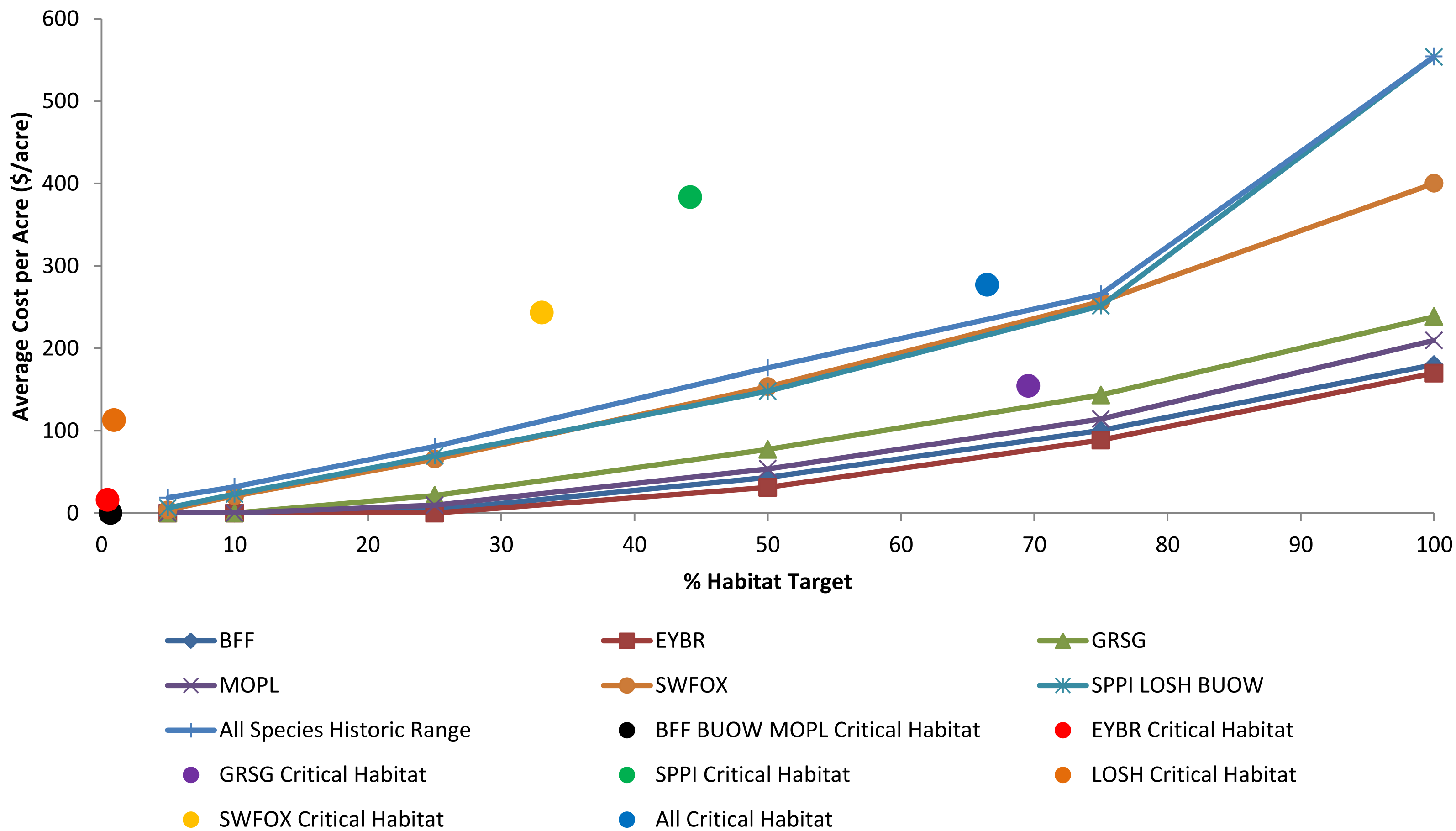

Figure 5.5. Model 1 species' cost curves shown as average cost per acre ($/acre) as habitat protection targets increase. The average cost per acre to protect all species is also included.

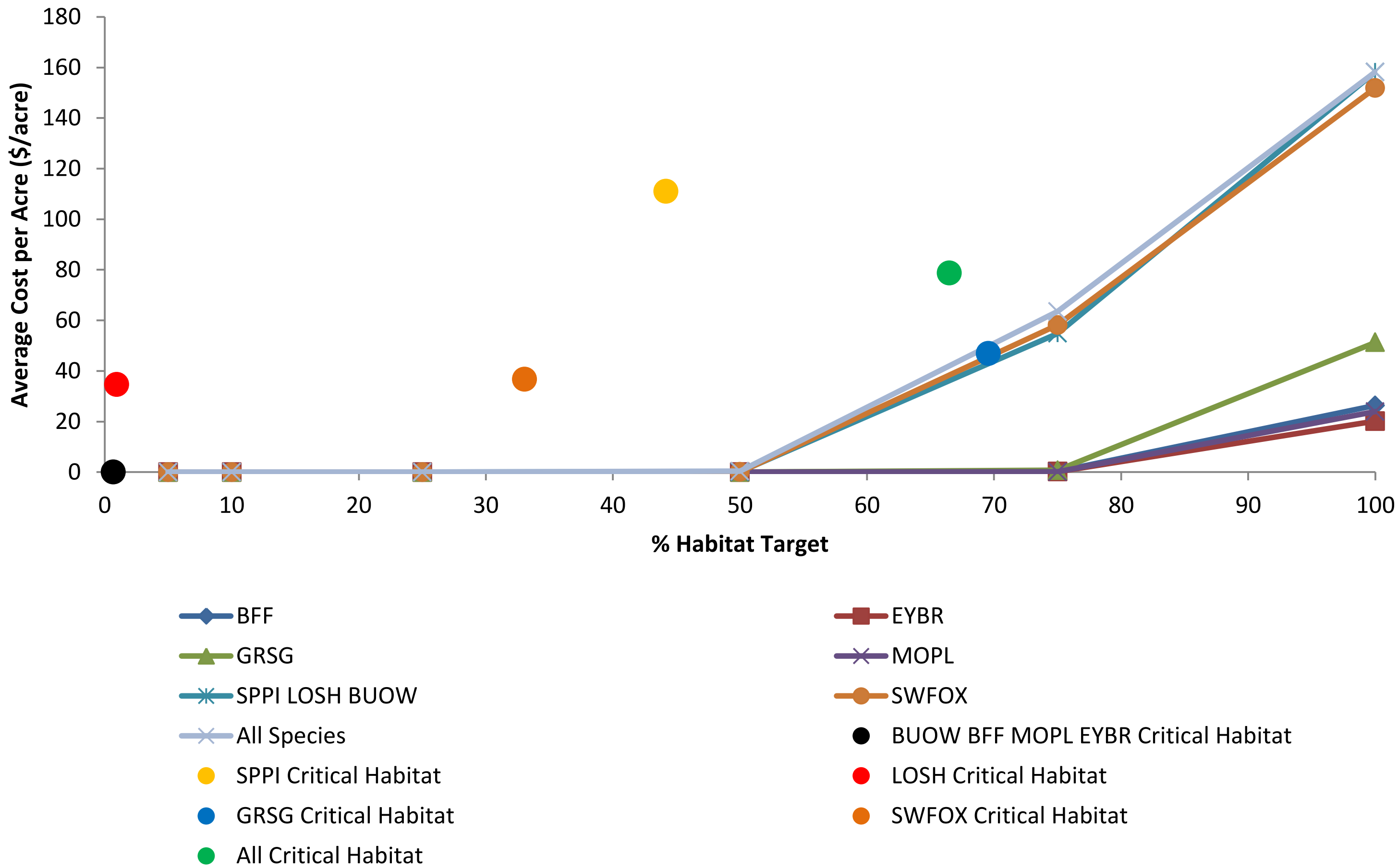

Figure 5.6. Model 2 species' cost curves shown as average cost per acre ($/acre) as habitat protection targets increase. The average cost per acre to protect all species is also included.

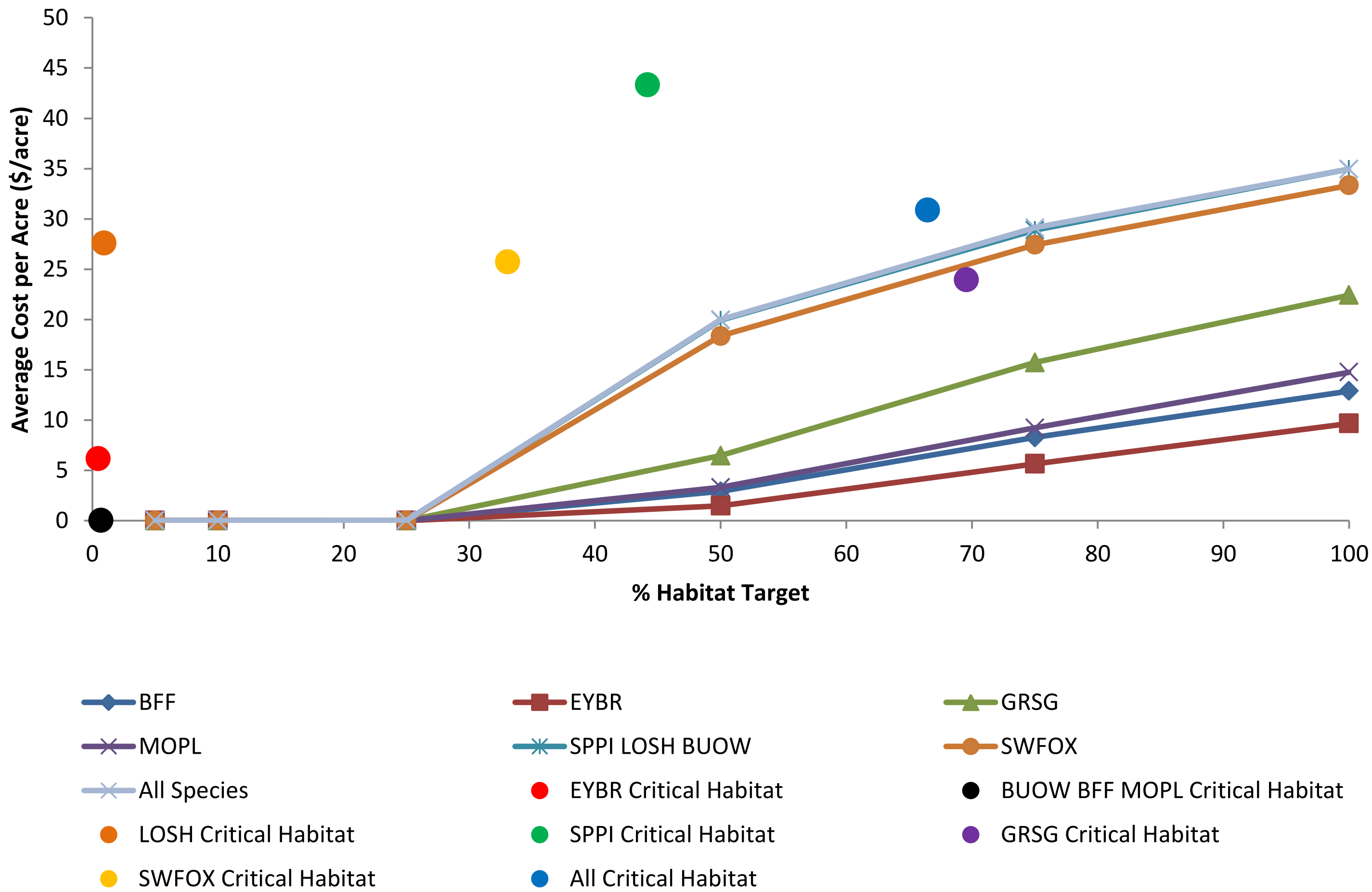

Figure 5.7. Model 3 species' cost curves shown as average cost per acre ($/acre) as habitat protection targets increase. The average cost per acre to protect all species is also included.

5.3.2.2 The Added Cost of Larger Habitat Patches

The additional cost of designing a reserve network with larger patch sizes was calculated. Each model (1 through 3) was run with and without the boundary length modifier term in the objective function. The costs (in percentage of total NPV) were compared between the two runs (larger habitat patch requirements on and off) when all species were managed simultaneously within a single reserve network and when species were included within their own models and later merged together.

Figure 5.8, Figure 5.9, and Figure 5.10 displays the difference in costs between models run requiring larger habitat patches – which result in reserve networks containing a small number of large habitat patches – and models run with no spatial habitat constraints – which result in reserve networks with a large number of small habitat patches. There is a substantial additional cost required to meet habitat protection targets when larger habitat patches with fewer edges are desired.

All the models exhibit the same trend (Figure 5.8, Figure 5.9, and Figure 5.10). There is a substantial cost to requiring larger habitat patches when species are managed within their own conservation planning models, but the cost is much reduced if a single reserve network simultaneously manages all eight species. In models 1, 2 and 3, when habitat patch costs are the highest, the cost is lowered by as much as $132 million (8% of total NPV), $64 million (12% of total NPV), and $15 million (13% of total NPV), respectively, when species are managed simultaneously within a single reserve network. Intuitively this makes sense. Better choices and trade-offs can be made if the reserve network is viewed and managed as a whole so larger habitat patches that will benefit multiple species can be targeted.

The maximum additional costs per acre vary widely between the models. In model 1, the maximum additional cost per acre is $172/acre (individual species management) and $124/acre (simultaneous species management). Simultaneous species management lowers costs an average of $22/acre across all habitat protection levels. In model 2, the maximum additional costs are $66/acre (individual species management) and $50/acre (simultaneous species management). In model 3 the maximum additional costs per acre are $21/acre (individual species management) and $17/acre (simultaneous species management).

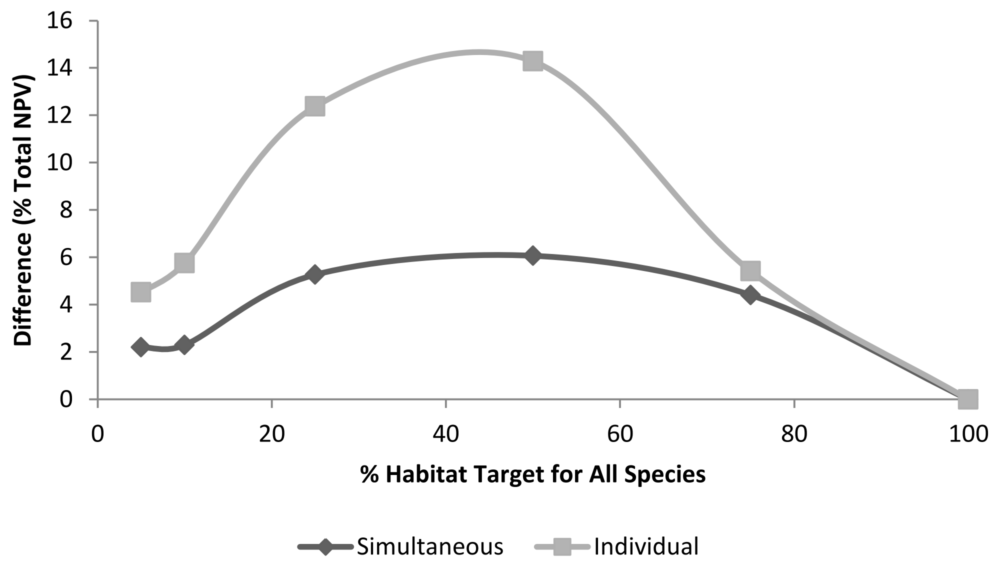

Figure 5.8. The additional costs borne when model 1 is run with habitat patch size requirements included in the optimization problem relative to the cost of model 1 run with no habitat patch size requirements. Differences were taken when species were managed simultaneously in one conservation planning model, and when they were managed individually and later merged into a single reserve network.

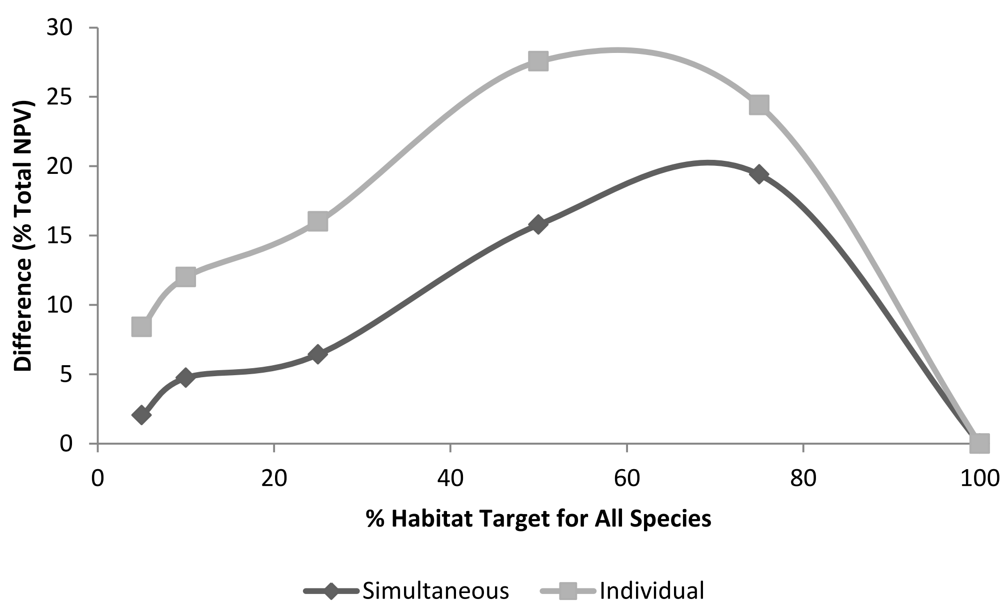

Figure 5.9. The additional costs borne when model 2 is run with habitat patch size requirements included in the optimization problem relative to the cost of model 1 run with no habitat patch size requirements. Differences were taken when species were managed simultaneously in one conservation planning model, and when they were managed individually and later merged into a single reserve network.

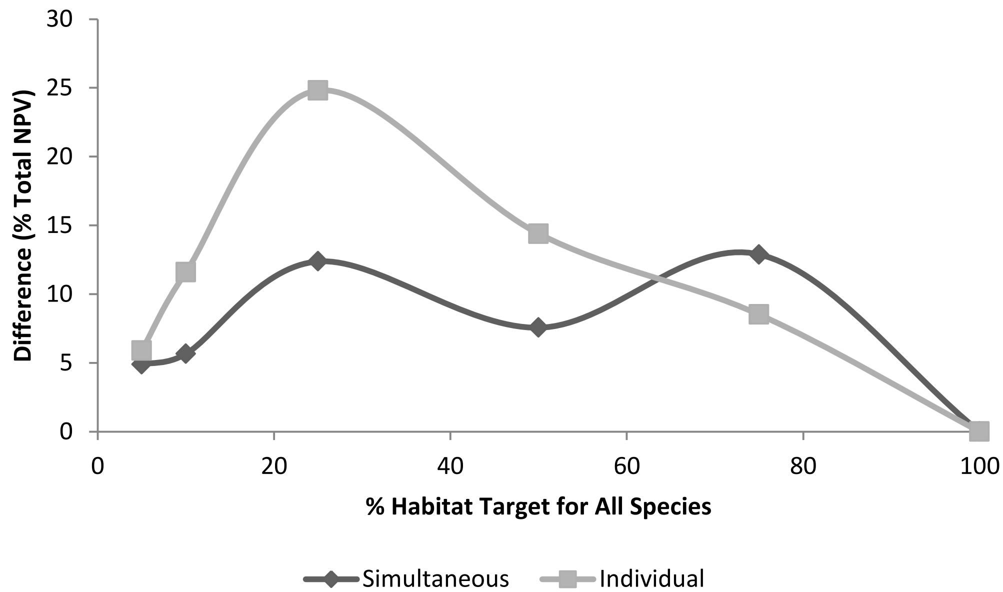

Figure 5.10. The additional costs borne when model 3 is run with habitat patch size requirements included in the optimization problem relative to the cost of model 1 run with no habitat patch size requirements. Differences were taken when species were managed simultaneously in one conservation planning model, and when they were managed individually and later merged into a single reserve network.

5.3.2.3 Multiple Species at Risk Planning versus Single Species Planning

In theory there should be large biological and economic gains achieved by protecting multiple species at risk in a single reserve network rather than individually designing reserve networks for the same number of species and later adding them together. Within the single, multi-species optimization model, it is easier to select areas with greater species richness for inclusion in the reserve network. However, the costs of all planning units must be traded off against the biological benefits that the planning units can provide. As such, even though a planning unit has a high level of species richness, this does not ensure its inclusion in the reserve network. This is the insight provided by Ando *et al.* (1998).

Figure 5.11, Figure 5.12, and Figure 5.13 show the percentage of total NPV saved as a result of planning a single reserve network for all eight species simultaneously. The advantage of simultaneous multiple species planning – observed as reduced habitat protection costs – is considerable, especially when larger habitat patches are desired within the conservation area design.

For all three models, when there is no habitat patch size requirement, the greatest advantage of multiple species management is achieved at the higher levels of habitat protection (but tapers toward zero when all quarter sections are ultimately required to be included in the reserve network). For models 1 and 2, the benefit reaches a maximum at around 10% of total NPV (worth $132 million and $60 million, respectively); however, model 3 reaches a maximum benefit of 20% of total NPV (worth $23 million). The large number of zero cost quarter sections available in models 2 and 3 limits the benefit that multiple species at risk planning can provide at the lower levels of habitat protection. However, model 1 starts receiving modest improvements instantly. For model 1, improvements of 0.02% of total NPV, 0.15% of total NPV, 1.03% of total NPV, and 3.36% of total NPV at habitat protection levels 5%, 10%, 25% and 50%, respectively save as much as $0.3 million, $2.5 million, $17 million, and $56 million.

When larger habitat patches are required within the optimization problem, there are large returns to simultaneously planning a reserve network for multiple species (Figure 5.11, Figure 5.12, and Figure 5.13). For models 1 and 3, the largest benefit comes at the 50% habitat protection point and equals 11.6% of total NPV ($192 million) and 24% of total NPV ($29 million), respectively. Model 2 receives the largest benefit – 16% of total NPV ($87 million) – at the 75% habitat protection target. If larger habitat patches are desired, millions of dollars could be saved by managing all eight species simultaneously.

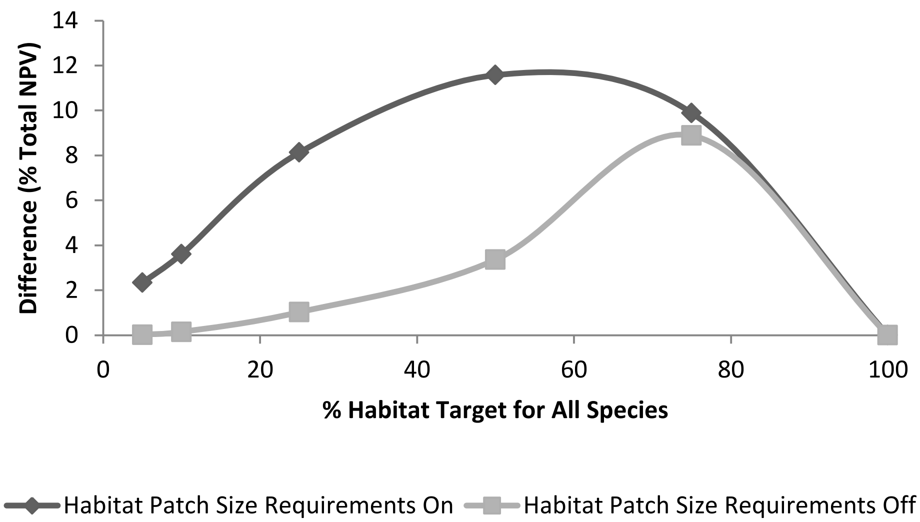

Figure 5.11. The percentage of model 1's total net present valued saved as a result of optimizing habitat protection in a single reserve network for all eight species simultaneously rather than optimizing habitat protection for all eight species individually and later forming them into one reserve network.

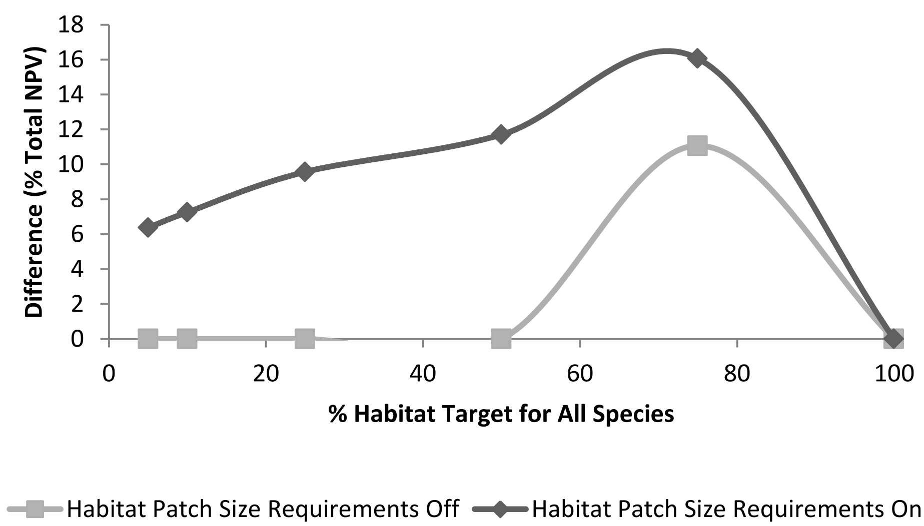

Figure 5.12. The percentage of model 2's total net present valued saved as a result of optimizing habitat protection in a single reserve network for all eight species simultaneously rather than optimizing habitat protection for all eight species individually and later forming them into one reserve network.

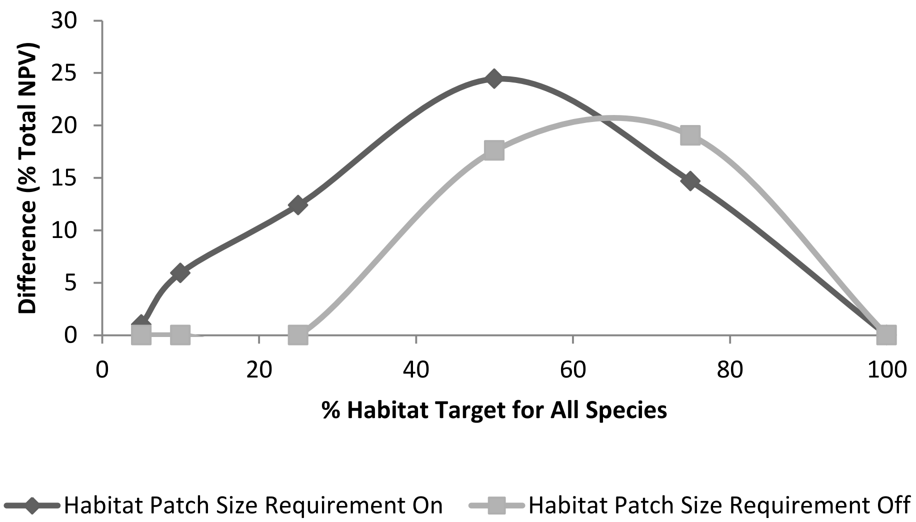

Figure 5.13. The percentage of model 3's total net present valued saved as a result of optimizing habitat protection in a single reserve network for all eight species simultaneously rather than optimizing habitat protection for all eight species individually and later forming them into one reserve network.

Following the trend discussed above, when investigating the potential advantages in cost per acre units, there is a larger advantage to simultaneous species management if larger habitat patches are desired. The average cost-savings of simultaneous species management for models 1, 2 and 3 are \$28.16/acre, \$12.44/acre and \$2.96/acre when larger habitat patches are desired, and \$5.83/acre, \$2.94/acre and \$1.26/acre, respectively, when larger habitat patches are not required.

5.3.2.3.1 Can Multiple Species Planning Reduce the Increased Cost of Larger Habitat Patches

The discussions above on planning multiple species and larger habitat patches highlight an interesting finding: multiple species planning can substantially decrease the cost of requiring larger habitat patch sizes. Figure 5.14 shows the difference in total costs resulting from different management scenarios using individual species planning under no patch size requirements as the basecase. The results are for model 1. The additional costs of larger habitat patches under individual species management are reduced by at least half at all habitat protection levels when using simultaneous species management. In fact, at a habitat protection level of 75%, larger habitat patches requires less cost than the costs imposed by individual species management when there are no habitat patch size requirements.

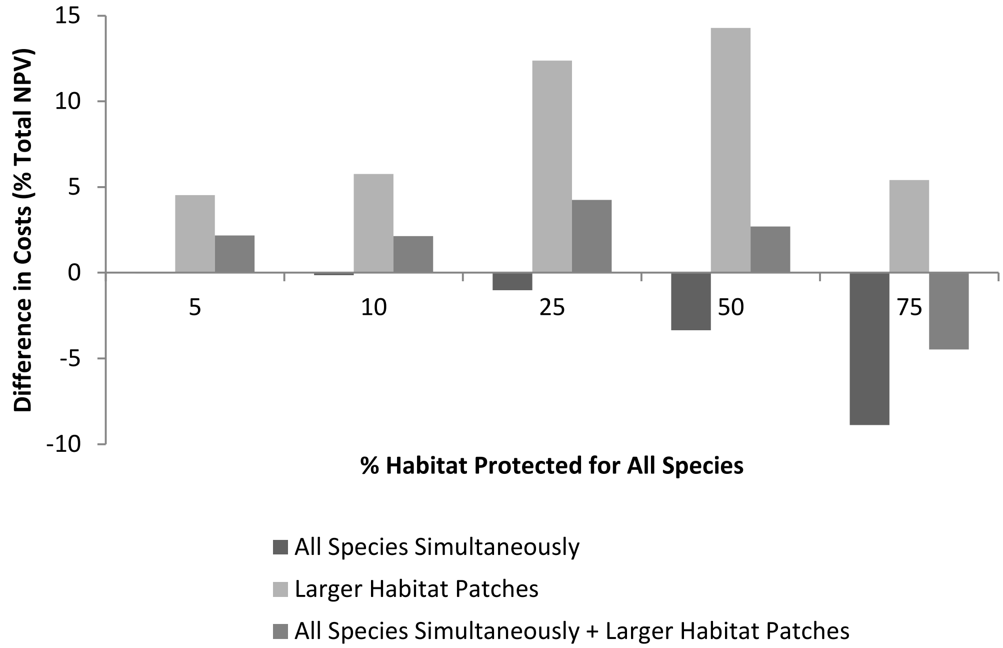

Figure 5.14. The difference in costs (% of Total NPV) in Marxan model 1 when different management scenarios are implemented compared to the basecase of running individual species optimization models with no habitat patch size requirements.

5.3.3 Distribution of Cost-Effective Habitat Protection for Models 1 to 3

Using a habitat protection level of 50% for all species managed simultaneously within a single optimization model, maps showing the frequency with which each quarter section is included in the overall reserve network are included for all three Marxan models. Figure 5.15, Figure 5.16, and Figure 5.17 are for models 1 to 3 under no habitat patch size requirements which means that quarter sections are selected solely to minimize the total cost of all quarter sections selected while still meeting the habitat protection constraint (a minimum of 50% of each species' historical range). As a result, the frequency with which each quarter section is selected is directly related to its cost relative to all other planning units[51]. Figure 5.18, Figure 5.19, and Figure 5.20 are for models 1 to 3 with habitat patch size requirements included within the optimization model. As a result quarter sections are selected to minimize both the conservation costs of the quarter section and the connectivity costs of small, fragmented habitat patches.

[51] The exception is currently protected areas which are locked into the reserve network and are always selected with 100% frequency.

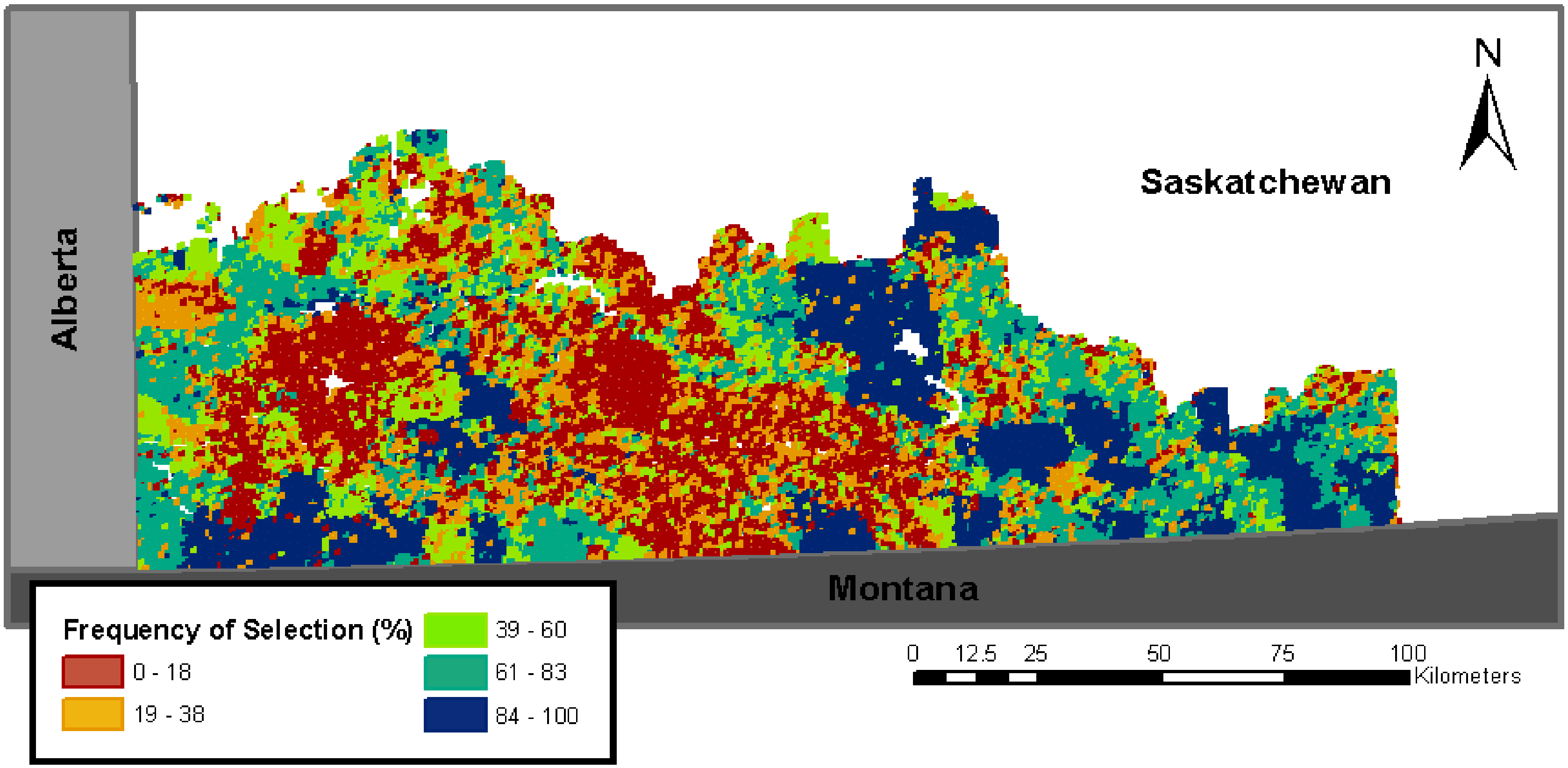

Figure 5.15. The frequency at which each quarter section is selected (%) within model 1 (habitat target = 50% for each species; all species run simultaneously; no habitat patch size requirements).

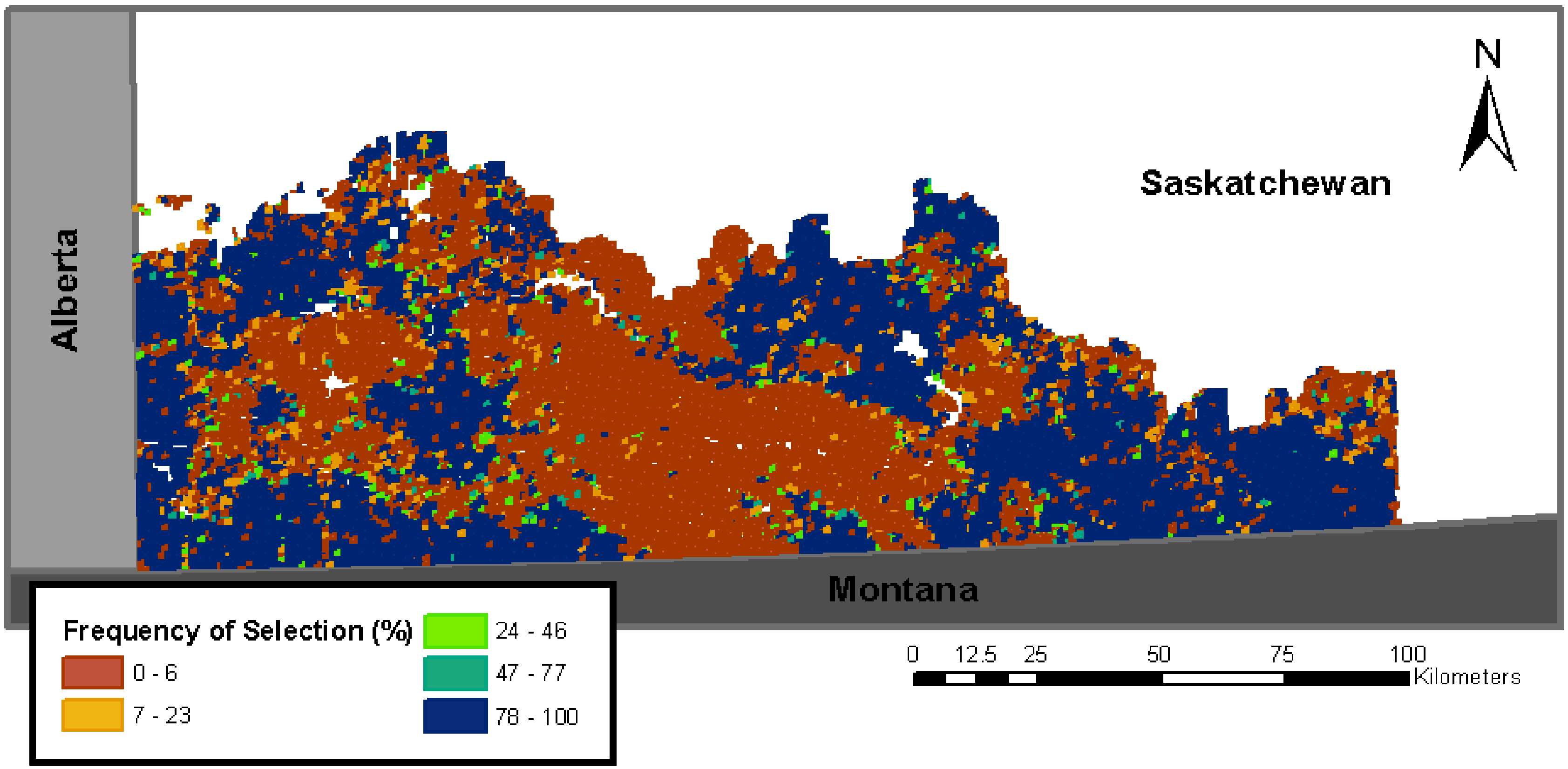

Figure 5.16. The frequency at which each quarter section is selected (%) within model 2 (habitat target = 50% for each species; all species run simultaneously; no habitat patch size requirements).

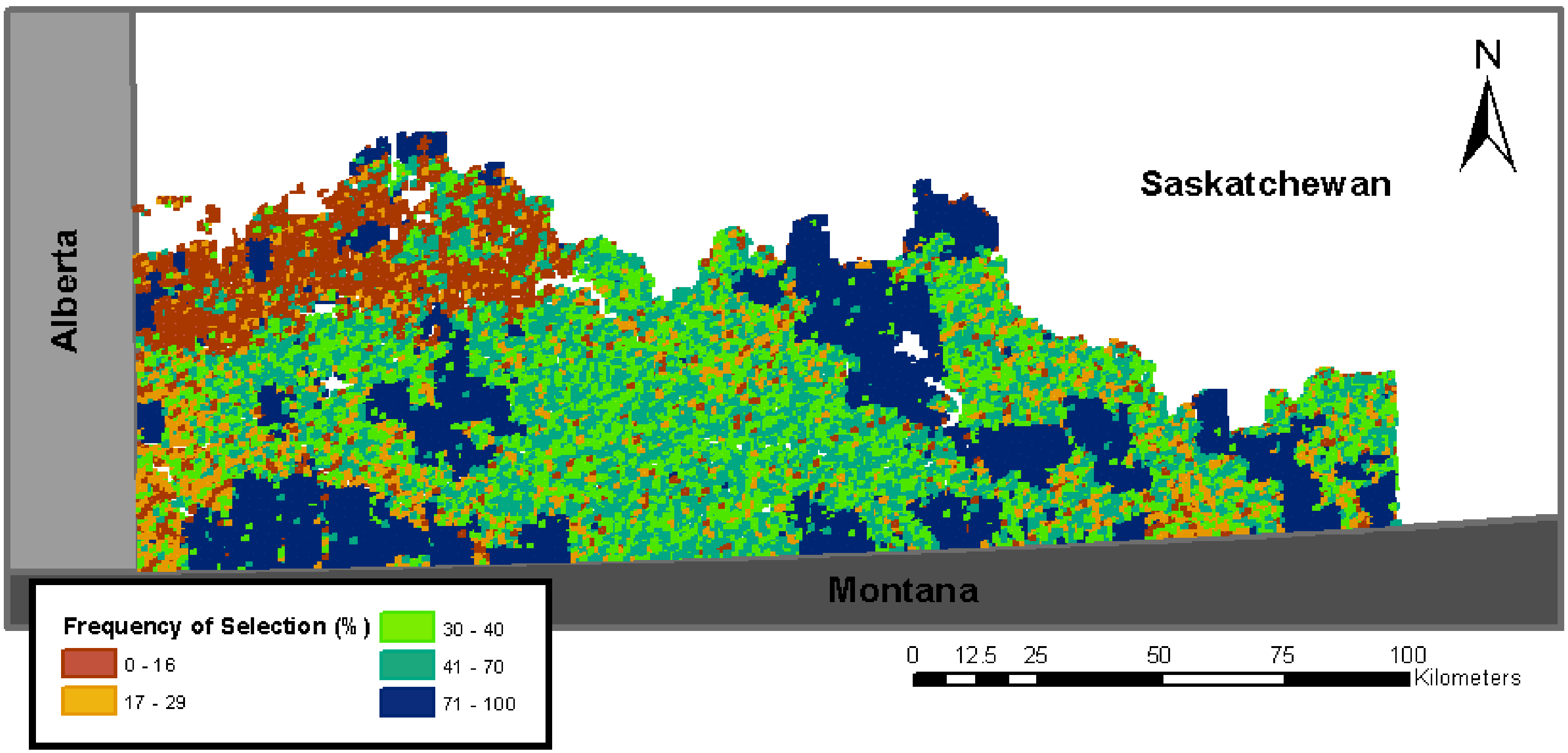

Figure 5.17. The frequency at which each quarter section is selected (%) within model 3 (habitat target = 50% for each species; all species run simultaneously; no habitat patch size requirements).

The pattern of quarter section selection, under the absence of habitat patch size requirements, varies between the three models. In model 1, community pastures (with no agricultural land costs) are selected with the greatest frequency, followed by privately managed remnant native grasslands including provincial lease lands (with no land conversion costs). Areas of current annual cropland (with land conversion costs) and oil resources (with high oil costs) are selected with the lowest frequencies (Figure 5.15). Model 2 follows a similar pattern to that of model 1. All publicly owned land including provincial lease land (with no conservation easement requirements and often no land conversion costs) and all remnant privately owned native grasslands (with no land conversion costs) are selected with a very high frequency while private land that is currently managed as annual cropland (requiring both conservation easements and land conversion costs) is selected with the lowest frequency (Figure 5.16). Model 3, however, shows a different selection frequency pattern from the other two models (Figure 5.17). While publicly managed grasslands (with no buffer costs or grazing management costs) are still selected with the highest frequency, privately managed native grasslands including provincial lease land (with grazing management costs) are selected with about the same frequency as privately owned annual cropland (with buffer strip costs). The exception to this pattern is the northwest corner of the study area where grazing management costs are so high that those quarter sections are selected with very low frequency despite already being native grasslands.

The same patterns of quarter section selection seen in the above maps are replicated in the maps below when habitat patch size requirements are included in the optimization problem (Figure 5.18, Figure 5.19, and Figure 5.20). The primary difference is that the maps show clumped areas with similar selection frequencies.

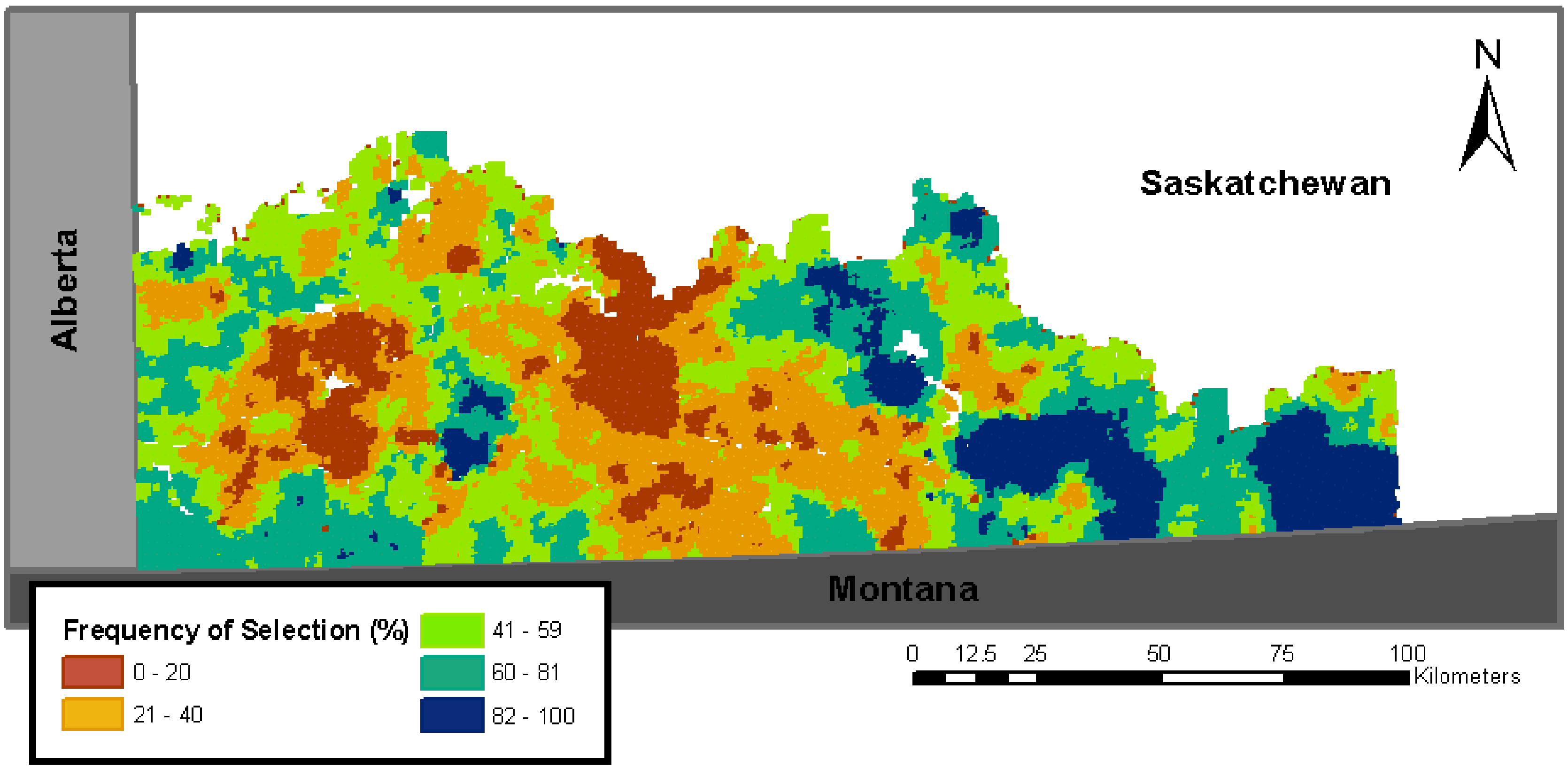

Figure 5.18. The frequency at which each quarter section is selected (%) in model 1 (habitat target = 50% for each species; all species run simultaneously; habitat patch size requirements on).

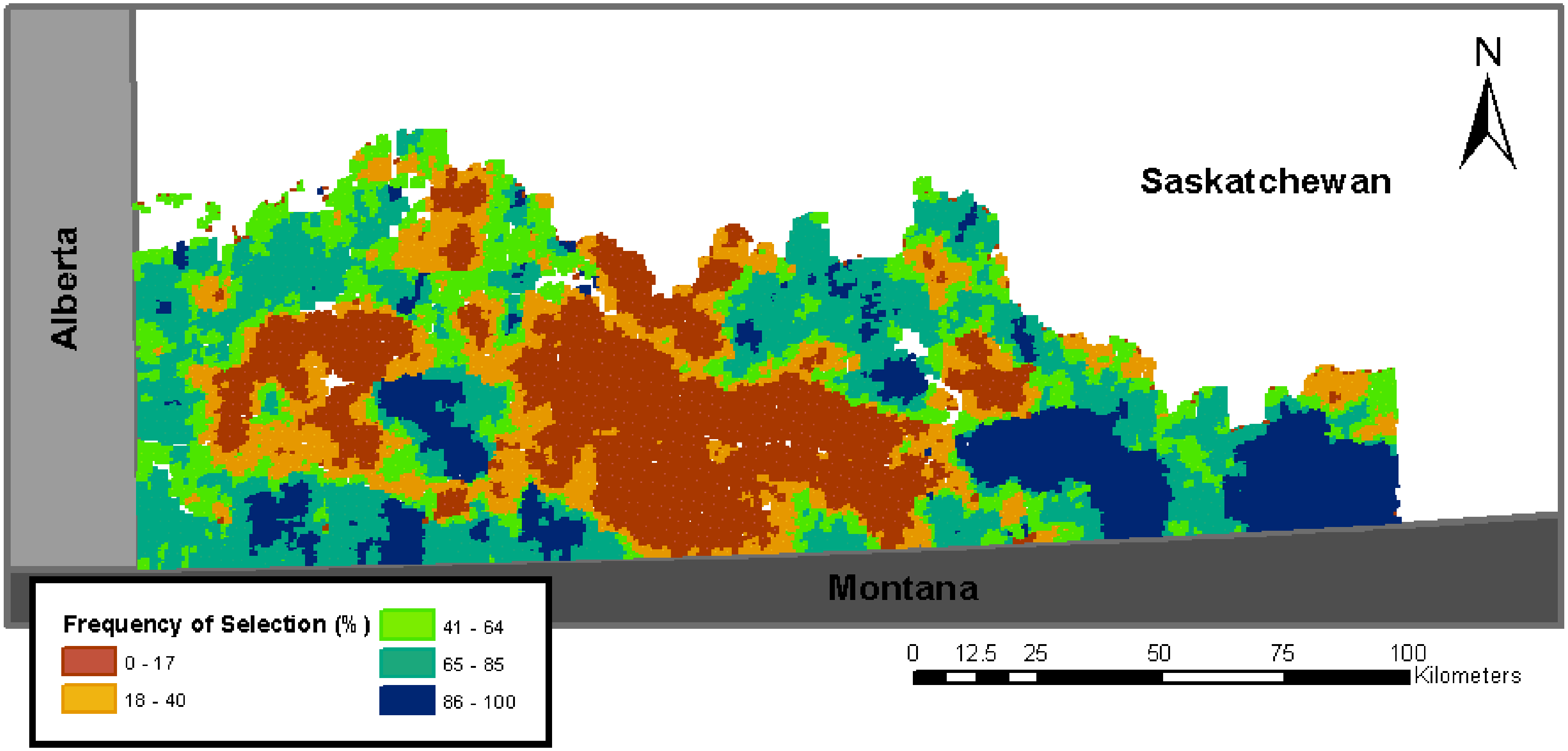

Figure 5.19. The frequency at which each quarter section is selected (%) in model 2 (habitat target = 50% for each species; all species run simultaneously; habitat patch size requirements on).

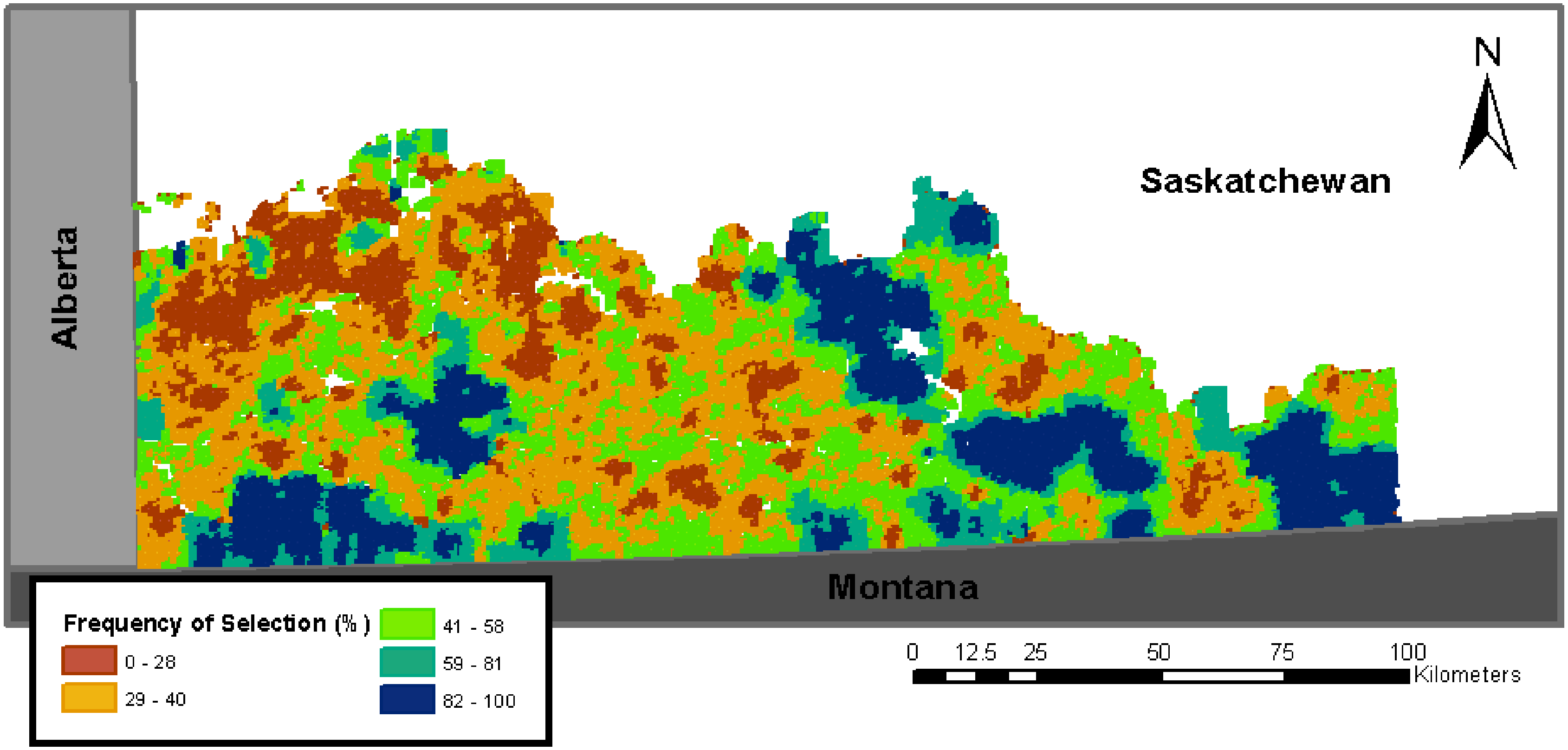

Figure 5.20. The frequency at which each quarter section is selected (%) in model 3 (habitat target = 50% for each species; all species run simultaneously; habitat patch size requirements on).

5.3.4 Summary of Marxan Models 1 to 3

When considering Marxan models 1, 2 and 3, there are clear and interesting results that come to light. The first is that the consideration of costs when designating critical habitat could potentially result in lower-cost habitat designations for several species including Sprague's Pipit, Swift Fox, and Greater Sage-Grouse. The second is that larger habitat patches come with a substantial cost for all three models. However, the additional cost associated with larger habitat patches can be reduced if simultaneous multi-species planning is implemented. In model 1, simultaneous planning can reduce the cost of clumping by as much as 8% of total NPV, and in models 2 and 3 the reduction is as high as 12% of total NPV. The third interesting finding is that simultaneously managing multiple species rather than adding individual species plans together in an ad-hoc manner can result in large reductions in the cost of habitat protection. These reduced costs are especially large when large habitat patches are desired, and these cost reductions may help recover some of the increased costs associated with the requirement for larger habitat patches.

Each of the three models preferentially selects the lower-cost quarter sections to be included in their reserve networks. The most preferred quarter sections for model 1, 2 and 3 are always publicly owned and managed native grasslands (i.e. federal and provincial community pastures). Publicly owned but privately managed grasslands are preferred in model 2 because they do not require a conservation easement to be purchased; however, these lands can still potentially be purchased by private land owners and, therefore, agricultural land values apply to these quarter sections in model 1 and grazing management changes apply to the quarters in model 3 (due to the privately managed nature of the lands[52]). Private native grasslands are preferred in models 1 and 2 because they do not require land conversion costs; however, in model 3 the assignment of grazing management costs to native grasslands and the option of buffer strips as a cheaper management alternative on annual cropland results in native grasslands and annual cropland being selected into the reserve network with similar

[52] The exceptions are the grazing cooperatives located on provincial lease land. These areas already follow the recommended stocking rates for the region and, therefore, have a grazing management cost of zero.

frequencies. Annual cropland is avoided in models 1 and 2 due to the high costs of land conversions, but quarter sections with oil resources are the most avoided quarter sections in model 1.

In summary, considerations of cost can inform the optimal location of habitat conservation, and potentially result in lower cost critical habitat designations. Requiring larger habitat patches comes with an increased cost of habitat protection, and managing multiple species simultaneously results in lower-cost habitat protection. If a reserve network containing larger habitat patches is desired or required, simultaneous species planning can be used to reduce the overall cost of the reserve network relative to planning large habitat patches for each species individually.

5.3.5 Marxan with Zones

Marxan with Zones is a reserve site selection model that allows a greater level of flexibility in both the allocation of planning units to conservation activities and the achievement of conservation targets (see section 4.3.2 for a complete discussion on the optimization model). Several key results for this model are discussed in the following sections. First, the cost curve resulting from simultaneously including all eight species in a single reserve network is presented followed by discussions on the costs of larger habitat patches and the benefits of simultaneous multi-species planning. Finally, information on the allocation of conservation activities across the region is presented for varying levels of habitat protection.

5.3.5.1 The Shape of the Cost Curve

Despite the flexibility in activity selection, the Marxan with Zones model eventually becomes equivalent to Marxan model 1 when high levels (>90%) of habitat is required. This is because there are few conservation activities that enable the reserve network to meet these habitat targets. Consequently, the Marxan with Zones cost curves are presented alongside the Marxan model 1 cost curves to show the differences in cost when a greater number (or flexibility) of conservation activities are possible on the landscape.

The cost curves in Figure 5.21 and Figure 5.22 show the average cost per acre of habitat protection when species conservation is modeled for all eight species simultaneously within a single reserve network. The Marxan with Zones model allows habitat protection to occur at a lower cost per acre than Marxan model 1 at habitat protection levels less than 90%. The largest cost-savings are achieved at 50% habitat protection levels with cost-savings tapering off at the higher and lower levels of habitat protection. At 50% habitat protection, the average cost per acre of effective habitat (acres in each land-use type adjusted by the contribution level of each land-use type) for the Marxan with Zones model ($58.63/acre) is approximately one third that of Marxan model 1 ($176.38/acre) when larger habitat patches are not required. When larger habitat patches are desired, the difference in costs at 50% habitat protection is $174/acre ($243.34/acre for model 1 compared to $69.35/acre for the Marxan with Zones model) which is a notable reduction in cost as a result of greater flexibility in conservation activity. These findings are consistent with the results of Wilson *et al.* (2007) which showed different combinations of conservation activities (rather than simply acquisition values) resulted in better biodiversity achievement and lowered conservation costs.

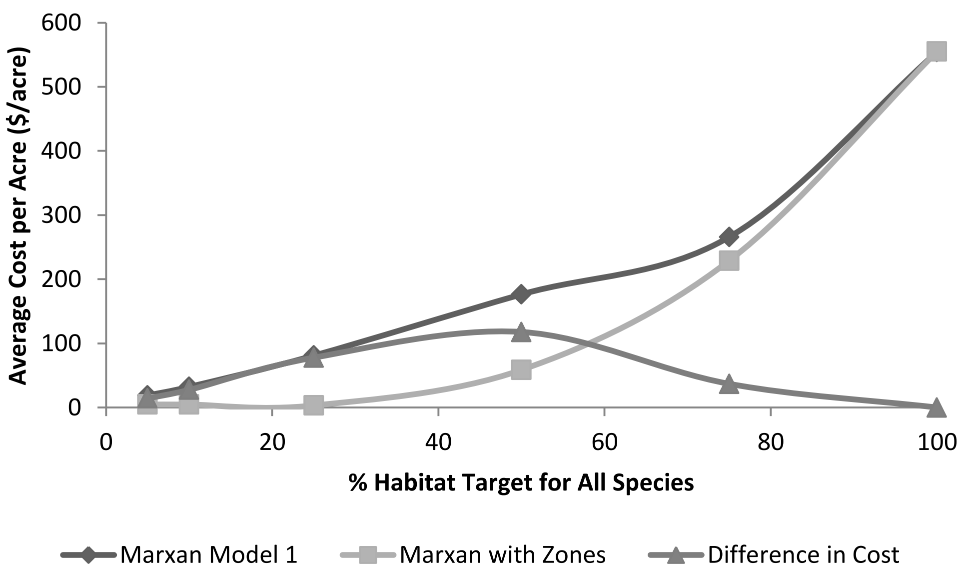

Figure 5.21. The average cost per acre (2008 dollars) of effective habitat for Marxan model 1 and the Marxan with Zones model (Species managed simultaneously within a single reserve network; no habitat patch size requirements). The difference in costs between the models is also shown.

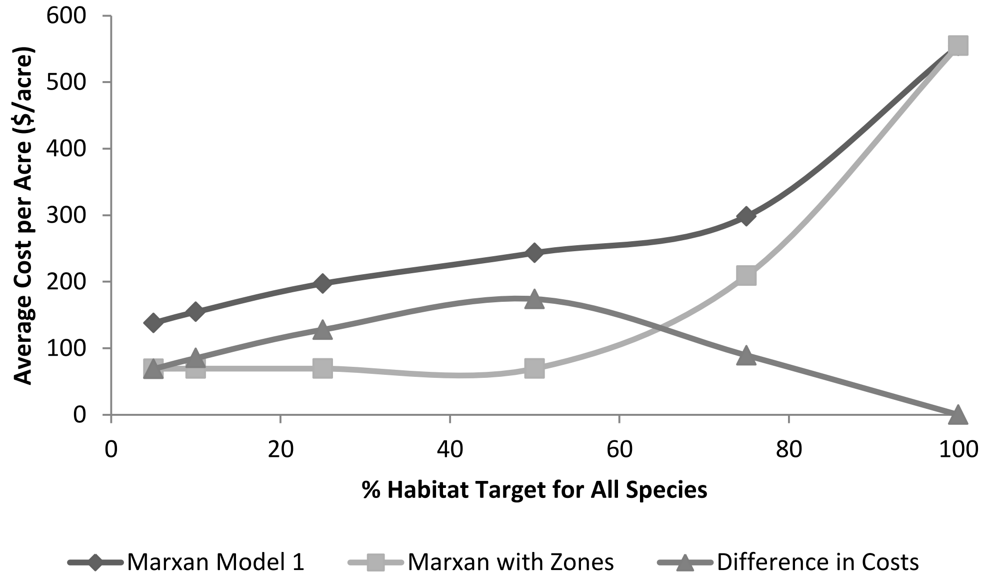

Figure 5.22. The average cost per acre (2008 dollars) of effective habitat for Marxan model 1 and the Marxan with Zones model (Species managed simultaneously within a single reserve network; habitat patch size requirements turned on). The difference in costs between the models is also shown.

5.3.5.2 The Added Costs of Larger Habitat Patches

The difference in cost between the Marxan with Zones model run with and without habitat patch size requirements has been calculated and is displayed in Figure 5.23. The difference is shown when species are managed simultaneously within a single optimization model and when species are managed individually into their own reserve networks and later amalgamated into one reserve.

There is a substantial cost when larger habitat patches with fewer edges are desired. However, the cost is much reduced if a reserve network simultaneously manages multiple species rather than managing species individually and later joining them together. The highest cost of large habitat patches is $232 million (14% of total NPV) and $100 million (6% of total NPV) when species are managed individually and simultaneously, respectively. The costs are highest at the lowest levels of habitat protection and then decrease after habitat protection exceeds 25%. This is because as effective habitat targets increase, a large proportion of all quarter sections in the study region begin to be selected.

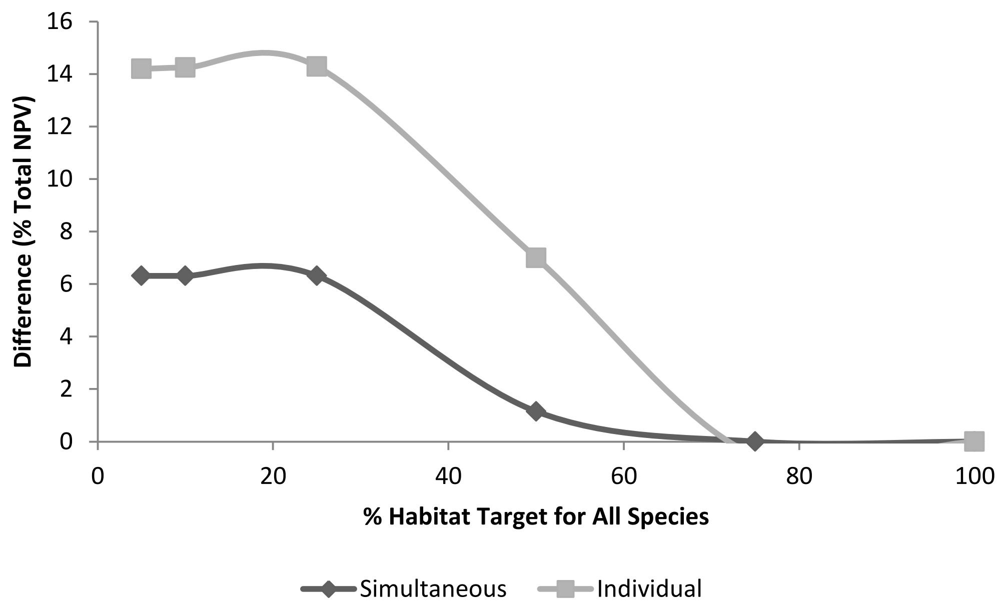

Figure 5.23. The additional cost borne when the Marxan with Zones model is run with habitat patch size requirements included in the optimization problem relative to the Marxan with Zones model run with no habitat patch size requirements. Additional costs were calculated both when species were managed simultaneously in a single reserve network, and when they were managed individually and later merged into one reserve network.

5.3.5.3 The Benefits of Simultaneous Multi-Species Planning

There are large cost-savings possible when habitat planning occurs simultaneously for multiple species at risk. Figure 5.24 shows the percentage of total NPV saved as a result of planning a reserve network for all eight species simultaneously. The advantage of simultaneous multiple species planning – observed as reduced habitat protection costs – is considerable, especially when larger habitat patches are desired. The cost-savings reach a maximum at 13% of total NPV ($216 million) with and without habitat patch size requirements. At lower habitat protection levels there is little to no benefit of multiple species management when larger habitat patches are not required; however, when larger habitat patches are required, there are large cost-savings as a result of simultaneous species planning (as much as 7.9% of total NPV valued at $131 million).

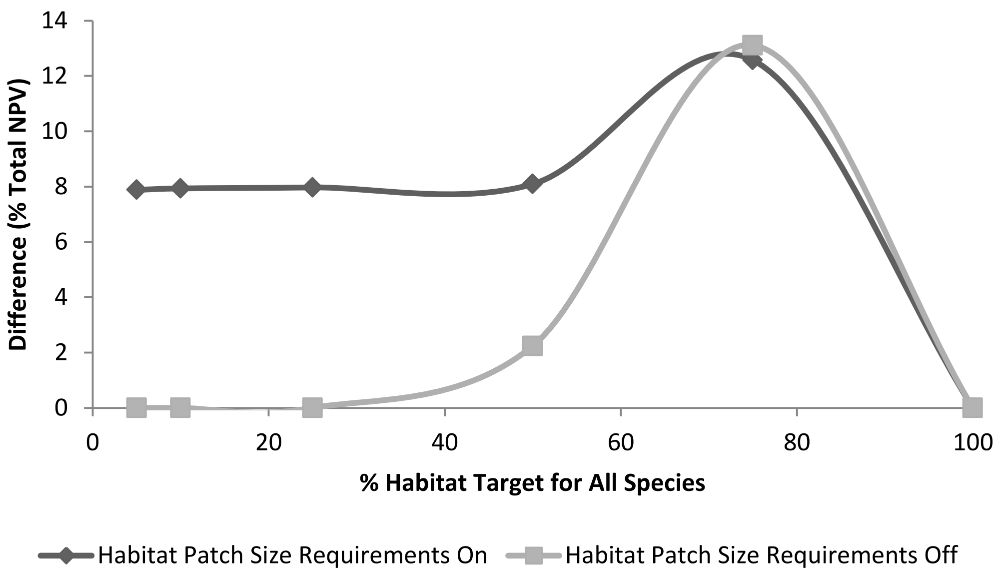

Figure 5.24. The percentage of the Marxan with Zones model's total net present valued saved as a result of managing all eight species simultaneously within a single reserve network rather than managing all eight species individually and later combining them into one reserve network. Costs savings were calculated both when habitat patch size requirements were turned on and off in the model.

Figure 5.25 is used to address the question of whether or not simultaneous species planning can offset some of the costs of larger habitat patch sizes. Figure 5.25 shows the difference in total costs resulting from different management scenarios using the basecase of individual species planning under no habitat patch size requirements. Simultaneous species planning in the absence of habitat patch size requirements does not reduce costs until at least 50% of the region is protected. However, adding habitat patch size requirements to the individual species planning scenario increases costs by 14% (habitat levels 5 – 25%), 8% (50% habitat protection), and 0% of total NPV (habitat levels 75% - 100%). At 75% habitat protection, larger patch sizes cost no additional money because a very large proportion of quarter sections have already been selected in a manner that creates large patches. When simultaneous planning of species is paired with patch size requirements, the additional costs of the larger patches is reduced by as much as 8% of total NPV and even results in a net cost-saving of 12% of total NPV when habitat protection levels reach 50% and above. If larger patches are desired, managing species simultaneously may allow them to be achieved at a much lower cost.

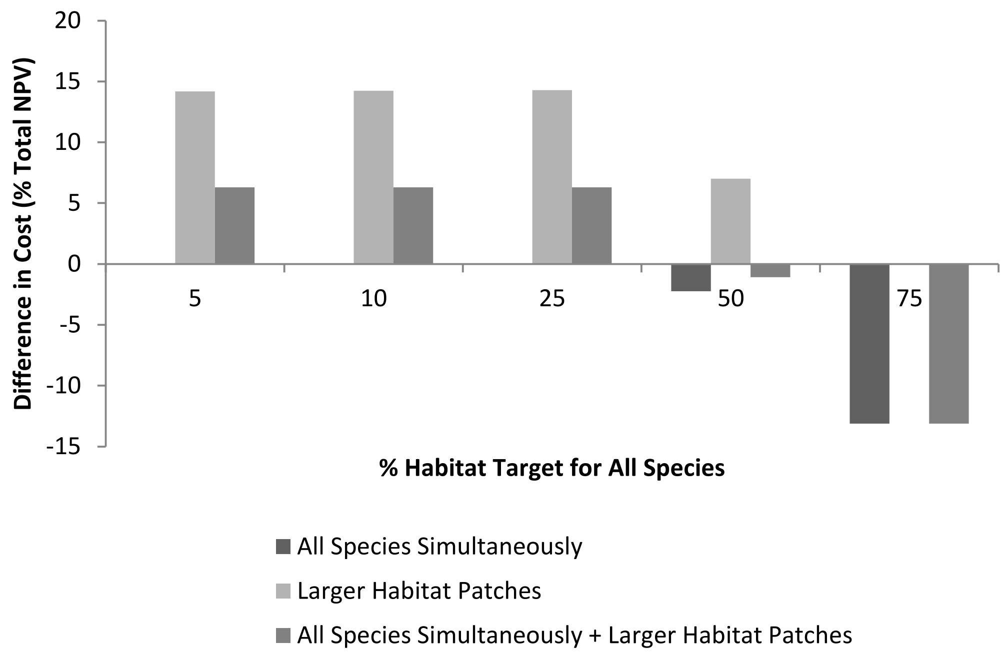

Figure 5.25**. The difference in costs (% of Total NPV) in the Marxan with Zones model when different management scenarios are implemented compared to the basecase of running individual species optimization models with no habitat patch size requirements.**

5.3.5.4 The Allocation of Conservation Activities

The allocation of different conservation activities on the South of the Divide region is an interesting piece of information that the Marxan with Zones optimization model is able to provide. The following graphs (Figure 5.26 and Figure 5.27) show the allocation of conservation activities under the presence and absence of habitat patch size requirements within the optimization model when all species are managed simultaneously.

In the absence of habitat size constraints, the conservation activities applied to the landscape at the 3 lowest levels of habitat protection (5, 10 and 25%) require little additional management or costs (current protected areas and areas currently managed as native grasslands provide sufficient habitat), and a large proportion of the area is left as “unprotected” (Figure 5.26). The only management activities required might be conversion to native grasslands or stocking rate changes on small areas. The higher levels of habitat protection result in the addition of other management activities including “new protected areas” where land is taken out of oil, gas and agricultural production and converted back to native grasslands; “community pasture reserves” where community pastures are managed in the absence of oil and gas development; "conservation easements" where land owners enter into a contractual agreement regarding the management of their land; and "buffer strips" where hay and crop land have standing vegetation strips left as habitat for species at risk. At the highest levels of protection, the effective habitat contribution levels (the proportion each acre in a specific conservation activity contributes to effective habitat protection) of different management activities begin to have a large impact on the activities chosen; however, it seems that stocking rate changes and land conversions are preferred over conservation easements despite their contribution levels being equal at 0.75. At 100% habitat protection only activities like the community pasture reserves and new protected areas that provide 100% contribution to a reserve network are chosen.

Figure 5.26 is particularly interesting if habitat protection targets can be assumed to correlate with the probability of species persistence. As the risk of losing species decreases (or, habitat protection increases), land moves from being unprotected to being protected in less restrictive conservation activities and then finally to being protected in very restrictive conservation activities. Figure 5.26 along with maps of the spatial allocation of conservation activities on the landscape could provide information on the allocation of conservation resources that would improve the probability of species' survival.

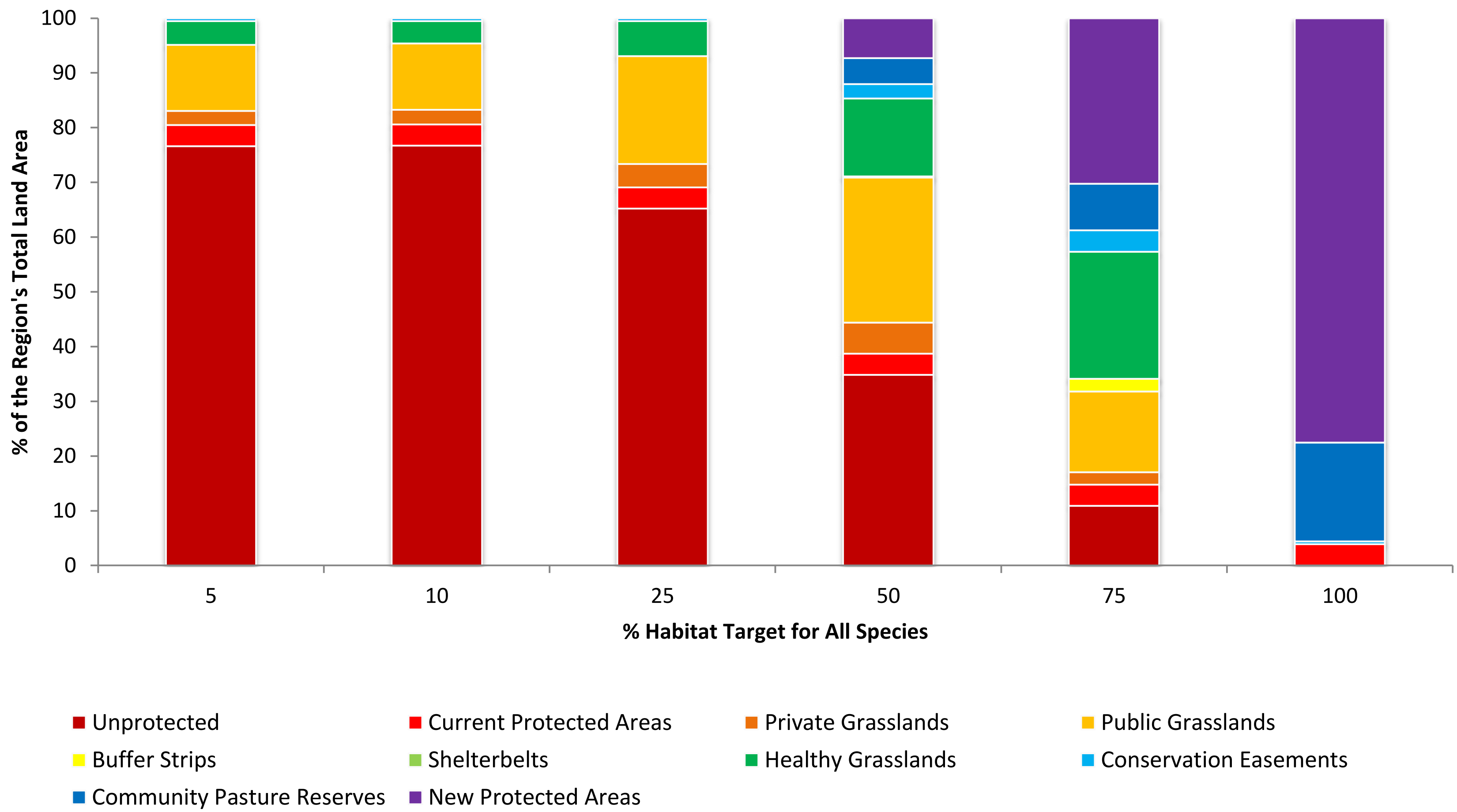

Figure 5.26. The percentage of the study region made up of each conservation activity within the Marxan with Zones model when all species are simultaneously included in a single reserve network with no habitat patch size requirements.

In the presence of habitat size requirements, very little land remains in the unprotected category and most areas are included in a low-cost conservation activity (Figure 5.27). Even at the lowest levels of habitat protection, all nine conservation activities are applied to the landscape in some capacity. The conservation activities with the lowest costs and contribution levels (current grasslands, buffer strips, shelterbelts, and stocking rate changes) dominate the landscape at the 5, 10, 25 and 50% habitat protection targets. Similar to Figure 5.26 above, stocking rate management changes seem to be preferred to conservation easements, and once habitat levels reach 75% and above, more expensive conservation activities with higher contribution levels are selected in order to effectively cover a greater proportion of the study area.

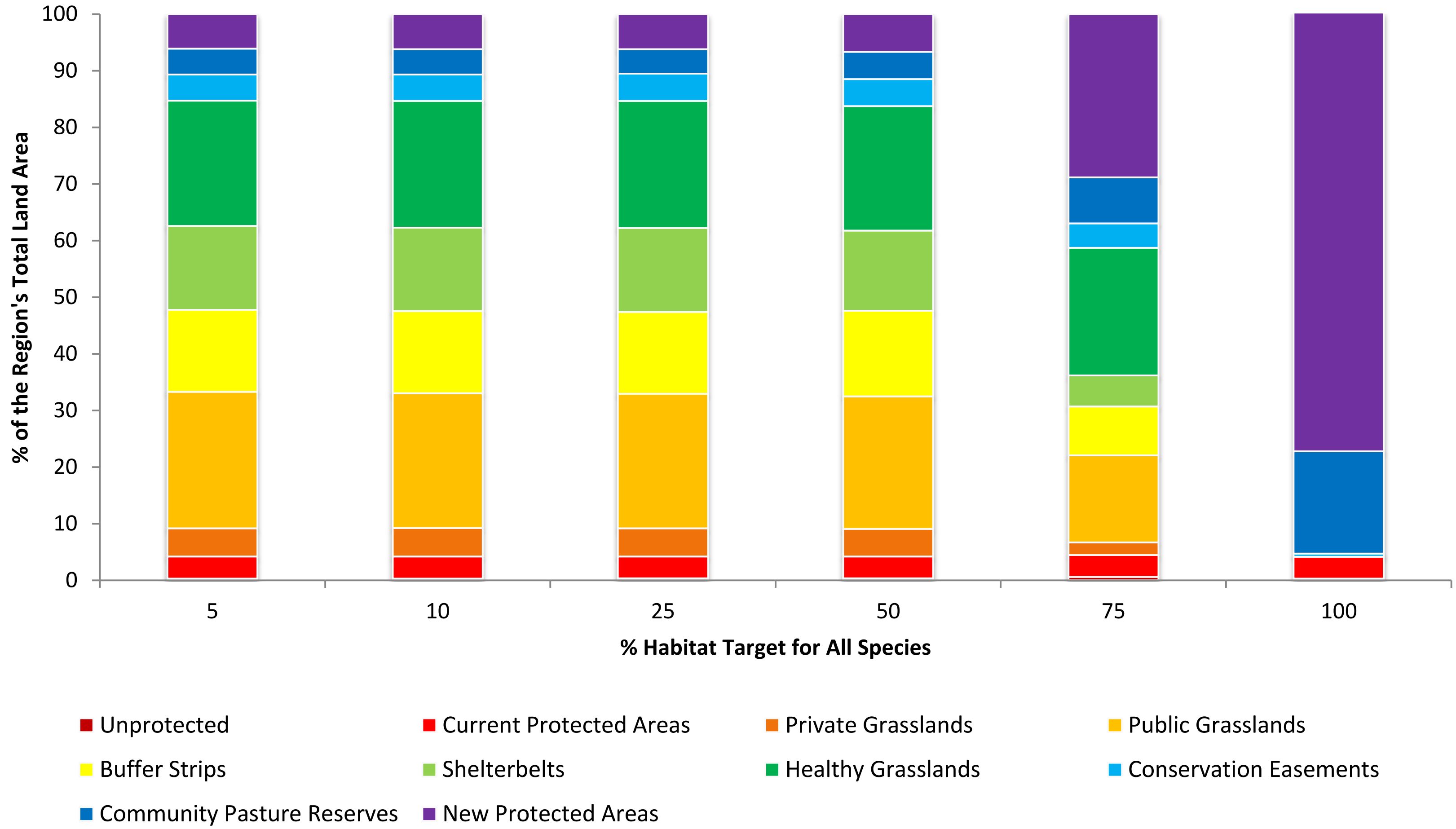

Figure 5.27. The percentage of the study region made up of each conservation activity within the Marxan with Zones model when all species are simultaneously included in a single reserve network with habitat patch size requirements turned on.

5.3.5.4.1 The Spatial Allocation of Conservation Activities

The spatial allocation of conservation activities for the best solution runs at the 25 and 75% habitat protection targets are shown below. The models were run for all species simultaneously under both the presence and absence of habitat patch size requirements. The 25% habitat protection level has conservation activity distributions that are representative of the 5 – 25% habitat protection levels under the absence of patch size requirements and of the 5 – 50% habitat protection levels under the presence of patch size requirements. The 75% habitat protection level shows how conservation activities begin to shift to higher cost and higher contributing activities on the landscape. Finally, at 100% habitat protection, all community pastures are managed as community pasture reserves, all leased and privately owned land is managed as new protected areas, and all current protected areas remain protected.

When investigating the distribution of activities at the 25% habitat protection level, Figure 5.28 shows a high proportion of the area (>60%) designated as unprotected when habitat patch size does not matter. There is a scattering of grassland and conservation easement management activities around the study area. Figure 5.29 shows a very low proportion (<1%) of the area in the unprotected zone when larger habitat patches are preferred. Buffer strips and shelterbelts are most common in the central part of the region that is currently dominated by annual cropland. The grasslands of the region are primarily divided up amongst unmanaged public and private grassland designation and healthy grassland management designation; however, smaller proportions of the area were also made into community pasture reserves, new protected areas and conservation easements.

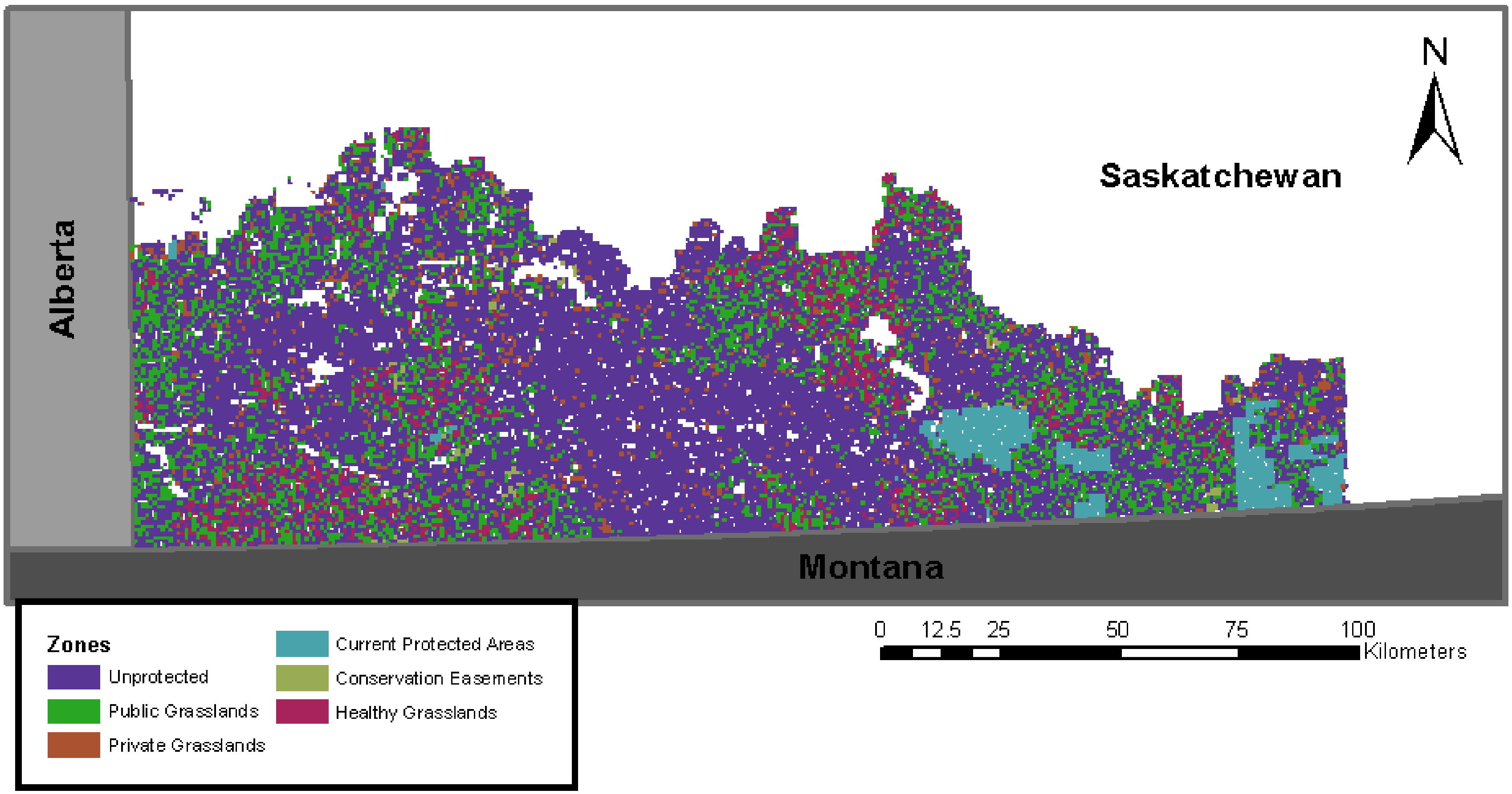

Figure 5.28. The distribution of conservation activities across the South of the Divide region when 25% of habitat is protected for all species simultaneously with no habitat patch size requirements.

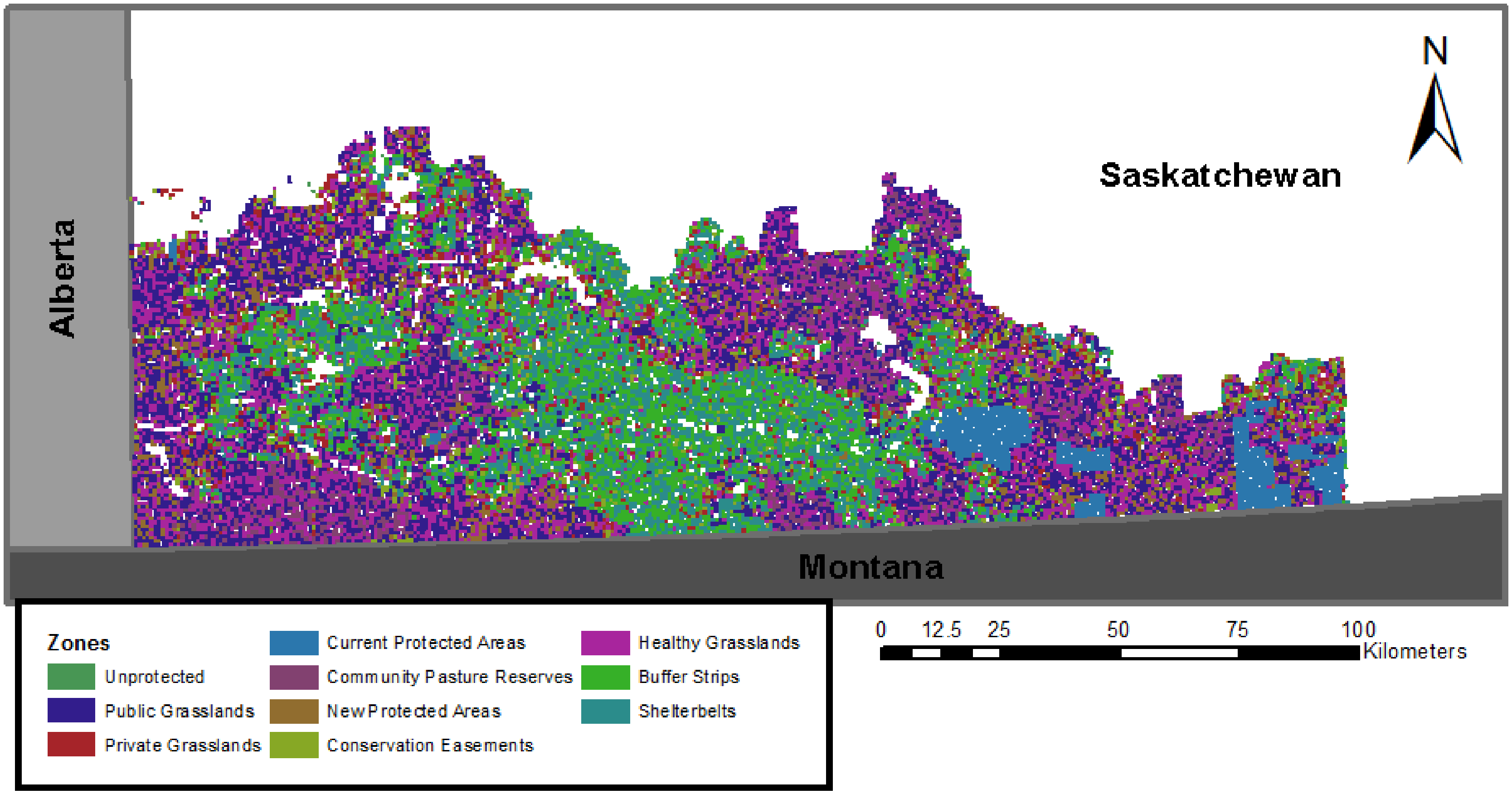

Figure 5.29. The distribution of conservation activities across the South of the Divide region when 25% of habitat is protected for all species simultaneously with habitat patch size requirements turned on.

At the 75% habitat protection level, there is less emphasis on unmanaged native grasslands and a greater emphasis on conservation activities that provide a higher contribution level. Figure 5.30 and Figure 5.31 show a greater proportion of public and private grasslands converted into community pasture reserves and new protected areas, respectively, as compared to the 25% habitat protected level figures above. The current cropland of the region is managed as a mix of buffer strips, shelterbelts, conservation easements and new protected areas. The two maps – with and without habitat patch size requirements – are very similar. This similarity in conservation activity frequency is also visible in Figure 5.26 and Figure 5.27 above that show the allocation (in % of acres) of the study area to different conservation activities. Once at 75% habitat protection, the addition of habitat patch size requirements has little impact on the allocation of conservation activities or on the cost of the reserve network (Figure 5.30 and Figure 5.31).

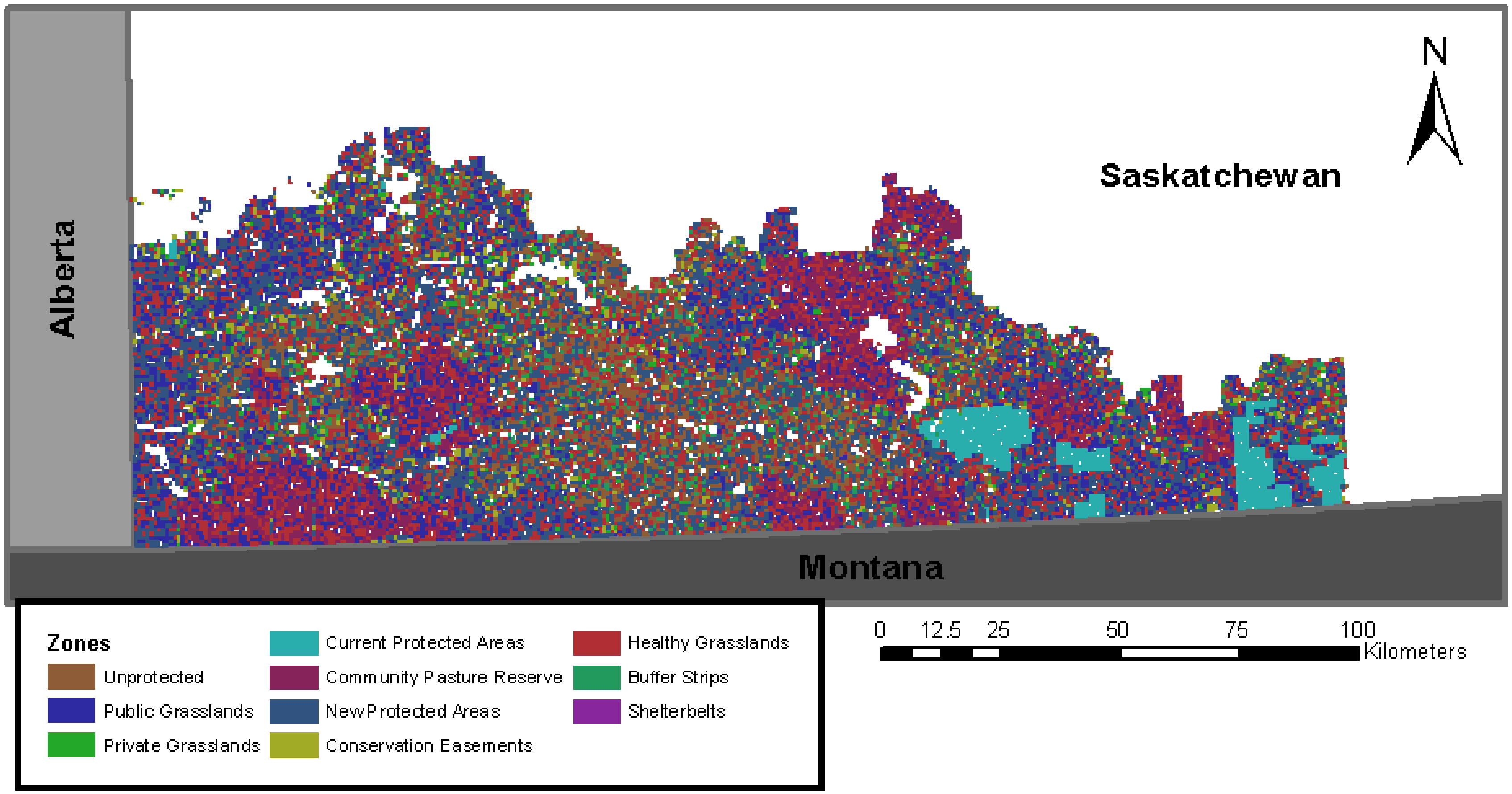

Figure 5.30. The distribution of conservation activities across the South of the Divide region when 75% of habitat is protected for all species simultaneously with no habitat patch size requirements.

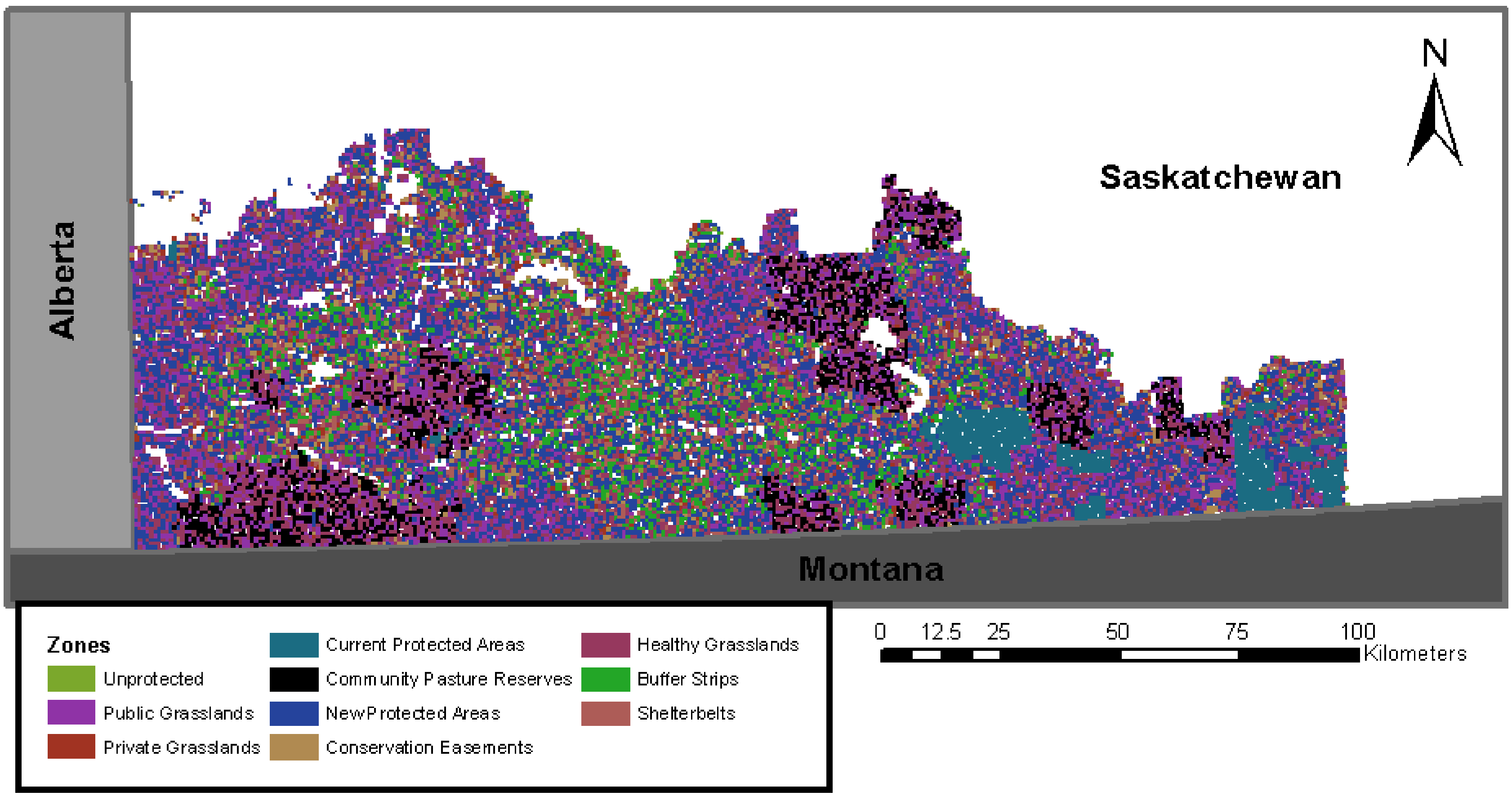

Figure 5.31. The distribution of conservation activities across the South of the Divide region when 75% of habitat is protected for all species simultaneously with habitat patch size requirements turned on.

5.4 Chapter Summary

The cost of species management varies and is dependent upon the conservation activities that will be chosen to implement habitat protection on the landscape (see Table 5.3). If the removal of land from production and conversion of non-native parcels back to grassland is desired (as in model 1), there are large costs for the region as a whole. However, there are large patches of existing native grasslands that could be managed minimally for very little cost, and lower-cost management strategies implemented on privately managed land (under the assumption that publicly managed lands are already managed in a manner conducive to the survival of species at risk) could aid species at risk for a fraction of the cost of removing all land from production.

The models create cost-curves that highlight the economic and ecological trade-offs that must be made at any point along the curve. Comparisons of the cost-effective curves to the cost of critical habitat designation in all four Marxan models suggest that efficiency gains are achievable if costs are included in critical habitat designations (contingent upon assumptions of equivalent habitat quality potential inside and outside the critical habitat polygons). The models also show that there are substantial cost-savings achieved when multiple species at risk are managed simultaneously within one reserve network rather than managing species individually and later merging them into one reserve network in an ad-hoc manner. And while larger habitat patches are costly, some of the costs of spatially clumped habitat can be offset by using simultaneous multi-species planning.

The Marxan with Zones model provides information on how conservation activities are allocated on the landscape at varying levels of habitat protection under the presence and absence of habitat patch size requirements when simultaneous species planning is utilized. When larger habitat patches are desired, it is more desirable to include almost all quarter sections (~99%) in habitat protection even at very low habitat targets (5% - 50%). This is the result of the availability of low cost, low contributing conservation activities within this model. At higher levels of protection, the proportion of the landscape represented by each of the varying conservation activities is similar under both the presence and absence of habitat patch size requirements. This is also shown in the lack of difference in cost between the two reserve networks (simultaneous without contiguity versus simultaneous with contiguity; Figure 5.23 and Figure 5.25 above). Of the lower cost habitat protection alternatives, buffer strips and stocking rate management changes appear to be preferred on the landscape over shelterbelts (which only benefit one species) and conservation easements (Figure 5.26 and Figure 5.27).

6 Conclusion

Within the South of the Divide region (located in southwest Saskatchewan) conservation costs, including foregone oil, gas and agriculture production and the cost of implementing beneficial management practices on the landscape, were calculated and used as inputs in four reserve site selection models that found cost-effective habitat protection designs for eight species at risk within the region. The reserve site selection models minimized conservation costs subject to meeting a range of habitat targets defined as percentages of species' historical ranges. The models not only provided information on the cost of protecting varying habitat protection targets (allowing the creation of habitat protection cost curves) but they also provided information on the spatial designation of habitat protection within the study area. The models were created (a) to develop estimates of cost-effective conservation plans and create habitat protection cost curves, (b) to compare the costs of the cost-effective plans with the costs of the proposed critical habitat polygons, (c) to assess the improvements in efficiency associated with multi-species plans relative to single species plans, and (d) to compare cost-effective plans with habitat patch size requirements to those without any habitat patch size requirements.

6.1 Research Contributions

The reserve site selection models tested several findings and assumptions present within the literature. The model tested the common finding (e.g. Naidoo *et al*. 2006; Naidoo and Ricketts 2006; Carwardine *et al.*2008; Stewart and Possingham 2005 among many others) that including economic and biological information within an optimization model for conservation planning will provide greater efficiencies and greatly reduce costs compared to conservation plans from optimization models that account only for biological information. The model also tested the common belief that multi-species conservation plans offer efficiencies over single species plans (Tear *et al*. 1995; Kirk and Pearce 2009) and ultimately was used to determine the magnitude of those efficiencies. Finally, it is well established in the literature that larger habitat patches are both biologically beneficial and costly (e.g. Klein *et al*. 2008). The reserve site selection models were used to quantify the additional cost of larger habitat patches.

6.1.1 Including Economics within Conservation Planning

The cost curves created by the reserve site selection models provide the cost of an efficient conservation plan at every habitat target. By illustrating the economic trade-offs required at each habitat protection level (i.e. the trade-off between higher habitat protection and the higher costs necessary to obtain it) the cost curve can provide valuable information for decision makers such as whether or not the economic trade-offs required to meet certain biological targets are economically or politically feasible. For example, if the desired biological target is on the flat part of the curve, little to no additional cost is required to increase the target (in this case decision makers may increase the habitat target).

Similar to many conservation plans that fail to incorporate economics within the planning process, proposed critical habitat polygons were designated species-by-species for the species at risk in the South of the Divide region with no explicit consideration of conservation costs. The cost of protecting each species' critical habitat was calculated using the conservation costs outlined in this thesis. These critical habitat costs were then compared to the cost of protecting an equivalent amount of area that was selected using the Marxan reserve site selection models. As is the case in Figure 1.1, critical habitat designations were often substantially more expensive than an equivalent amount of habitat selected from a species' historical range using the optimization model.

In model 1, all quarter sections were completely removed from agricultural production, oil and gas production, and were restored back to native grasslands. Critical habitat designation for Greater-Sage Grouse cost approximately $19 million (1% of NPV) more than an equivalent area of land selected by the model. The critical habitat designations of Sprague's Pipit and Swift Fox cost $401 million (24% of NPV) and $148 million (9% of NPV) more than equivalent levels of habitat selected within the cost-effective conservation plans. The results of models 2 and 3 repeat this trend. It's clear that substantial cost-savings are possible by the creation of efficient, cost-effective conservation plans assuming that land outside the critical habitat polygons can truly provide sufficient and adequate high-quality habitat for the species at risk (potentially a very large and/or erroneous assumption).

6.1.2 Multi-species Conservation Planning

All four reserve site selection models displayed significant cost-savings (i.e. efficiency gains) when multiple species are considered simultaneously within a habitat selection optimization model. When larger habitat patches (i.e. habitat connectivity) are desired, the efficiencies gained by including all species simultaneously is even larger than when there are no habitat patch size requirements. Within model 1 the efficiency gains of multi-species planning reach as high as $132 million (8% of NPV) when there are no habitat patch size requirements, and $192 million (12% of NPV) when habitat patch size requirements are present in the model. Models 2 and 3 have efficiency gains as high as $60 million (10% of NPV) and $23 million (20% of NPV) in the absence of habitat patch size requirements while the efficiency gains are as high as $87 million (16% of NPV) and $29 million (24% of NPV) when habitat patch size requirements are present. Within the Marxan with Zones model, maximum efficiency gains are approximately the same under both the presence and absence of habitat patch size requirements and equal $216 million (13% of NPV).

Additional advantages of simultaneous multi-species planning are not explicitly considered in this project. These advantages include the ability to satisfy SARA requirements (recovery strategies and action plans) for multiple species simultaneously, and the ability to streamline conversations and BMP implementation with stakeholders in the watershed.

6.1.3 Larger Habitat Patches within Conservation Planning

Habitat patch size requirements substantially increase the costs of a conservation plan; however, the costs of habitat patch size requirements are reduced when multiple species are simultaneously included within a conservation plan. Within models 1, 2 and 3 the added cost of larger habitat patches is reduced by as much as $132 million (8% of NPV), $64 million (12% of NPV), and $15 million (13% of NPV) when species are managed simultaneously. Within the Marxan with Zones model, larger habitat patches add $232 million (14% of NPV) to a conservation plan that individually manages species at risk, but that added cost is reduced to $100 million (6% of NPV) when species are simultaneously managed. It makes sense that there should be greater benefits when managing multiple species because species' habitat areas can be strategically located to fill in the gaps between other species' protected habitat areas.

6.2 Limitations of the Research

While this study provided a number of interesting findings, there remain limitations to the research. These limitations center on data quality and availability, cost uncertainty, and model simplicity. The biological information used within the reserve site selection models (i.e. species' historical ranges) may limit the ability to achieve species' survival and recovery by applying the results of the models. The conservation activity costs were at times calculated with limited information and it is uncertain how well the calculated costs – both as inputs into the models and outputs of the models – will predict the costs of conservation that will ultimately be realized in the region.[53] Finally, the Marxan models are relatively simplistic.

Using species' historical ranges as the biological information within the reserve site selection models likely oversimplifies the issue of selecting sufficient, suitable habitat that will ensure species' survival and recovery. Historic ranges are a low resolution source of species habitat information. Species are unlikely to use all the quarter sections within their range to the same degree (some quarter sections will have unsuitable habitat and some will have higher quality habitat); however, the Marxan models assume that all quarter sections within a species' range provide an equivalent level of habitat protection and assistance to the survival and recovery of the species.

Cost calculations were completed using the best available data; however, sometimes data availability was limited. Within the oil and gas analysis, reserve information was limited. Reserves were provided at a low resolution (per township or 100 km^2) with no information on individual gas pools or play formations. Cost information and well extraction profiles were borrowed from Alberta studies. Within the stocking rate cost calculations, strong assumptions were made regarding the current stocking rates

[53] The accuracy of the calculated reserve network and critical habitat costs will also depend on the conservation actions that will ultimately be implemented on the landscape. If the activities are very different from the activities included in the models, the models will be unable to provide meaningful insight into conservation costs.

employed in the region within the South of the Divide region. Detailed surveys would be required in order to know what current stocking rates are in the region and where different grassland habitat conditions could be optimally located to achieve the grassland heterogeneity required by several of the species at risk

Costs, while calculated using the best available data and techniques, have assumed that the agriculture and energy sectors operate under the principle of profit maximization. If this is truly the case, conservation cost estimates provided for the region will be fairly accurate. However, if this is not the case, realized costs will likely differ from calculated costs. For example, if landowners are profit maximizers, they would require total compensation of their opportunity costs of conservation actions. However, landowners may receive a personal benefit from habitat conservation and, therefore, voluntarily implement beneficial management practices (BMPs) or provide BMPs at a cost lower than their opportunity costs. This will change the realized costs of conservation in the study area.

Several additional explanations for cost divergences include behavioural complexities, asymmetric information, leakages and substitutions. If market based instruments (e.g. reverse auctions) are used to achieve conservation outcomes, asymmetric information and/or landowner's unfamiliarity with the process can result in a divergence between calculated and realized costs. In the case of grazing management, leakages – where stocking rates are lowered on some parcels of land to meet conservation targets, but increased on other parcels of land to offset cots – may occur which would lower the true cost of the BMP to land managers.[54] The energy sector might reduce its opportunity costs by substituting development in the South of the Divide for development in other regions. Leakages and substitutions would likely cause the NPVs calculated in this region to become an upper bound.

The Marxan models are simple and inherently static in nature. The static nature of the reserve site selection model results in the assumption that all land in the reserve network is protected instantaneously. Realistically parcels of land are slowly

[54] This phenomenon would also change the pattern of both land-use and grassland quality in the region.

incorporated into reserve networks and protected areas. The models also assume that land inside the reserve contributes only to species habitat, land outside the reserve only contributes to economic production, that species persistence is implicit in habitat targets, and that the presence or absence of species is known at each site with certainty. Realistically there are instances where parcels of land can still provide habitat while being economically productive and vice versa. The Marxan with Zones model, unlike the traditional Marxan models, allows areas to provide both economic and biological values by permitting parcels of land to be allocated amongst a number of different conservation zones that provide a mix of economic production and conservation.

There are a number of additional components or considerations that were not included within the Marxan models. These additional considerations include climate change or other systematic changes to the landscape as well as more sophisticated inclusions of economic and biological risk and uncertainty (e.g. cost uncertainty and the uncertainty of species recovery/persistence, respectively). Despite the limitations listed in the paragraphs above, the Marxan modes were still provided valuable information with regard to several interesting questions. The models are best thought of as forecasting tools that can approximate conservation costs and provide information on areas that would provide lower-cost habitat within the South of the Divide study area.

6.3 Future Research

Sensitivity analyses were conducted within this thesis[55]; however, future extensions could provide interesting insights. One interesting sensitivity analysis question could investigate the price at which conservation easements become a more commonly used conservation tool within the Marxan with Zones optimization model. Another analysis could focus on how changing contribution levels in the Marxan with Zones models

[55] For example, the oil and gas expected net present values were calculated over a range of reserve scenarios (low, mid and high) and the grazing management costs were calculated over different assumptions of grazing management practices (light, moderate and heavy). The three Marxan models provided a range of conservation cost estimates (high conservation, mid conservation and low conservation).

changes the costs of habitat protection, the selection of conservation activities, and the spatial design of habitat protection.

A dynamic conservation framework could be designed for the South of the Divide region. By modeling a sequence of conservation investment decisions through time, a more real-world model is created (Naidoo *et al*. 2006). This model can address the fact that conservation opportunities do not occur simultaneously (as the Marxan models assume they do) and conservation investments must be prioritized through time (Naidoo *et al*. 2006). This model could even be extended to account for dynamics in conservation costs.

The next step for the South of the Divide Action Plan will be determining which conservation activities to implement on the landscape and how to go about doing so. Voluntary stewardship is often preferred by the both the federal and provincial governments, but there will likely be a requirement for additional action in the region due to the large amount of critical habitat proposed on privately owned land. Regulations are unlikely to be used by the provincial government on private land and the federal government has no jurisdiction under SARA to apply regulations on private land (except in the special cases of migratory birds and aquatic species at risk). Market based instruments (subsidies, reverse auctions, payments for ecosystem services etc.), however, would have the power to be effective in the region due to the heterogeneity in conservation costs. These instruments can be used to efficiently achieve habitat targets by selecting habitat areas that have a low marginal cost of habitat protection. The use of market based instruments would achieve habitat targets at a lower cost than complete removal of economic (oil, gas and agriculture) production. The difficulty lies in determining which instruments to use and how to implement them.

In the future, a melding of biological resource selection or habitat suitability models with economic conservation area design models has the potential to be a valuable tool for the allocation of critical habitat under SARA. Biological models could be used to predict the probability of a species using each land type and that land type could then be weighted within a reserve site selection model. For example, each land use type would have its own probability of species occurrence (or equivalently a habitat quality weight) multiplied by its area so that it is weighted by the quality of habitat it provides.

Within the reserve site selection model, habitat areas that biologists feel are vital for a species could be locked in and all other parcels of land would be selected based on their quality of habitat provision and cost. If costs are properly included within the model, the model's output will provide information on the trade-offs required at each habitat target and decision making can be based on comprehensive information. As a result, any action plan designed using these methods would be effective, least-cost, and feasible.

Recent advances in the theory of systematic conservation planning has resulted in the increased prevalence of cost considerations and dynamics in the decision of where, when and how much resources should be invested in conservation (Wilson *et al.*2007). However, there is still work to be done in the field of systematic conservation planning, but the field is growing in popularity and new extensions of old questions have begun to emerge. It is hoped that the insights provided in this thesis regarding conservation planning efficiency, multiple species planning and habitat patch size requirements will help to further the systematic conservation planning discussion.

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7.1 Personal Communications

Gord Larson. 2011. Personal communication with Gord Larson, Director of Policy and Liason, Saskatchewan Assessment Management Agency, Regina, Saskatchewan.

Jessica Williams. 2011. Personal communication with Jessica Williams, Resource Agrologist, Saskatchewan Ministry of Agriculture, Lands Branch, Swift Current Saskatchewan.

Patrick J. Fargey. 2011. Personal communication with Patrick J. Fargey, Species at Risk Biologist, Parks Canada Agency, Grasslands National Park.

Randy Currence. 2011. Personal communication with Randy Currence, Board Member on the Scottsguard Grazing Cooperative located within the South of the Divide region.

South of the Divide Steering Committee. 2011. South of the Divide Steering Committee Meeting. Regina November 16th, 2011.

Stephen Davis. 2011. Personal communication with Stephen K. Davis, Wildlife Biologist, Canadian Wildlife Service Prairie and Northern Division, Regina Saskatchewan. Head of the critical habitat task group for the South of the Divide Action Plan.

Tara Davidson. 2011. Personal communication with Tara Davidson, Range Management Specialist, Agriculture and Agri-Food Canada, Swift Current Saskatchewan.

Trevor Lennox. 2011. Personal communication with Trevor Lennox, Regional Forage Specialist Saskatchewan Ministry of Agriculture, Swift Current Saskatchewan

A Appendix: The Species of the South of the Divide

A.1 The List of Species

The species at risk whose ranges overlap with, or are contained within, the South of the Divide are listed in Table A.1.

Table A.1. The species at risk whose historic ranges are located within the South of the Divide region.

	Species	Scientific Name	Taxon	Status
1	Alkali winged-nerve moss	*Pterygoneurum kozlovii*	Mosses	Schedule 1 – Threatened
2	Black-footed Ferret**	*Mustela nigripes*	Mammals	Schedule 1 – Extirpated
3	Black-tailed Prairie Dog	*Cynomys ludovicianus*	Mammals	Schedule 1 – Threatened
4	Burrowing Owl**	*Athene cunicularia*	Birds	Schedule 1 – Endangered
5	Common Nighthawk	*Chordeiles minor*	Birds	Schedule 1 – Threatened
6	Eastern Yellow-bellied Racer**	*Coluber constrictor flaviventris*	Reptiles	Schedule 1 – Threatened
7	Ferruginous Hawk	*Buteo regalis*	Birds	Schedule 1 – Threatened
8	Great Plains Toad	*Anaxyrus cognatus*	Reptiles	Schedule 1 – Special Concern
9	Greater Prairie Chicken*	*Tympanuchus cupido*	Birds	Schedule 1 – Extirpated**
10	Greater Sage Grouse**	*Centrocercus urophasianus urophasianus*	Birds	Schedule 1 – Endangered
11	Greater Short-horned Lizard	*Phrynosoma hernandesi*	Reptiles	Schedule 1 – Endangered
12	Grizzly Bear*	*Ursus arctos*	Mammals	Schedule 1 – Extirpated**
13	Loggerhead Shrike**	*Lanius ludovicianus excubitorides*	Birds	Schedule 1 – Threatened
14	Long-billed Curlew	*Numenius americanus*	Birds	Schedule 1 – Special Concern
15	McCown's Longspur	*Calcarius mccownii*	Birds	Schedule 1 – Special Concern
16	Monarch	*Danaus plexippus*	Arthropods	Schedule 1 – Special Concern
17	Mormon Metalmark	*Apodemia mormo*	Arthropods	Schedule 1 – Threatened
18	Mountain Plover**	*Charadrius montanus*	Birds	Schedule 1 – Endangered
19	Northern Leopard Frog	*Lithobates pipiens*	Reptiles	Schedule 1 – Special Concern
20	Peregrine Falcon	*Falco peregrinus anatum*	Birds	Schedule 1 – Threatened
21	Plains Bison*	*Bison bison bison*	Mammals	No Schedule** – No Status*
22	Sage Thrasher	*Oreoscoptes montanus*	Birds	Schedule 1 – Endangered
23	Short-eared Owl	*Asio flammeus*	Birds	Schedule 3 – Special Concern
24	Sprague's Pipit**	*Anthus spragueii*	Birds	Schedule 1 – Threatened
25	Swift Fox**	*Vulpes velox*	Mammals	Schedule 1 – Endangered*

* These species will not be included within the overall South of the Divide Action Plan
**These species will be explicitly included within the economic analysis portion of the action plan

A.2 Species Habitat Requirements

Habitat, threat, and beneficial agricultural practices information are based on compilations of literature reviews and species expert opinion (Environment Canada 2011c). However, despite the very best information being used to create these descriptions and recommendations, Environment Canada (2011) acknowledges that there are always information gaps in the knowledge of species at risk and, thus, recommendations may be changed or updated as additional information is acquired.

The majority (4 out of 5) of the birds included within the South of the Divide Action Plan's economic analysis – Loggerhead Shrike, Sprague's Pipit, Mountain Plover and Burrowing Owls – are summer residents of the Canadian prairies. Year round residents that make their overwintering homes in burrows include Swift Fox, Black-footed Ferrets and Eastern Yellow-bellied racers. Greater Sage-Grouse are year round residents that overwinter in sagebrush flats (Table A.2). Loggerhead Shrikes are the only species at risk of the eight that benefits from the presence of woody vegetation. The species uses thorny shrubs and trees for nesting (Environment Canada 2011c). Black-footed Ferrets are specialist predators on Black-tailed Prairie Dogs and are, therefore, found only in association with thriving prairie dog colonies (Tuckwell and Everest 2009). Burrowing Owls and Mountain Plovers are also found in close association with prairie dog colonies. Burrowing Owls make use of prairie dog colonies for their nests and burrows; however, they prefer a mosaic of short grass – located in the colonies – and longer grass for nesting and foraging (Environment Canada 2011c). Mountain Plovers prefer prairie dog colonies because they require heavily grazed areas with very short grass and even bare ground. Cultivated fields will sometimes be used by the birds, but breeding pairs using these areas are often unsuccessful and fields are likely a population sink (Environment Canada 2006). Sprague's Pipit, Swift Fox and Greater Sage-Grouse all require large areas of contiguous native grasslands with mosaics of vegetation communities and heights (Environment Canada 2011c; Lungle and Pruss 2008). Greater Sage-Grouse require sagebrush-grassland complexes, and so too does the Eastern Yellow-bellied Racer (Parks Canada Agency 2010).

Table A.2.Habitat descriptions for the eight species included within the opportunity cost model and reserve network design.

Species	Habitat Descriptions
Sprague's Pipit (SPPI)	Summer resident (April through September) that prefers open, upland grassland relatively void of trees and dense shrubs. They prefer native vegetation (10 to 30 cm high) and areas with moderate amounts of litter, residual vegetation and minimal amounts of bare ground. They avoid habitats fragmented by roads, shelterbelts, pipelines and other sites supporting taller vegetation (Environment Canada 2011c)
Swift Fox (SWFOX)	A year-round prairie resident that prefers open grassland where they have a long, unimpeded line of sight and good mobility (Environment Canada 2011c).
Burrowing Owl (BUOW)	A summer resident (April through September) that prefers large areas of open, native prairie relatively void of trees and dense shrubs. Nesting and foraging habitats ideally combine areas of short, sparse grasses within a mosaic of taller, denser vegetation. Relies on burrowing mammals for their burrows (Environment Canada 2011c).
Loggerhead Shrike (LOSH)	A summer resident (April through September) that prefers open areas such as native or tame pasture for feeding with nearby thorny shrubs or trees for nesting. They are also found in farmyards, golf courses, cemeteries and other sites containing shelter belts (Environment Canada 2011c).
Black-footed Ferret (BFF)	A year-round prairie resident that inhabits short grass prairies that closely coincides with the colonies of the black-tailed prairie dogs on which it preys. The ferrets also use the prairie dog burrows for shelter and to raise their young (Tuckwell and Everest 2009).
Greater Sage-Grouse (GRSG)	A year-round prairie resident that is closely associated with silver sagebrush habitat for breading, nesting, brood-rearing, and overwintering. Sage Grouse also require native grasslands adjacent to sagebrush habitat. Lekking grounds are often found on adjacent flat, open grassland areas. Sage Grouse feed on sagebrush leaves and buds and insects (Lungle and Pruss 2008).
Mountain Plover (MOPL)	A summer resident (April through September) that inhabits flat areas with short vegetation (<10 cm high) and bare ground. Prefer heavily grazed native grasslands; however, cultivated fields can also be used for nesting (Environment Canada 2006).
Eastern Yellow-bellied Racer (EYBR)	A year-round resident that inhabits native grasslands and sagebrush thickets during the summer. During the winters, holes or burrows dug by other animals provide hibernacula. They are known to hibernate alongside rattlesnakes (Parks Canada Agency 2010).

A.3 Threats to Species Habitats

The primary threats to species at risk within Saskatchewan's Milk River Watershed are habitat loss, habitat fragmentation or habitat degradation (Kirk and Pearce 2009; Kerr and Cihlar 2004; Kerr and Deguise 2004). Habitat conversion and fragmentation are often caused by the same activities. The activities that cause habitat loss and fragmentation include agriculture (cropland conversion), road construction, oil and gas development, and residential, commercial or recreational developments. All eight species suffer from loss of habitat, and those species requiring large areas of contiguous grasslands – Swift Fox, Sprague's Pipit and Greater Sage-Grouse – all suffer from habitat fragmentation. Habitat degradation often results from poor management of the land, or disturbance from the activities that fragment the landscape (Kirk and Pearce 2009). For example, disturbance from oil and gas extraction, recreational activities, edge effects along linear features, planting non-native species (including trees) and poor management of livestock grazing all degrade species' habitats (Kirk and Pearce 2009). Habitat degradation affects all species in the study region, but to a lesser extent Burrowing Owls, Black-footed Ferrets and Swift Fox (Kirk and Pearce 2009).

Other threats include environmental stochasticity, invasive species, altered hydrologic patterns, increased predation, direct human-caused mortality and threats in over-wintering ranges (Kirk and Pearce 2009). Environmental stochasticity includes threats such as climate change, drought, floods, severe winters, inbreeding depression (due to small population sizes), disease etc. Exotic or invasive species include the introduction of non-native disease as well as the introduction of species that can out-compete native species. For example, Black-footed Ferret populations are small due to their recent re-introduction to Grasslands National Park. Thus, their population is highly susceptible to sylvatic plague (Tuckwell and Everest 2009). Sprague's Pipit avoid grasslands planted to agronomic and invasive species such as Alfalfa and Crested Wheat Grass (Stephen Davis pers. comm.). Altered hydrologic patterns result from cattle management (the creation of dugouts and other water impoundments) as well as issues associated with roads and other linear features on the landscape (Kirk and Pearce 2009). Increased predation often results from a combination of increased linear features and increased number of predators in altered landscapes (e.g. red foxes and coyotes). Human caused mortality can be caused by a number of things including motor vehicles, agricultural equipment, hunting/collecting, environmental toxins, oil/gas pipelines, utilities (including wind turbines) (Kirk and Pearce 2009). Threats in the wintering range are an issue for migratory species and can include a large number of more specific threats. Table A.3 contains detailed threat information for each species. Threats are listed from highest to lowest concern within the table.

Climate change is a threat that requires a more detailed discussion. Thorpe (2010) created a set of models to predict temperature, precipitation, and vegetation production patterns for the South of the Divide region under varying scenarios. There are five overall future trends that are probable for vegetation in the region (Thorpe 2010). The first is that there will be a gradual reduction in trees and tall shrubs at higher elevations (most applicable to the Cypress Hills in the northwest corner of the study area). Second, grassland structure will change with a movement from mid-height grasses to short grasses. Third, there will be a shift from cool-season grasses (C3 photosynthetic pathway) to warm-season grasses (C4 synthetic pathway). Fourth, there will be an increase in sagebrush steppe (which will benefit Greater Sage-Grouse), and finally, there will be a gradual introduction of plant species currently found only/primarily in the United States (e.g. Buffalograss – *Buchloe dactyloides,* and Big Sagebrush – *Artemisia tridentata*). With the change in vegetation there will come an associated change in animal species. Likely there will be a decrease in species dependent on woody cover, and an increase in species currently found further south in the United States (Thorpe 2010). Since the eight species under consideration are located on the northern edge of their range, and often have larger population in the United States, it is clear that they can survive in a warmer, drier habitat akin to that already located within the United States. As such, climate change is not believed to be a large threat to the habitat quality of these species (Pat Fargey pers. comm; Stephen Davis pers. comm). However, possible increases in the number of extreme weather events could have the potential to impact species' in the region.

Table A.3. A list of threats to species survival or recovery (listed from most severe, prevalent or probable to least severe, prevalent or probable) for all eight species included within the South of the Divide Action Plan's economic analysis.

Species	Threats
Sprague's Pipit (SPPI) (Environment Canada 2008)	1) Habitat Loss (loss of native grasslands) a. Cultivation, non-native pastures and hay fields, linear developments, resource extraction, and poor grazing management 2) Habitat fragmentation (fragmentation of native grasslands) a. Cultivation, non-native pastures and hay fields, linear developments, and resource extraction 3) Habitat Degradation (degradation of native grasslands) a. Poor grazing management, and introduction of invasive species from roadways, lease sites or adjacent croplands and non-native grasslands 4) Direct mortality from vehicles and haying equipment 5) Nest predation/parasitism 6) Pollution a. Pesticides, herbicides and industrial pollution 7) Climate change (?)
Swift Fox (SWFOX) (Pruss *et al.* 2008)	1) Habitat Loss (loss of native grasslands) a. Cultivation, non-native pastures and hay fields, linear developments, resource extraction, and poor grazing management 2) Habitat Degradation (degradation of native grasslands) a. Cultivation, non-native pastures and hay fields, linear developments, resource extraction, and poor grazing management 3) Habitat fragmentation (fragmentation of native grasslands) a. Cultivation, non-native pastures and hay fields, linear developments, and resource extraction 4) Predation and competitive exclusion by coyotes and red fox 5) Direct mortality from vehicles 6) Indirect mortality due to disease, poisoning, or trapping 7) Climate change (?)
Burrowing Owl (BUOW) (Environment Canada 2010)	1) Habitat loss, degradation and fragmentation a. Cultivation, non-native pastures and hay fields, linear developments, resource extraction, and poor grazing management 2) Decreased availability of prey and starvation a. Wet-dry cycles, inclement weather, grazing intensity, prey peaks, etc. 3) Increased predation by mammalian and avian predators a. Extirpation of wolves, construction of fences, utility poles and outbuilding, the planting of shelterbelts and trees, agricultural development, and fire suppression 4) Direct mortality from vehicles (including burial within burrows by agricultural and industrial machinery) 5) Environmental contaminants (Indirect mortality) a. Pesticides, herbicides 6) Loss of burrows a. Population declines in burrowing mammals such as badgers, black-tailed prairie dogs, Richardson's ground squirrels
Loggerhead Shrike (LOSH) (COSEWIC 2004)	1) Habitat loss a. Land-use conversion 2) Habitat Degradation a. Cattle damage/kill trees used as nests 3) Environmental contaminants a. Pesticides (decrease prey abundance, thin egg shells, bioaccumulation) 4) Direct mortality from vehicles 5) Predation a. Roads and hedgerows 6) Weather a. Storms, cold and wet breeding seasons 7) Climate change (?)

Black-footed Ferret (BFF) (Tuckwell and Everest 2009)	1) Sylvatic Plague a. Direct mortality as well as reduced prey due to black-tailed prairie dog mortality 2) Natural diseases (Distemper, rabies, etc.) 3) Predation a. Susceptibility of newly released ferrets to natural predators b. Shelterbelts and abandoned buildings aid raptor predation 4) Indirect mortality due to rodent poisoning a. Poisoning of their prey: Richardson's ground squirrels and black-tailed prairie dogs 5) Reduced genetic diversity (bottleneck) a. Small reintroduced population 6) Climate change (?)
Greater Sage-Grouse (GRSG) (Lungle and Pruss 2008)	1) Habitat loss (loss of sagebrush-grasslands) a. Cultivation, non-native pastures and hay fields 2) Habitat degradation (degradation of sagebrush-grasslands) a. Poor grazing management, fire suppression 3) Habitat fragmentation (fragmentation of sagebrush-grasslands) a. Linear developments (fences, power lines, roads, etc.), water impoundments, resource extraction 4) Predation a. Increased susceptibility due to habitat fragmentation and increases in edge b. Increases in predators due to farm yards and land use changes 5) Disease a. West Nile Virus 6) Direct mortality factors a. Farm machinery, vehicles, power lines, fences, communication towers, wind turbines 7) Alteration of natural hydrology a. Reducing flood events that maintain sagebrush flats b. Higher stocking rates adjacent to water impoundments 8) Climate change (?)
Mountain Plover (MOPL) (Environment Canada 2006)	1) Grassland Management a. Exotic/invasive taller grass species (Crested wheatgrass) b. Fire suppression c. Lack of grassland heterogeneity 2) Habitat loss a. Cultivation, and planting of non-native pastures and hay fields 3) Loss of keystone species: Prairie Dogs a. Not an issue so much in Canada as it is in the United States 4) Human disturbance a. Linear developments, resource extraction and pesticide use (direct and indirect mortality) b. Direct mortality by vehicles 5) Fluctuation in precipitation 6) Threats in wintering habitat a. Agricultural land use changes, urban development, environmental contaminants, etc.
Eastern Yellow-bellied Racer (EYBR) (Parks Canada Agency 2010)	1) Habitat loss or degradation a. Habitat conversion or fragmentation by agricultural or industrial activities b. Trampling or vandalism of hibernacula 2) Road and farm machinery mortality 3) Small population size 4) Human disturbance of individuals a. Disturbance by recreational and industrial activity 5) Climate change (?)

A.4 Species Critical Habitat

The current (as of October 2011; Stephen Davis pers. comm.[56]) critical habitat designations for all eight species considered in the South of the Divide action plan's economic analysis are presented below:

Legally designated critical habitat for Eastern Yellow-bellied Racer in Canada is currently designated as seven active hibernacula as well as a 500 meter radius around each hibernacula (Figure A.1). The seven hibernacula are located within Grasslands National Park and the AAFC (Agriculture and Agri-Food Canada) Val Marie Community Pasture in southwest Saskatchewan (Parks Canada Agency 2010).

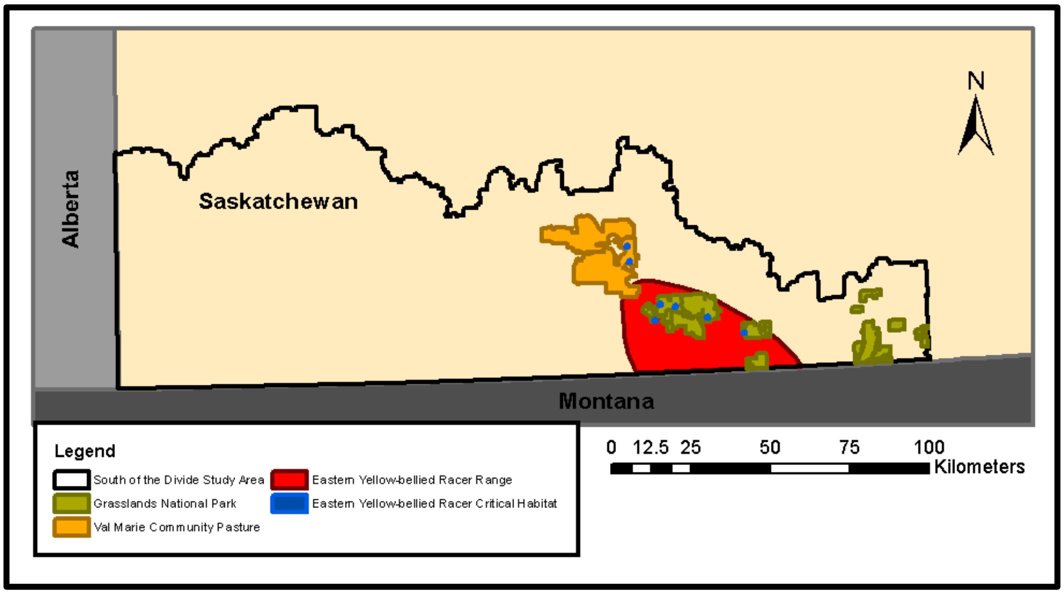

Figure A.1. Critical habitat for Eastern Yellow-bellied Racer in Canada. All of the designated Canadian critical habitat is located within the South of the Divide study region.

Critical habitat for Burrowing Owls (proposed critical habitat) and Black-footed Ferrets (legally designated critical habitat) in Canada is identified within the 2007 mapped boundaries of Black-tailed Prairie Dog colonies (Environment Canada 2010; Tuckwell and Everest 2009; Figure A.2 and Figure A.3). The prairie dog colonies are found within Grasslands National Park, Masefield Community Pasture, and Dixon Community Pasture as well as on private land and lease land that are both part of the proposed boundary of Grasslands National Park (Tuckwell and Everest 2009 The highest known densities of owls in Canada occur within colonies of prairie dogs (COSEWIC 2006) and for the past 5 years the prairie dog colonies have been home to 10 – 15% of the nesting owls in Canada (Environment Canada 2010). Black-footed Ferrets are specialists on Black-tailed Prairie Dogs, and use the prairie dog tunnels for shelter and hunting grounds (Tuckwell and Everest 2009).

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[56] Stephen K. Davis, of the Canadian Wildlife Service's Prairie and Northern Region office in Regina Saskatchewan is the head of the Critical Habitat task group for the South of the Divide Action Plan. All critical habitat polygons (final or proposed) were supplied by Stephen Davis out of the Canadian Wildlife Service office in Regina, SK.

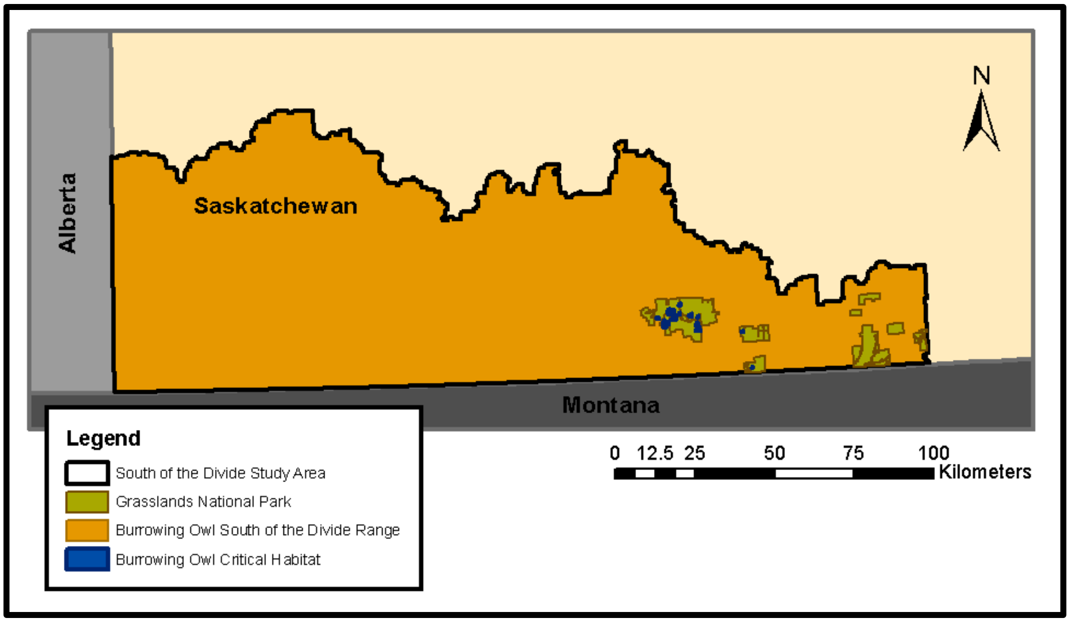

Figure A.2. Proposed critical habitat for Burrowing Owls in Canada. The proposed critical habitat for all of Canada is located within the South of the Divide study region.

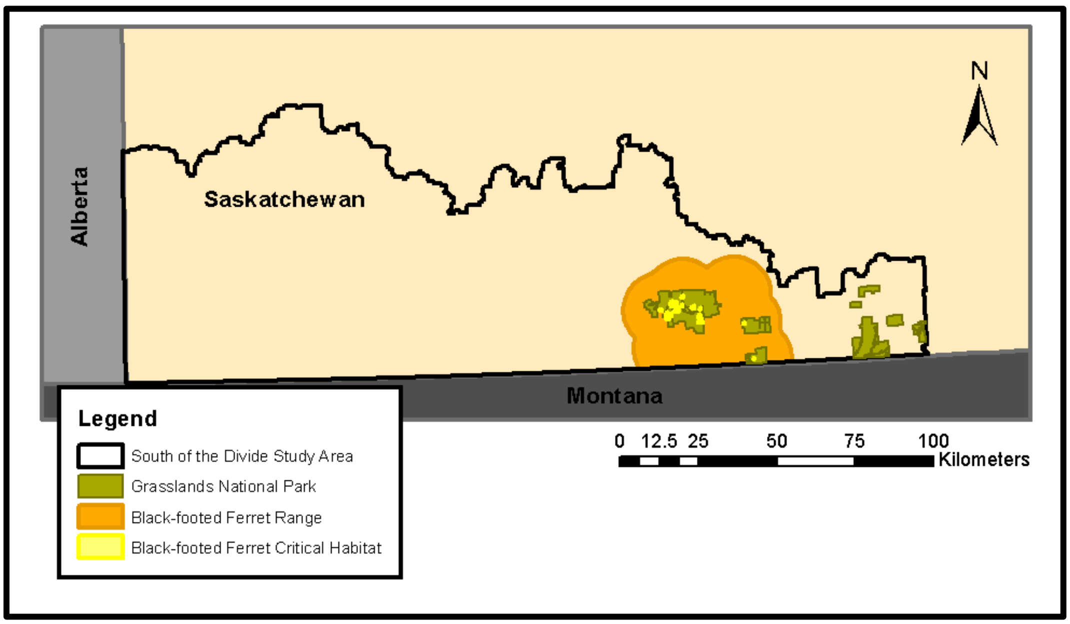

Figure A.3. Critical habitat for Black-footed Ferrets in Canada. All of the designated Canadian habitat is located within the South of the Divide study region.

Mountain Plover critical habitat was not identified in the 2006 recovery strategy (Environment Canada 2006). However, several key areas of interest in Saskatchewan were listed. These include prairie dog colonies within and surrounding Grasslands National Park as well as the very southwest corner of the study area and in the Govenlock AAFC Community pasture along highway 21 (Environment Canada 2006). The proposed critical habitat layer received from the Canadian Wildlife Service in 2011 indicated that proposed critical habitat for the Mountain Plover within Saskatchewan was the same as the critical habitat areas provided for the Black-footed Ferret and the

Burrowing Owl. Once again, this species' proposed critical habitat was defined by the Black-tailed Prairie Dog colonies located within Grasslands National Park (Figure A.4).

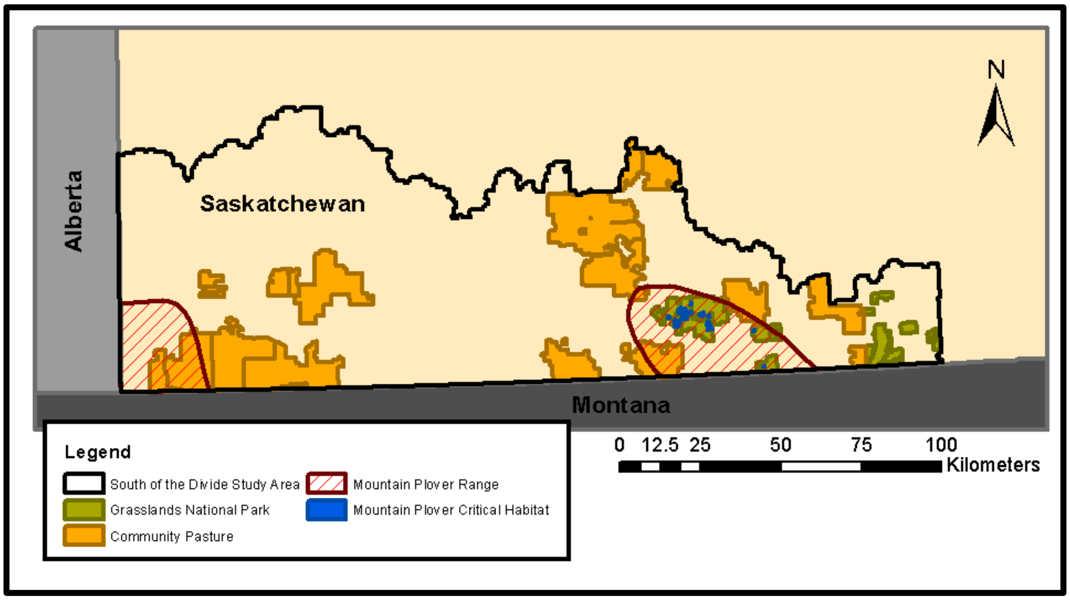

Figure A.4. Proposed critical habitat for Mountain Plovers within Saskatchewan.

As of the 2008 Greater Sage-Grouse recovery strategy, critical habitat was not defined within Saskatchewan or the South of the Divide region (Lungle and Pruss 2008). However, in 2009, partial identification of critical habitat was completed by the Parks Canada Agency.[57] Only active leks were identified as critical habitat which provided the necessary protection for these key areas, but not sufficient protection for the species itself. The newest information provided in 2011 for Saskatchewan has included additional area beyond the leks that would be required for foraging, nesting and raising chicks (Figure A.5).

[57] The amendment to the recovery strategy of Lungle and Pruss 2008 is available at on the Species at Risk Act's public registy.
http://www.sararegistry.gc.ca/virtual_sara/files/plans/rs_sage_grouse_sec_2-6_1009_e1.pdf

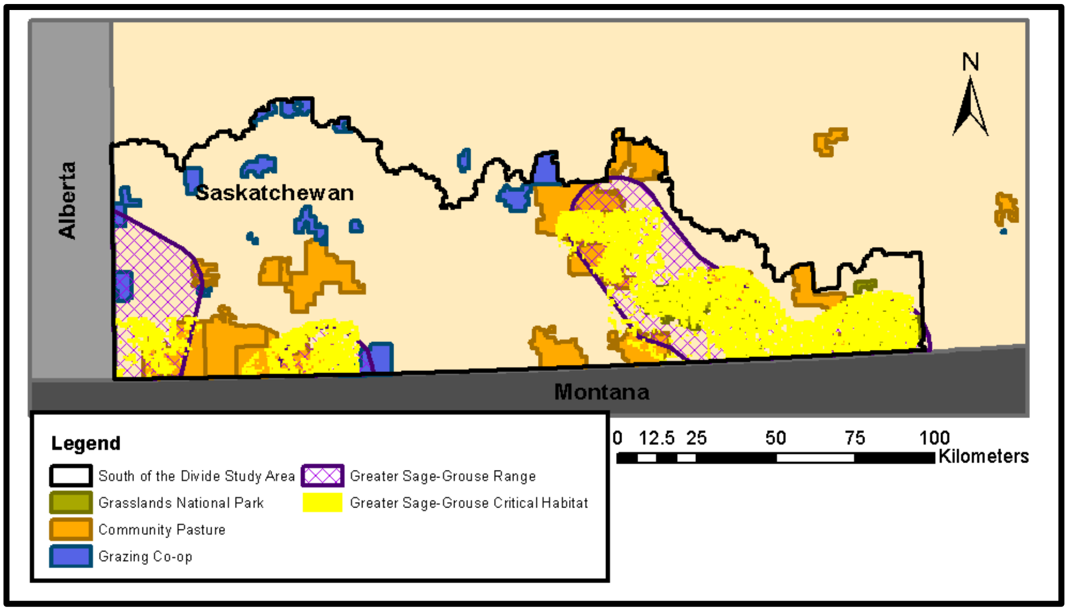

Figure A.5. Proposed critical habitat for Greater Sage-Grouse within Saskatchewan.

Within the original 2008 Swift Fox recovery strategy, critical habitat is not identified (Pruss *et al.* 2008). However, the Canadian Wildlife Service (with the assistance of Parks Canada Agency) provided a proposed critical habitat layer in 2011 for Swift Fox within the South of the Divide region. Habitat covers most of the federal and provincial community pastures in the area as well as Grasslands National Park. A notable portion of the designated critical habitat is also located on provincial lease land and private deeded land (Figure A.6).

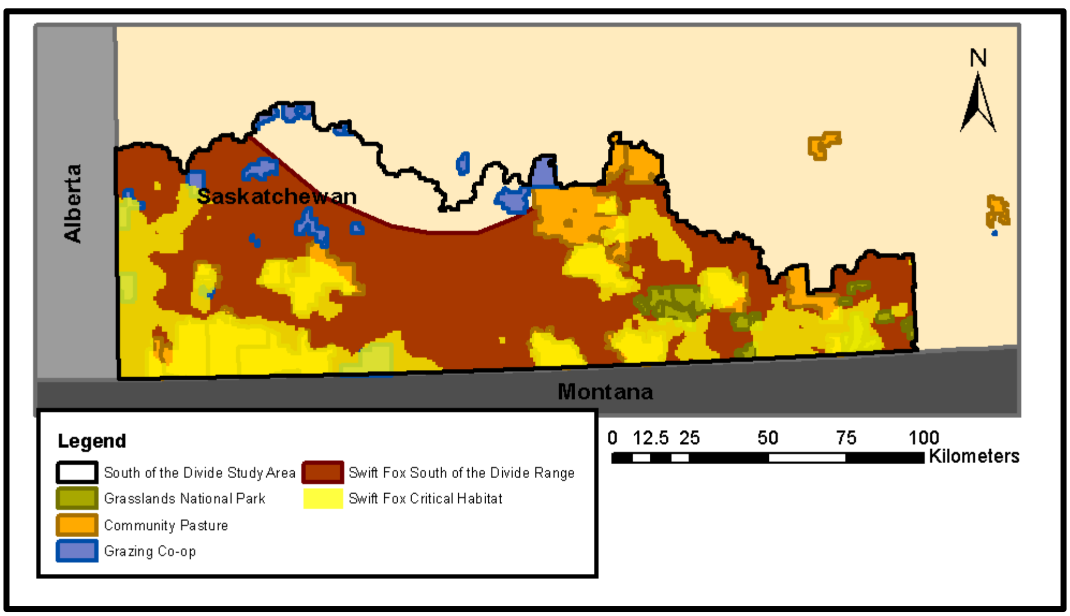

Figure A.6. Proposed critical habitat for Swift Fox within Saskatchewan.

As of October 3rd, 2011 there was no recovery strategy or critical habitat designation on the Species at Risk Act's public registry (www.sararegistry.gc.ca) for Loggerhead Shrike. However, receipt of a proposed critical habitat layer from the Canadian Wildlife Service indicates that proposed critical habitat, for at least the South of the Divide region, has been identified for the species. It appears that coulees with woody vegetation (especially tall shrubs with spines) have been selected as prime foraging and nesting habitat for Loggerhead Shrikes. As such, areas of the Beaver Valley Community Pasture and Grasslands National Park have been designated as proposed critical habitat along with several parcels of privately deeded land and leased provincial crown land (Figure A.7).

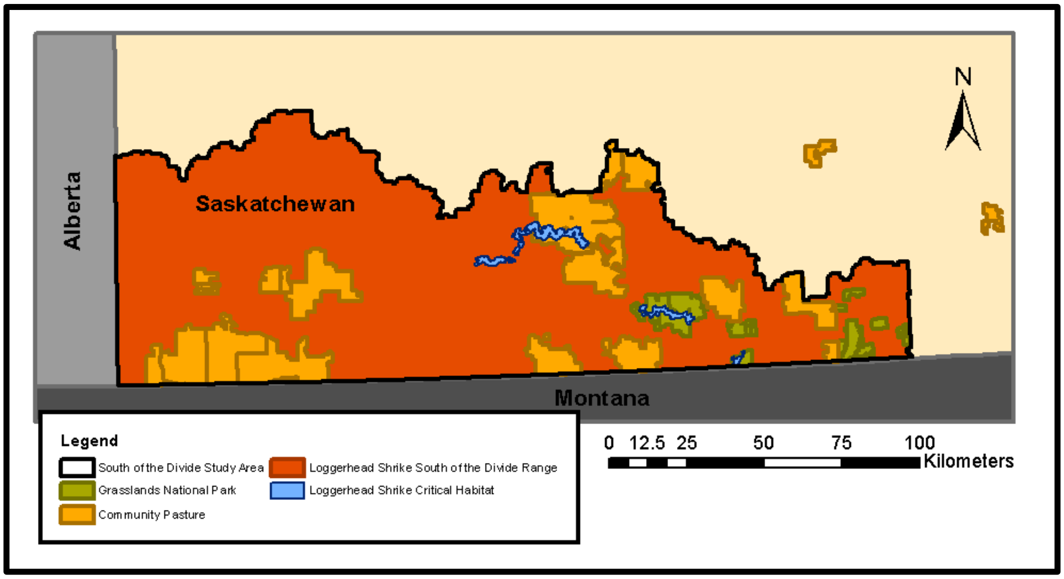

Figure A.7. Proposed critical habitat for Loggerhead Shrike within the South of the Divide.

As of October 3rd, 2011 there is no critical habitat designation for Sprague's Pipit. However, Stephen Davis from the Canadian Wildlife Service provided a proposed critical habitat map for the species. The map is not the final legal critical habitat designation but rather an intermediate step in the process of determining the final critical habitat designation. Habitat for Sprague's Pipit has been designated on most remaining native grasslands within the study area (Figure A.8).

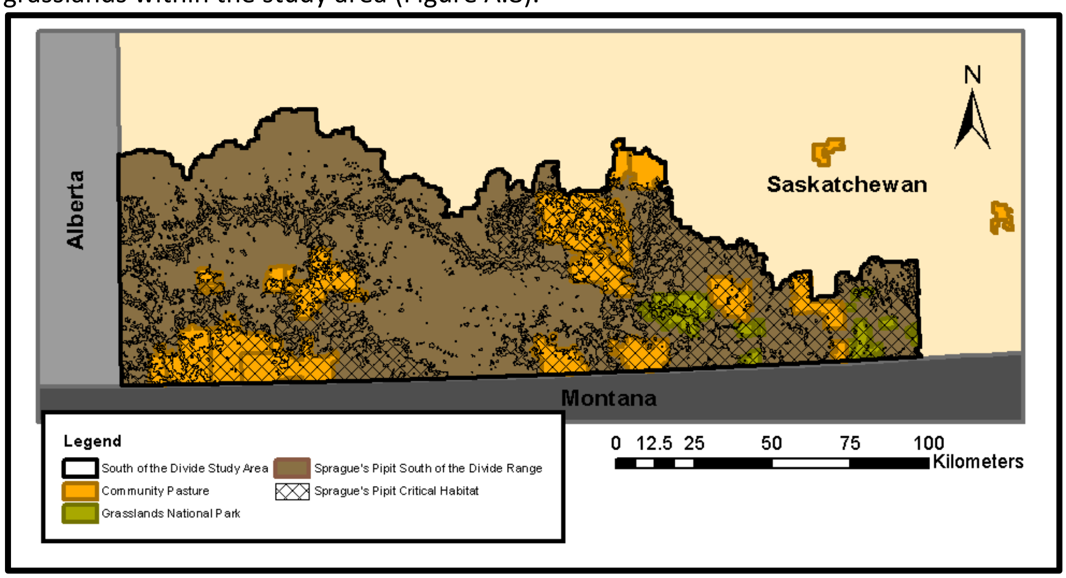

Figure A.8. Proposed critical habitat for Sprague's Pipit within the South of the Divide.

A.5 Beneficial Management Practices (BMPs)

The Environment Canada (2011) publication on beneficial management practices (BMPs) provides recommendations that can reduce or eliminate some of the threats to grassland species at risk. Five of the species at risk considered in this study were included within this publication. Only three – Black-footed Ferret, Mountian Plover, and Eastern Yellow-bellied Racer – were not included within the publication, and agricultural BMPs for these species were created using an integration of the suggestions for the other five species and each species individual recovery strategy documents.

It is possible that land owners and land managers can help promote the recovery of species at risk on their lands by following the BMPs outlined in Table A.4 below. The re-occurring BMPs that benefit most or all of the species at risk in the South of the Divide region were included as conservation activities within the reserve site selection model used to estimate the opportunity costs of habitat protection. The BMPs included are 1) Protecting existing native grasslands, 2) Converting cultivated lands to perennial cover (where native grasslands are preferred to tame pasture or hay fields), 3) Grazing at the recommended stocking rates for each ecosite and ecoregion in order to promote grassland health, 4) Leaving buffer strips within hay fields and planting buffer strips of perennial cover in cropland, and 5) Planting shelterbelts in already modified landscapes such as cropland or tame hay fields or pastures. Cost summaries, maps and results can be found in Chapter 4 and a detailed outline of the cost calculations are included within Appendices C - H.

Table A.4. The beneficial management practices for each of the eight species at risk included in the South of the Divide action plan's economic analysis. Information provided by Environment Canada (2011), Tuckwell and Everest (2009), Environment Canada (2006), and Parks Canada Agency (2010).

Species	Best Agricultural Management Plans
Sprague's Pipit (SPPI)	**1) Retain fragments of native prairie in patches of 65 ha (160 acres, or 1 quarter section) or more** **2) Convert cultivated land (especially lands adjacent to native prairie) to perennial cover** **3) Removing grazing or grazing at low intensities are beneficial within the drier grasslands of south-western Saskatchewan** 4) Do not plant alfalfa, clover, smooth brome or crested wheatgrass as they are avoided by SPPI 5) Do not plant trees or shrubs within 100 m of native or tame grassland; reduce or remove woody vegetation and manmade structures that provide habitat for avian predators 6) Use fire to manage woody or invasive vegetation 7) Avoid building roads (especially through native grasslands), but when necessary to do so, be sure to re-vegetate with appropriate species **8) Delaying haying until after July 15th in the dry mixed grass ecoregion and July 21st in the Cypress uplands. Cut hay from the centre of the field outwards, leave narrow buffer strips of vegetation, and avoid second cuts**
Swift Fox (SWFOX)	**1) Retain fragments of primarily native prairie in patches of 14 000 acres (~20 sections or 80 quarter sections) or more, and retain smaller fragments (320 acres or more) within 50 km of larger blocks of native grasslands** 2) Do not plant trees or shrubs on or adjacent to native grassland **3) Graze moderate to heavy in tame pastures, moderate in the Cypress uplands, and low to moderate in the dry mixed grass** **4) Promote vegetation structural heterogeneity with grazing** 5) Avoid constructing built-up roads, but if necessary be sure to re-vegetate with native species 6) Restrict traffic speeds on agricultural roads, and restrict traffic altogether on agricultural roads from dusk to dawn **7) Convert cultivated land (especially lands adjacent to native prairie) to perennial cover. Use species that are native or at least non-invasive that grow no taller than 25 to 30 cm in height** 8) Use fall or winter seeded crops on cropland adjacent to swift fox habitat 9) Avoid the use of rodenticides, but if control is necessary shoot of fumigate to avoid the death of non-target species such as swift fox 10) Do not reduce American badger populations; if coyote control is necessary shoot rather than trap or poison and do not entirely eliminate populations 11) Dispose of dead livestock at randomly located sites rather that a single site and limit the number of carcasses on the landscape to 1 or 2 at any given time 12) Vaccinate domestic dogs against distemper and parvovirus
Burrowing Owl (BUOW)	**1) Maintain grassland pastures of at least a quarter-section (65 ha; 160 acres) in size, preferably in close proximity to other native or tame grassland** 2) Do not plant trees or shrubs on native or tame grassland, and remove man-made structure from grasslands that can serve as roots for avian predators **3) Graze cattle in a manner that creates a heterogeneous pattern of vegetation** 4) Reduce heavy livestock use around nest sites during May and June 5) Avoid introducing non-native species to native pastures and disrupting natural water flow regimes (due to dugouts and dams) 6) Delay haying until after July 1st **7) Leave strips/patches of hay field unmowed to provide habitat for prey (also catches snow and reseeds the hay field)** 8) Avoid using heavy machinery near burrows to prevent collapse 9) Use zero-till or direct seeding when possible to avoid tilling the land during the nesting season **10) Convert cultivated land to perennial cover of appropriate species** 11) Do not use rodenticides and maintain healthy populations of burrowing mammals and avoid spraying insecticides that reduce prey populations 12) Minimize the establishment of roads and trails in native grassland; restrict speed on roads that already exist; and avoid roads when owls are hunting between dusk and dawn

Loggerhead Shrike (LOSH)	1)	Preserve native prairie; where this isn't possible, provide pastures seeded to perennial forages
	2)	Protect areas large enough for several average sized territories (6 to 9 ha)
	3)	Maintain riparian corridors especially those with thorny buffalo berry, and plant trees and shrubs on modified landscapes (tame pasture, cropland)
	4)	**Avoid promoting non-native and invasive bird species by reducing their access to grains and other feeds**
	5)	Stock at moderate grazing intensities between May and October, but restrict cattle access to woody vegetation in the spring when they are susceptible to damage by livestock
	6)	**Remove buildings and other manmade structures that provide habitat for raptors**
Black-footed Ferret (BFF)	**1)**	**Retain areas of native prairie on which prairie dog colonies are located**
	2)	Avoid the construction of roads or buildings adjacent to prairie dog colonies
	3)	**Refrain from resource extraction within or adjacent to prairie dog colonies**
	4)	Refrain from killing (shooting, poisoning, etc.) prairie dogs
Greater Sage Grouse (GRSG)	**1)**	**Retain all remaining native prairie within a 5 – 10 km radius around leks**
	2)	Do not plant trees or tall shrubs within 5 – 10 km of a lek and remove all manmade structures that can provide habitat for avian predators
	3)	Avoid early spring grazing of sage grouse habitat; dormant season grazing would minimize competition between sage grouse and livestock, but do not use concentrated grazing on habitat overwinter as this can reduce sagebrush growth
	4)	**Use light grazing intensities in sage grouse habitat**
	5)	Avoid water developments that change the natural hydrologic flow; avoid installing fences where they do not already exist and when rebuilding fences make the top two wires smooth to prevent the grouse from getting hooked
	6)	Restrict traffic within 3 km of a lek; restrict speed within 10 km of a lek; encourage resource development to avoid road/trail construction within 3 km of a lek
	7)	Avoid ecotourism and ATV usage in sage grouse habitat between early March and the end of June when they are breeding and nesting
Mountain Plover (MOPL)	**1)**	**Maintain native grassland and refrain from converting to cropland**
	2)	**Limit resource extraction activities, ecotourism and road/trail construction within plover habitat**
	3)	Avoid the use, and prevent the spread, of exotic or invasive grassland species that are taller than native species
	4)	**Use a combination of burning and grazing to provide the necessary vegetation heterogeneity and short grass habitat required by the plovers**
	5)	Avoid activities that would harm or disrupt prairie dogs and their colonies
Eastern Yellow-bellied Racer (EYBR)	**1)**	**Maintain native grassland fragments**
	2)	**Avoid heavy grazing that reduces soil stability and vegetative cover**
	3)	Restrict traffic speeds on roadways near known hibernacula
	4)	Avoid the use of heavy farm machinery in areas with known hibernacula
	5)	**Limit resource extraction and road construction in areas with known hibernacula**
	6)	Limit ecotourism and promote responsible behaviour by people observing the snakes (guided hibernaculum visitation and education programs)

B Appendix: Deriving the Marxan and Marxan with Zones Objective Functions

The Marxan and Marxan with Zones models (Ball *et al.* 2009; Watts *et al.* 2009) use a linear objective function and linear constraints like a traditional linear programming model. However, in practice, Marxan actually solves the conservation design problem by placing the objective function and the constraints together into the objective function. It accomplished this by transforming the constraint(s) into a penalty term that is minimized within the objective function. The inclusion of the constraint into the objective function allows a value to be assigned to a reserve system that does not me*et al*l of its conservation targets. This is useful within the annealing process.

The constraint setup is slightly different between the Marxan and Marxan with Zones models. As such, the two models are discussed separately with regard to the creation of their final objective function. However, the Marxan model is discussed in greater detail and the discussion of the Marxan with Zones model simply provides a quick overview of the differences between the two models.

B.1 Appendix: Marxan

The steps discussed below provide a detailed account of the transformation of the constraints into the term that is included in the Marxan objective function. The steps are modified from Ball *et al.* (2009) and Watts *et al.* (2009).

Equation B-1 is the penalty term that will be included within the objective function:

Equation B-1 $$\sum_{j=1}^{n} \boldsymbol{FPF_j FR_j H(s)} \left(\frac{s}{j}\right)$$

There are *n* conservation features under consideration. If every feature*, j*, meets its target in the reserve system, then the penalty term has a value of zero. The penalty term has a positive value if not all of the targets are met, and it increases in value as the conserved amount and its target amount become further apart. The terms FPF_j and FR_j are the feature penalty factor (also known as the SPF or species penalty factor) and the feature representation respectively, which are scaling factors used when a feature fails to meet its representation targets. FPF_j is used to determine the relative importance of meeting the representation target for feature *j*. FR_j is the representation cost of meeting the representation target of feature *j* – or put another way, it equals the cost of a reserve system that satisfies only the target for feature *j*. The representation cost includes the planning unit site-specific costs as well as the connectivity costs. The shortfall, *s*, is the gap between the amount of a conservation feature's target and the amount that is actually reserved (Equation B-2). The Heaviside function, *H(s),* is a step function that turns the penalty term off or on. It takes a value of zero if there is no shortfall, and takes a value of 1 if there is a target shortfall (Equation B-3). The expression $\left(\frac{s}{t_j}\right)$ is the measure of the shortfall in representation for feature *j* (Equation B-4). It is represented as a proportion and equals 1 if feature *j* is not represented in the reserve system, and approaches zero as the feature approaches its target level.

Equation B-2 $$s = t_j - \sum_{i=1}^{m} a_{ij}x_i$$

Equation B-3 $$H(s)\begin{cases}0, if\ s \leq 0\\ 1, if\ s > 0\end{cases}$$

Equation B-4 $$\left(\frac{s}{t_j}\right)\begin{cases}0, if\ s = 0\\ (0,1), if\ 0 < s > t_j\\ \to 1, as\ s \to t_j\end{cases}$$

The shortfall ratio is used as a weighting factor of the total cost to meet the target. It assumes that that the cost of a reserve system that fails to meet the conservation target is simply a linear proportion of the total cost to meet the target (FR_j). This is a simplification since total costs may vary non-linearly as the shortfall, *s*, changes (in fact, it is likely that costs increase at an increasing rate as the shortfall ratio approaches zero since cheaper planning units will be selected first). This simplification is used because it is computationally expensive to find the actual cost of meeting the target in every iteration and it usually provides little improvement in the final answer.

The overall Marxan objective function is the product of combining Equation 4-1 and Equation B-1. This objective function (Equation B-5) can give a value to any reserve system that is a configuration of selected planning units. By varying the control variables, x_i, Marxan minimizes the objective function score using its simulated annealing algorithm.

Equation B-5 $$\sum_{i=1}^{m} c_i x_i + b\sum_{i1=1}^{m}\sum_{i2=1}^{m} x_{i1}(1 - x_{i2})\, cv_{i1,i2} + \sum_{j=1}^{n} FPF_j FR_j H(s)\left(\frac{s}{t_j}\right)$$

B.2 Marxan with Zones

The following equations highlight the differences in the equations used between the Marxan and Marxan with Zones model. The steps below are modified from Watts *et al.* (2009).

Equation B-6 is the penalty term that will be included within the objective function:

Equation B-6 $$\sum_{j=1}^{n} FPF_j FR_j\left(H(s1)\left(\frac{s1}{t1_j}\right) + \sum_{k}^{p} H(s2)\left(\frac{s2}{t2_{jk}}\right)\right)$$

Again, there are *n* features under consideration. The shortfalls, *s1* and *s2* are the amount by which the two different representation targets are not met. Equation B-7 and Equation B-8 define the target shortfalls (see section 4.1.1.1 for a comprehensive discussion on each of the two target constraints). Both shortfalls are used as weightings for the feature dependent factors of FPF_j and FR_j in the same ways they are in the Marxan problem formulation.

Equation B-7 $$s1 = t1_j - \sum_{i=1}^{m}\sum_{k=1}^{p} a_{ij} ca_{jk} x_{ik}$$

Equation B-8 $$s2 = t2_{jk} - \sum_{i=1}^{m} a_{ij} x_{ik}$$

Once the Equation 4-4 and Equation B-6 are combined, the final objective function is complete (Equation B-9).

Equation B-9

$$\sum_{i=1}^{m}\sum_{k=1}^{p} c_{ik}x_{ik} + b\sum_{i1=1}^{m}\sum_{i2=1}^{m}\sum_{k1=1}^{p}\sum_{k2=2}^{p} cv_{i1,i2,k1,k2}x_{i1,k1}x_{i2,k2} + \sum_{j=1}^{n} FPF_jFR_j\left(H(s1)\left(\frac{s1}{t1_j}\right) + \sum_{k}^{p} H(s2)\left(\frac{s2}{t2_{jk}}\right)\right)$$

C Appendix: Oil and Natural Gas Net Present Values

C.1 Method and Information Sources

The method used to calculate oil and natural gas net present values for the South of the Divide region followed the methods of the 2010 Project Report ‘A Net Present Value Model of Natural Gas Exploitation in Northern Alberta: An Analysis of Land Values in Woodland Caribou Ranges’ written by Hauer *et al.* (2010b). Changes to the calculation method were necessary due to differences in the data type and quality available for the South of the Divide Region. As a result of these changes, a complete discussion of the methods used will follow. Oil and natural gas will be discussed together in each section with natural gas discussed first followed by a discussion on oil.

The Saskatchewan Ministry of Energy and Resources manages information on reserves, wells, taxes, and royalties for the oil and gas sector in Saskatchewan. As a result, much of the data used in the oil and natural gas analysis was collected from reports, publications, information sheets, and InfoMaps provided on the Ministry of Energy and Resources’ website: http://www.er.gov.sk.ca/. Information on costs associated with exploration, drilling and extraction came from Hauer at al. (2010b), Alberta Department of Energy (2007), and Petroleum Services Association of Canada (2007). The South of the Divide region is located in the Petroleum Services Association of Canada (PSAC) region SK2. This petroleum producing region is adjacent to PSAC region AB3 and the two regions share similar attributes and several natural gas producing formations (Figure C.1). When data was unable to be found for PSAC region SK2, information available for PSAC region AB3 was used as a close approximation.

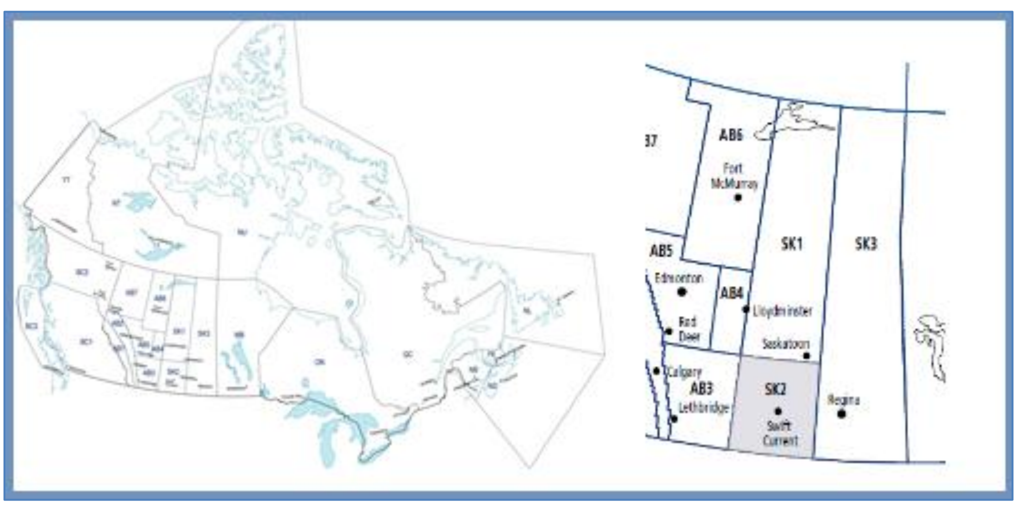

Figure C.1.The location of PSAC regions within Canada (Petroleum Services Association of Canada 2011), and the location of PSAC region SK2 in relation to PSAC region AB3 (Petroleum Services Association of Canada 2007).

C.1.1 Gas Information: Sources and Description

Information on the spatial location of Saskatchewan’s remaining ultimate potential for marketable natural gas was found in a 2008 report published by the National Energy Board and the Saskatchewan Ministry of Energy and Resources (ER/NEB 2008). Very little gas in Saskatchewan is produced in association with crude oil reserves (ER/NEB 2008); as a result, the gas reserve estimates for the South of the Divide are non-associated conventional natural gas estimates. The report outlines the methods used to calculate future (potential) non-associated gas reserves. A low, medium and high probability method was used to estimate potential reserves; this analysis made use of the medium probability estimates for undiscovered reserves since this estimate was termed the 'most realistic estimate' within the report (ER/NEB 2008).

Reserves can be classified in several different ways. Within Saskatchewan's gas reserve reports, reserves are broken down into discovered and undiscovered resources (Figure C.2). Ultimate potential is defined as the sum of discovered and undiscovered (future) resources; remaining ultimate potential is an estimate of total remaining natural gas reserves (ultimate potential minus cumulative production) and it represents the volume that is assumed to be available to meet future market demands (ER/NEB 2008). Gas reserves can also be classified to indicate the amount of gas available at different processing stages: gas in place (GIP) is the initial volume of gas in the reservoir (the total available reserve), recoverable gas is the volume of gas that can be extracted (GIP multiplied by current recovery factors – an average of 73% in Saskatchewan) and marketable gas is the volume that remains after processing and is the amount of gas that is available to the market (recoverable gas minus surface losses – an average of 5% in Saskatchewan). The reserves used in this study were marketable remaining ultimate potential reserves.

Terminology used for Study of Saskatchewan's Ultimate Potential for Conventional Natural Gas

<table>
<tr><th colspan="3">Terms</th><th>Level of Uncertainty</th></tr>
<tr><td rowspan="3">Ultimate Potential</td><td rowspan="2">Discovered</td><td>Cumulative Production</td><td>None</td></tr>
<tr><td>Reserves</td><td>Low</td></tr>
<tr><td>Undiscovered</td><td>Future</td><td>High</td></tr>
</table>

Figure C.2. Chart taken from the ER/NEB (2008) report on Saskatchewan's Natural Gas Potential. The chart highlights the classification system used to distinguish between discovered and undiscovered gas resources within Saskatchewan.

Within the ER/NEB (2008) report, gas reserves were displayed in ranges of million cubic meters per township (~100 km^2 or 36 land sections). The ER/NEB (2008) report did not provide any spatial information on individual gas pools or play formations; as a result, gas reserves were not able to be separated by pools or play formations, and instead all reserves were aggregated into a total reserve value for each surface area unit. The ranges of gas reserves that were present within the South of the Divide were 1 – 25, 25 – 50, 50 – 100 and 100 – 250 million cubic meters of natural gas per township (Figure C.3). These were the lowest ranges within the province's gas producing areas. Estimates of marketable remaining ultimate potential within Saskatchewan's gas producing areas[58]

[58] Many areas of Saskatchewan have no current or future natural gas reserves. Natural gas reserves are primarily located in the western half of the province.

ranged from 1-25 million cubic meters to as much as 2 500 – 5 000 million cubic meters. The gas hotspots in Saskatchewan are found just north of the South of the Divide region.

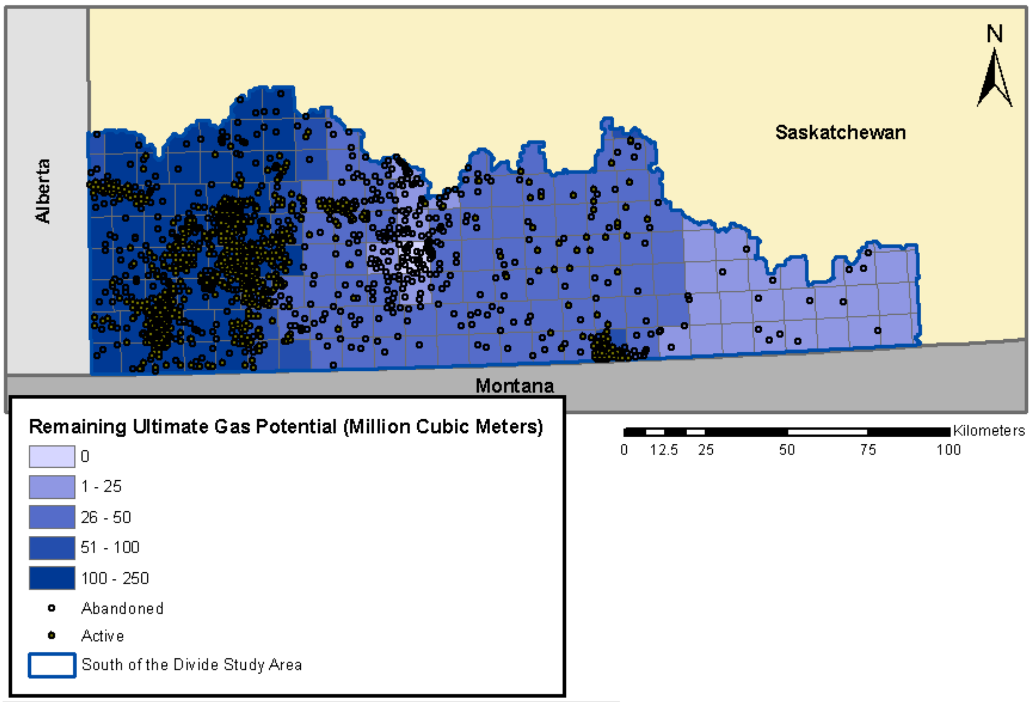

Figure C.3. Natural gas remaining ultimate marketable potential (million cubic meters per township) and natural gas well presence within the South of the Divide study area (reserve information from ER/NEB 2008 and well information from Saskatchewan Industry and Resources 2011).

The unit of study within the final reserve site selection model is a quarter section; therefore, natural gas reserves were scaled down to quarter sections. There are 36 sections in a township and 4 quarter sections in 1 section. Since the unit of study is a quarter section (160 acres; 65 hectares) the reserves reported for each quarter were divided by 144 (36 x 4) to give the gas reserve value per quarter section (Figure C.4). This division relies on the assumption that gas reserves are equally distributed amongst quarter sections within each of the townships of the South of the Divide region.

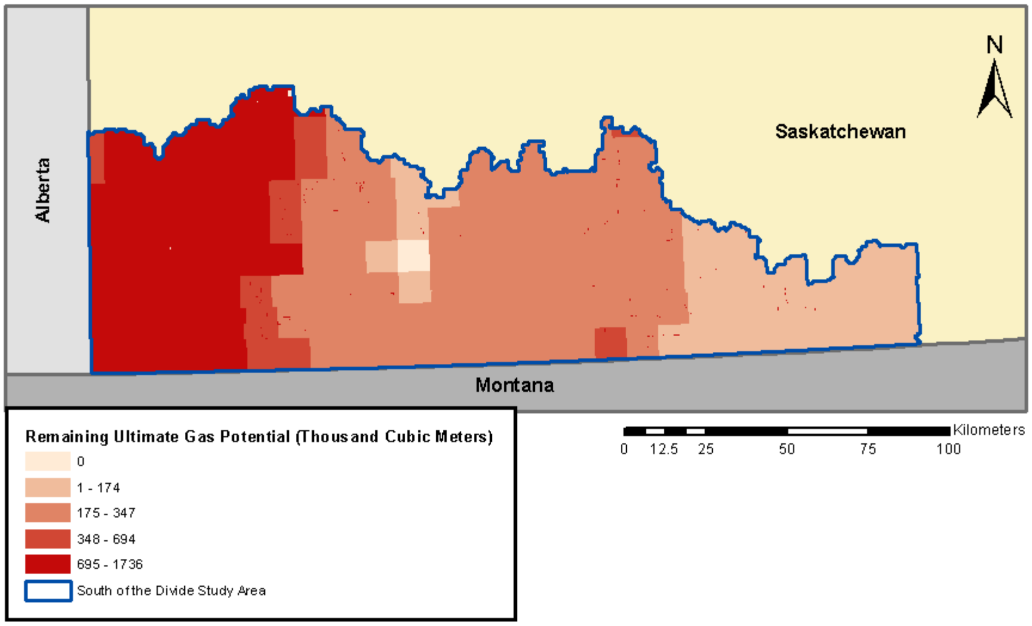

Figure C.4. Natural gas remaining ultimate marketable potential (thousand cubic meters per quarter section) wihtin the South of the Divide study area (reserve information from ER/NEB 2008).

The Saskatchewan Ministry of Energy and Resources' website provided information on oil and natural gas wells for the South of the Divide region. The Ministry's website provides a link to an interactive oil and gas InfoMap (Saskatchewan Industry and Resources 2011). The InfoMap provides information on oil and gas wells as well as information on oil and gas pool boundaries. Information on wells is updated daily by the provincial government, and well information was downloaded on the 3rd of May, 2011 (Figure C.3). The information downloaded included well location (UTM coordinates and legal land description), well type (oil, gas, water), well status (abandoned, active), well depth (meters), well age (date license), and many other additional characteristics. The InfoMap allows the extraction of information layers into a format usable by ESRI's ArcGIS platform. All the gas wells for the province were extracted, designated as abandoned or active, and later clipped to the South of the Divide region using ArcMap 10.0.

Since the ER/NEB (2008) report did not include any pool maps, information on the spatial location of discovered gas pools was also collected using the InfoMap (Saskatchewan Industry and Resources 2011). A total of 15 pools can be found within the South of the Divide region (Figure C.5). While pool information was not included in the gas net present value analysis, it provided useful information to verify the accuracy of the information collected from the ER/NEB (2008) report.

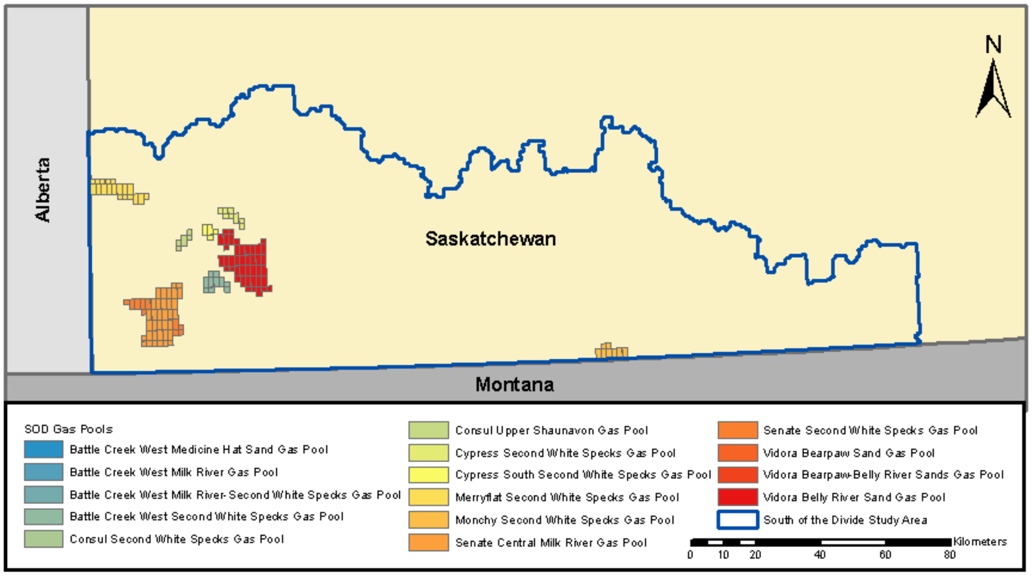

Figure C.5. Locations and names of the 15 natural gas pools located within the South of the Divide study region (pool information from Saskatchewan Industry and Resources 2011).

C.1.2 Oil Information: Sources and Description

Information on the spatial location of oil pools within the South of the Divide Region was obtained from the Saskatchewan Ministry of Energy and Resources' interactive oil and gas InfoMap (Saskatchewan Industry and Resource 2011). Oil pool boundaries were extracted into an ArcGIS compatible format. The area of each pool (acres) was calculated within ArcMap 10.0 and the oil pool layer was clipped to the South of the Divide Region (Figure C.6).

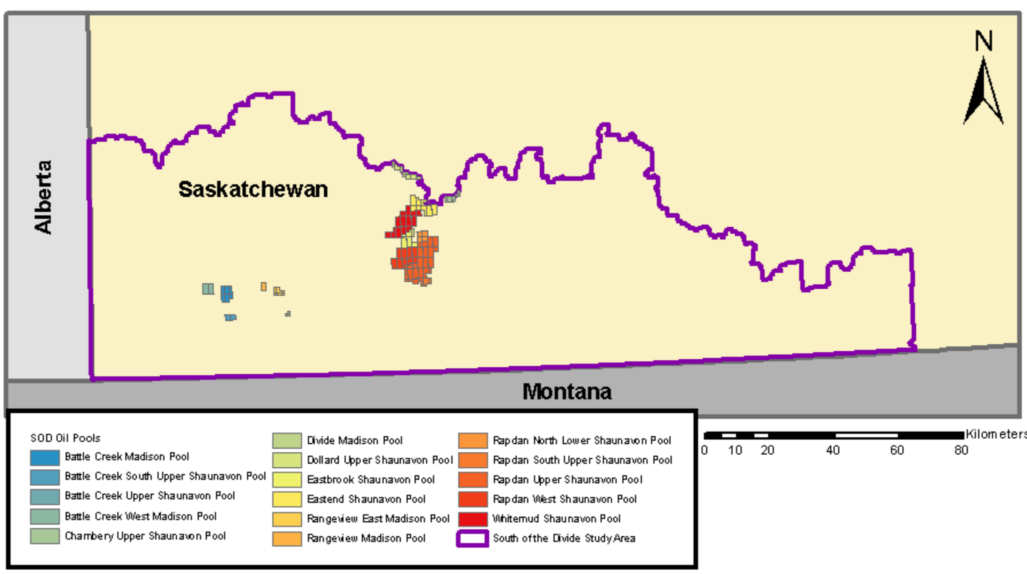

Figure C.6. Names and locations of oil pools within the South of the Divide study area (pool information from Saskatchewan Industry and Resources 2011).

Remaining reserve information for each of the 16 oil pools within the study region was collected from a Reserve Summary Report located on the Ministry of Energy and

Resources' website (ER 2008). This summary report provided information on each formation's remaining oil reserves (in million cubic meters) as well as information on its depth. There were only 2 oil pools that spatially overlapped, and, in fact, their boundaries were identical and the pools differed only by depth. The South of the Divide region contains medium density crude oil reserves. Unfortunately, information on future reserves was not available. Predicted future reserve information was available for conventional oil reserves in the southeast part of the province and oil sand reserves within the northwest part of the province; however, no reports or other information could be found to indicate the presence of future reserves within southwest Saskatchewan. As a result, only discovered reserves were used within the oil analysis.

Joining information on Saskatchewan's remaining oil reserves (ER 2008) and information on the spatial location of oil pools (Saskatchewan Industry and Resources 2011) allowed a spatial map of discovered remaining oil reserves to be created (Figure C.7). Since the reserve site selection model ultimately works with quarter sections, oil reserves were required to be scaled down from reserves/pool to reserves/quarter section. To accomplish this, the total remaining reserves within a pool were divided by the total area (acres) of that pool and then multiplied by 160 (160 acres/quarter section) to get the total reserves that would be found under each quarter section. This, like the gas reserve discussion above, assumes an equal spatial distribution of the oil reserves. Quarter sections and pools perfectly aligned, so all quarter sections were either completely included within the oil pools or were completely excluded (i.e. no quarters were partially included within a pool), and, thus, every quarter section overlaying a particular oil pool would receive the same calculated amount of remaining oil reserves (Figure C.8).

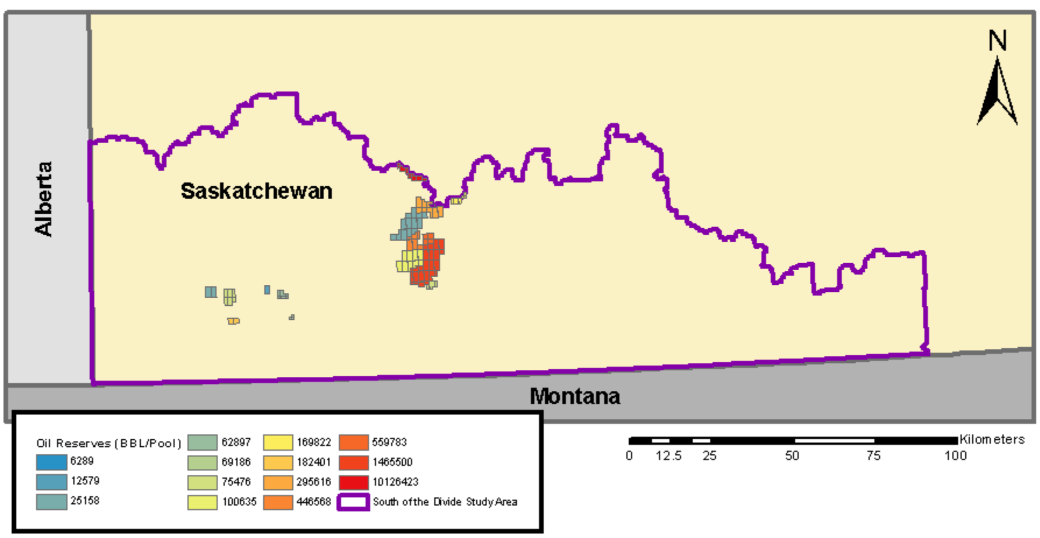

Figure C.7. The oil reserves (bbl) remaining within each oil pool in the South of the Divide region (information from ER 2008 and Saskatchewan Industry and Resources 2011).

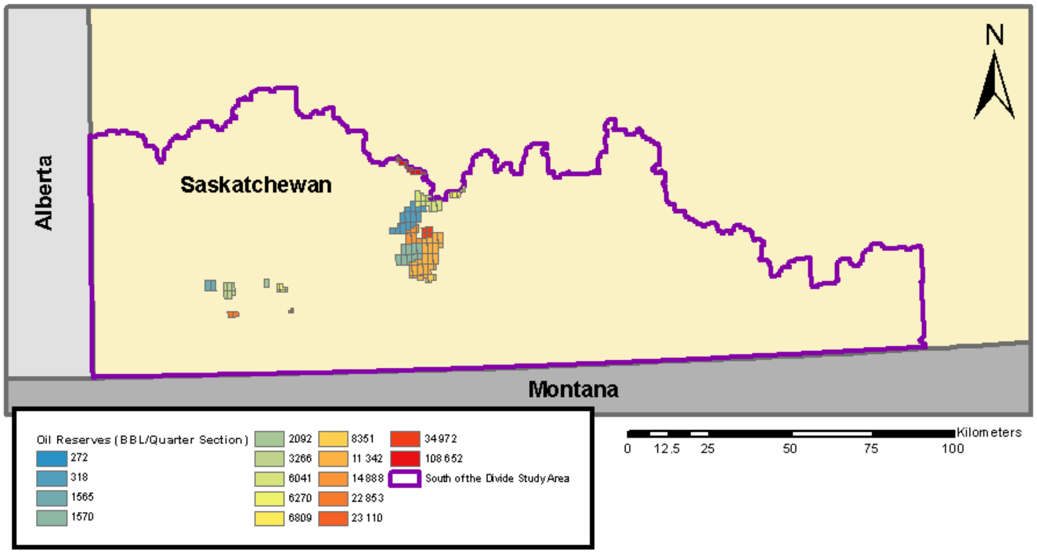

Figure C.8. Oil reserves (BBL) per quarter section within the South of the Divide region (information from ER 2008 and Saskatchewan Industry and Resources 2011).

The Saskatchewan Ministry of Energy and Resources' oil and gas InfoMap provided information on oil wells for the South of the Divide region. The information collected included well location (UTM coordinates and legal land description), well type (oil, gas, water), well status (abandoned, active), well depth (meters), well age (date license), and many other additional characteristics. All the oil wells for the province were extracted from the InfoMap on May 3rd, 2011 into a format usable by ESRI's ArcGIS platform. The wells for the province were later classified as abandoned or active, and clipped to the South of the Divide region using ArcMap 10.0 (Figure C.9).

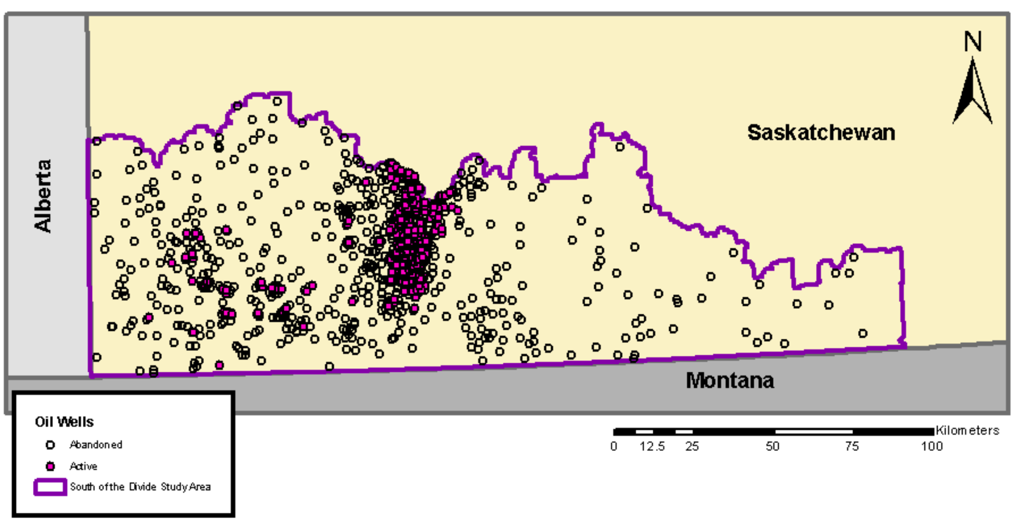

Figure C.9. Active and abandoned oil wells located within the South of the Divide study area (information from Saskatchewan Industry and Resources 2011).

C.2 Calculating Net Present Value (NPV)

Following the methods of Hauer *et al.* (2010b), a model that accounts for remaining resources, costs of exploration and drilling, and the probability of successful exploration and drilling was created to calculate the net present value (NPV) of subsurface resources. While the Hauer *et al.* (2010b) oil and gas models were based on tracts – a combination of a section of land and a resource producing stratigraphic interval – the South of the Divide gas model is simplified to be based solely on land area and uses quarter sections as its land units. The inability to use tracts results from the fact that the information on gas reserves is not available for each formation (or stratigraphic level) but is rather an aggregated value for all formations underneath a particular unit of land (i.e. a quarter section). Only in the case of a quarter section having both discovered and undiscovered resources, would resources be divided (into discovered and undiscovered) and have their NPVs calculated separately and then summed. For the oil analysis, however, the presence of oil pool information allows the oil model to be based on tracts. There are only 3 697 acres (23 quarter sections) within the study area that have oil pools that overlap (The Battle Creek Madison Pool and The Battle Creek Upper Shaunavon Pool). Thus, for the quarter sections overlying these pools, an NPV will be calculated separately for each pool and then summed. For all the other quarter sections, the oil NPV calculation is essentially based on land area – the analogous to the gas analysis – since there is only one stratigraphic interval of interest.

C.2.1 Net Present Value Model

There are 3 different NPV equations that were used in this analysis. For resources that have been discovered with certainty due to the existence of currently active wells, Equation C-1 is used. Discovered resources with a low level of uncertainty use expected NPV Equation C-2, and undiscovered resources with a high level of uncertainty use expected NPV Equation C-3.

For resources currently being extracted by active wells, the NPV model is as follows:

Equation C-1

$$\boldsymbol{NPV = W^s\left(\sum_{t=1}^{L} \beta_t\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - T_t^{ax}\right]\right)}$$

Where

$\beta_t = \left[\frac{1}{1+r}\right]$ = a discount factor set to 0.96 which is equivalent to a 4% interest/discount rate;

V_t = volume of resource (natural gas, medium oil) extracted per well in year *t;*

P_t = price of resource (natural gas, medium oil) in year *t*;

T_t^{ax} = corporate taxes collected in year *t*;

C_t^{roy} = royalties collected on the resource (natural gas, medium oil) in year *t*;

C^{oper} = unit cost of operating a well;

W^s= the number of successful wells on the quarter section (known);

L = lifespan of a well.

In this equation, initial capital costs (drilling, equipment and tie in costs if applicable) are considered sunk and are not included in the equation. Taxes are computed as normal (discussed in section C.2.8), but ages of the wells were computed in order to properly calculate taxes.

Like in Hauer *et al.* (2010b), the volume of gas extracted per well per year V_t is computed based on the initial marketable reserves in the quarter section and a computed curve of volume extraction over time. This computed curve is called the volume extraction profile. The number of wells per quarter section, W^S, alters the volume extraction profiles. In Equation C-1 W^S is known, but in Equation C-2 and Equation C-3, W^S is estimated using information on oil and gas wells within the region. The length of time the well operates is implicit in the volume extraction profile and varies from 7 – 12 years for oil resources and 9 – 29 for natural gas resources. Section C.2.2 describes in detail the method used to create the extraction profiles.

Since cumulative production was not available for the wells in the study area, it was not possible to appropriately adjust their volume extraction profiles according to the volume already extracted during their time in production. Thus, it is assumed that the existing wells are capable of extracting all remaining resources contained underneath their quarter section. As such, the volume extraction profiles are calculated as if they are new wells and start extracting resources at year 1 just as in Equation C-2 and Equation C-3 where wells have yet to be drilled. In this model, year 1 is assumed to be 2012. As such, prices, and tax rates have been used in the calculation such that the starting year would reflect conditions in 2012.

For discovered resources that are not currently being extracted, the NPV model is adjusted to account for the probability of successful drilling and is as follows:

Equation C-2

$$\boldsymbol{ENPV = P^{success} W^{s}\left(C^{drillcomp} + C^{tiein} + C^{equip} + \sum_{t=1}^{L} \beta_t\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - T_t^{ax}\right]\right) + P^{success} W^{sa} C^{drillabandon} + (1 - P^{success}) W^{a} C^{drillabandon}}$$

Where

$\beta_t = \left[\frac{1}{1+r}\right]$ = a discount factor set to 0.96 which is equivalent to a 4% interest/discount rate;

V_t = volume of resource (natural gas, medium oil) extracted per well in year *t;*

P_t = price of resource (natural gas, medium oil) in year *t*;

T_t^{ax} = corporate taxes collected in year *t*;

C_t^{roy} = royalties collected on the resource (natural gas, medium oil) in year *t*;

C^{oper} = unit cost of operating a well;

$C^{drillcomp}$ = cost of drilling and completing a well;

C^{tiein} = the cost of tying in the gas well to the pipeline gathering and processing system (not included in medium oil NPV equations)

C^{equip}= the cost of equipment used to extract the natural gas or medium oil;

$C^{drillabandon}$ = the cost of drilling and abandoning a well;

$P^{success}$ = probability that drilling activity on the section will result in discovery of oil and/or gas;

W^{s}= the number of successful wells required to extract gas given successfully drilled quarter section (estimated);

W^{sa} = the number of unsuccessful wells given that the quarter section has been successfully drilled;

W^{a} = the number of wells abandoned on a quarter section given that drilling has been unsuccessful;

L = lifespan of a well.

Equation C-2 suggests a 2 stage process (Figure C.10). In stage one, drilling is completed which triggers its associated costs. Drilling is successful with probability $P^{success}$ and unsuccessful with probability $(1 - P^{success})$. A successfully drilled and completed well incurs cost $C^{drillcomp}$ and an unsuccessfully drilled well incurs cost $C^{drillabandon}$. Using past well data, the average number of wells on a quarter is calculated based on whether or not drilling on that quarter section is successful. If the quarter section has been successfully drilled (it has resources present) the number of successful wells drilled will be W^{s}, and the number of unsuccessful wells will be W^{sa}. However, if the quarter section fails to be successfully drilled (it has no resource) the number of unsuccessful wells is W^{a}. In the second stage, the successful wells are completed and set up to extract gas which adds additional tie in and equipment costs. Royalties and taxes are also collected and subtracted from revenues.

For undiscovered future resources, the NPV model was altered to consider the probabilities of successful exploration and drilling and is as follows:

Equation C-3

$$\boldsymbol{ENPV = C^{seis}[P^{success}(W^{s} + W^{sa}) + (1 - P^{success})W^{a}] + P^{seis}\Big[P^{success}W^{s}\Big(C^{drillcomp} + C^{tiein} + C^{equip} + \sum_{t=1}^{L} \beta_t\big[V_t\big(P_t - C^{oper} - C_t^{roy}\big) - T_t^{ax}\big]\Big) + P^{success}W^{sa}C^{drillabandon} + (1 - P^{success})W^{a}C^{drillabandon}\Big]}$$

Where

$\beta_t = \left[\frac{1}{1+r}\right]$ = a discount factor set to 0.96 which is equivalent to a 4% interest/discount rate;

V_t = volume of resource (natural gas, medium oil) extracted per well in year *t;*

P_t = price of resource (natural gas, medium oil) in year t;

T_t^{ax} = corporate taxes collected in year t;

C_t^{roy} = royalties collected on the resource (natural gas, medium oil) in year t;

C^{oper} = unit cost of operating a well;

C^{seis}= cost of seismic activities per well;

$C^{drillcomp}$ = cost of drilling and completing a well;

C^{tiein} = the cost of tying in the gas well to the pipeline gathering and processing system (not included in medium oil NPV equations)

C^{equip}= the cost of equipment used to extract the natural gas or medium oil;

$C^{drillabandon}$ = the cost of drilling and abandoning a well;

P^{seis} = the probability that seismic and/or other information indicate that resources are present in the quarter section;

$P^{success}$ = probability that drilling activity on the section will result in discovery of oil and/or gas;

W^{s}= the number of successful wells required to extract gas given successfully drilled quarter section (this is estimated);

W^{sa} = the number of unsuccessful wells given that the quarter section has been successfully drilled;

W^{a} = the number of wells abandoned on a quarter section given that drilling has been unsuccessful;

L = lifespan of a well.

Equation C-3 is similar to Equation C-2 except for the addition of the cost and uncertainty associated with exploration. Thus, the equation models a 3 stage process (Figure C.10). In the first stage, quarter sections with undiscovered reserves are tested using seismic exploration or some other exploration method. Resources are found with a probability of P^{seis}, and exploration incurs a cost of C^{seis}. Seismic costs are pre-well exploration costs, but are often reported on a per-well basis (Hauer *et al.* 2010b). Seismic costs were adjusted to reflect quarter section costs by multiplying by the expected number of wells for the quarter section. The second and third stages of the process are drilling and completion which are modeled in Equation C-2 and explained in detail above.

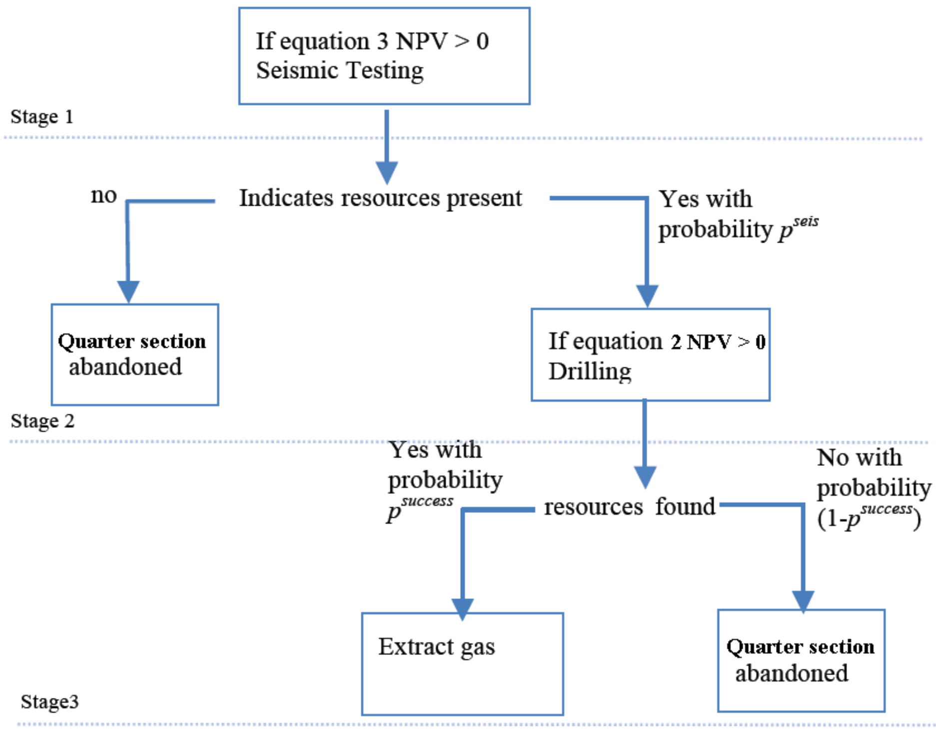

Figure C.10. Showing the 3-stage process – exploration, discovery and extraction – used by expected NPV Equation C-3. Nested within the 3-stage process is the 2-stage process – discovery and extraction – used by expected NPV Equation C-2. Flow chart is adapted from Hauer *et al.* (2010b).

A flow chart was created (Figure C.11) to highlight the decision process that guided which NPV equation was used for each quarter section. In the case of gas resources, there are quarter sections whose reserves are classified as discovered and/or undiscovered. There are also quarter sections that have active wells currently in place, as a result there are 4 possible categories that quarter sections with gas resources can be placed into: 1) Existing active wells present, 2) Discovered reserves only (no active wells), 3) Undiscovered reserves only (no active wells) and 4) Both discovered and undiscovered reserves present (no active wells). The quarters that fall within category 4 have their total reserves divided between those reserves that are discovered and those that are classified as undiscovered. With respect to oil resources, all the quarter sections have discovered reserves (as a result of the lack of available information on future reserves in the area) and consequently there are only 2 possible categories that quarter sections can fall within: 1) Existing active wells present and 2) Discovered reserves only (no active wells). Figure C.11 highlights the classification process for quarter sections based on the quarter section's reserve information; it displays the proper NPV equation that would be used on each quarter section.

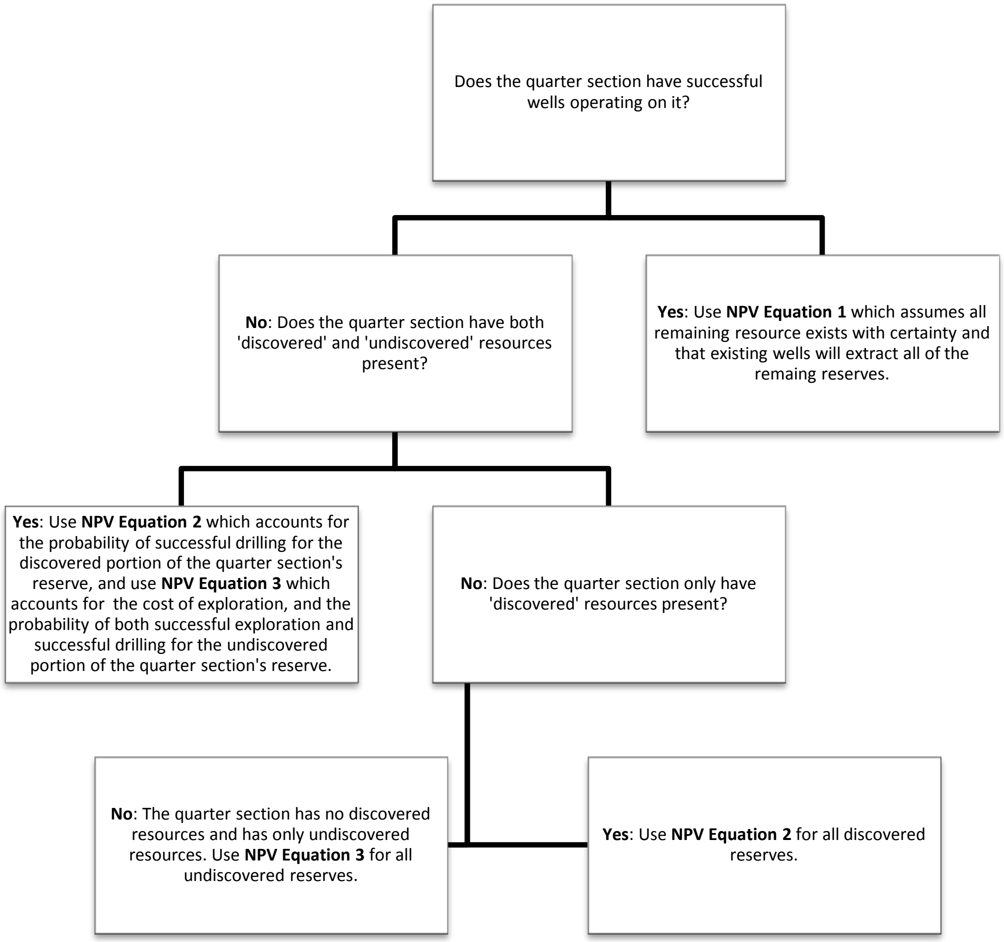

Figure C.11. Decision process used to select the appropriate NPV equation used to calculate the value of each quarter section's resources. This chart is applicable for both the natural gas and oil analysis; however, only a portion of the chart pertains to quarter sections with oil resources. **Note: Some quarter sections would use this process for their natural gas resources, and then again for their oil resources.

F.1.1.1 NPV of Royalties and Taxes

Equation C-1, Equation C-2, and Equation C-3 reflect industry perspectives and the concern for profits. However, government may be more interested in the royalty and tax components of the equation. Each NPV equation would have its own associated tax and royalty equations due to differences in uncertainty. The following equations would permit the calculation of royalties and taxes:

Associated with Equation C-1 would be Equation C-4 for royalties per quarter section and Equation C-5 for taxes per quarter section.

Equation C-4

$$NPV^{roy} = W^{s}\left(\sum_{t=1}^{L} \beta_t V_t C_t^{Roy}\right)$$

Equation C-5

$$NPV^{tax} = W^{s}\left(\sum_{t=1}^{L} \beta_t T_t^{ax}\right)$$

Associated with Equation C-2 would be Equation C-6 for royalties per quarter section and Equation C-7 for taxes per quarter section.

Equation C-6

$$ENPV^{roy} = P^{success} W^{s}\left(\sum_{t=1}^{L} \beta_t V_t C_t^{Roy}\right)$$

Equation C-7

$$ENPV^{tax} = P^{success} W^{s}\left(\sum_{t=1}^{L} \beta_t T_t^{ax}\right)$$

Associated with Equation C-3 would be Equation C-8 for royalties per quarter section and Equation C-9 for taxes per quarter section.

Equation C-8

$$ENPV^{roy} = P^{seis} P^{success} W^{s}\left(\sum_{t=1}^{L} \beta_t V_t C_t^{Roy}\right)$$

Equation C-9

$$ENPV^{tax} = P^{seis} P^{success} W^{s}\left(\sum_{t=1}^{L} \beta_t T_t^{ax}\right)$$

C.2.2 Volume Extraction over Time

The volume of oil or gas extracted from a well over time is dependent upon a number of factors, a large one being prices. For simplicity, this model does not attempt to model changes in volume extraction that would result from changes in prices. Instead volume flow over time is treated as a fixed set of parameters.

A technical background document for Alberta's Royalty Review (Alberta Department of Energy 2007) provided well profiles representative of each oil and gas producing region in Alberta. Production profiles were based on wells drilled between 1998 and 2002. The production profiles were developed to represent wells in different production percentiles and create a representative range of production profiles for each PSAC region in Alberta. There were 6 gas production curves and 3 oil production curves (Table C.1) presented for each PSAC (Petroleum Services Association of Canada) region within Alberta. Production profiles created for PSAC region AB3 were used to approximate production profiles for PSAC region SK2.

Table C.1.Production profiles for PSAC region AB3 showing extraction rates of oil (bbl/year) and natural gas (1000m3/year) for typical wells (Alberta Department of Energy 2007). These production profiles were used to approximate production profiles in the South of the Divide region (PSAC region SK2).

Year	Gas Well 1	Gas Well 2	Gas Well 3	Gas Well 4	Gas Well 5	Gas Well 6	Oil Well 1	Oil Well 2	Oil Well 3
2012	198	510	736	963	2464	3002	1400	18400	57300
2013	170	396	566	736	1727	2152	1000	12000	37400
2014	170	368	481	623	1331	1671	800	8300	25500
2015	113	227	396	510	1104	1388	600	5700	17300
2016	85	142	340	425	934	1133	500	3900	11800
2017	57	113	255	340	736	906	100	2700	8000
2018	142	255	227	255	595	736	0	1800	5500
2019	113	283	170	198	481	595	-	1300	3700
2020	85	170	142	170	396	510	-	900	2500
2021	0	0	113	142	340	425	-	600	1700
2022	-	-	85	142	311	340	-	300	1200
2023	-	-	28	85	255	311	-	0	800
2024	-	-	28	57	227	255	-	-	600
2025	-	-	28	57	170	198	-	-	200
2026	-	-	28	57	142	170	-	-	0
2027	-	-	28	28	142	142	-	-	-
2028	-	-	28	28	142	142	-	-	-
2029	-	-	0	0	113	113	-	-	-
2030	-	-	-	-	113	113	-	-	-
2031	-	-	-	-	113	113	-	-	-
2032	-	-	-	-	57	85	-	-	-
2033	-	-	-	-	28	57	-	-	-
2034	-	-	-	-	28	57	-	-	-
2035	-	-	-	-	28	57	-	-	-
2036	-	-	-	-	28	57	-	-	-
2037	-	-	-	-	28	57	-	-	-
2038	-	-	-	-	28	57	-	-	-
2039	-	-	-	-	28	57	-	-	-
2040	-	-	-	-	28	28	-	-	-
2041	-	-	-	-	0	0	-	-	-
TOTAL	**1133**	**2464**	**3681**	**4814**	**12091**	**14895**	**4300**	**55700**	**173600**

Following the approach of Hauer *et al.* (2010b), production profiles were calculated for each quarter section based on the amount of marketable resource present, the total flow over a well's life, and an assumption about the number of wells that would be used to extract the resource from the quarter section. The following equations highlight the method used to derive the production profiles.

Equation C-10

$$V_t^{R/W^s} = \begin{cases} \dfrac{R/W^w}{P_1} \times V_t^{P_1} \; when \; \dfrac{R}{W^s} \leq P_1 \\ \left(1 - \dfrac{(R/W^s - P_l)}{(P_{l+1} - P_l)}\right) \times V_t^{P_l} + \dfrac{(R/W^s - P_l)}{(P_{l+1} - P_l)} \times V_t^{P_{l+1}} \; when\ there\ is\ a\ P_l\ and\ P_{l+1}\ such\ that\ P_l \leq \dfrac{R}{W^s} \leq P_{l+1} \\ \dfrac{R/W^s}{P_6} \times V_t^{P_6} \; when \; \dfrac{R}{W^s} > P_6 \end{cases}$$

Equation C-11

$$V_t^{R/W^s} = \begin{cases} \dfrac{R/W^w}{P_1} \times V_t^{P_1} \; when \; \dfrac{R}{W^s} \leq P_1 \\ \left(1 - \dfrac{(R/W^s - P_l)}{(P_{l+1} - P_l)}\right) \times V_t^{P_l} + \dfrac{(R/W^s - P_l)}{(P_{l+1} - P_l)} \times V_t^{P_{l+1}} \; when\ there\ is\ a\ P_l\ and\ P_{l+1}\ such\ that\ P_l \leq \dfrac{R}{W^s} \leq P_{l+1} \\ \dfrac{R/W^s}{P_3} \times V_t^{P_3} \; when \; \dfrac{R}{W^s} > P_3 \end{cases}$$

Where

R is the quantity of reserves in the tract in 000 m^3 (natural gas) or bbl (medium oil);

W^s is the number of wells extracting the quarter section's resources (natural gas, medium oil);

V_t^{R/W^s} is the volume extracted from a quarter section's well in year t given that the well has R reserves (000 m^3 or bbl) and a total of W^s wells extracting its reserves;

$P_1, \ldots, P_l, P_{l+1}, \ldots, P_6$ $for\ natural\ gas\ reserves$; and $P_1, \ldots, P_l, P_{l+1}, \ldots, P_3$ $for\ oil\ reserves$ are lists of all the production levels over well life for each resource, ordered smallest to largest.

P_l is the total well production level which is the greatest of all production levels less than or equal to R/W^s and P_{l+1} is the well in the list with the smallest total production of all wells with greater production than R/W^s – essentially, $P_l \leq \frac{R}{W^s} \leq P_{l+1}$.

Figure C.12 displays an example production profile that was derived for a natural gas well in the study area. The example gas well is found on a quarter section with an estimated natural gas reserve of 521 thousand cubic meters (R), and an estimated well density of 0.065 (W^s) for a total estimated $R/W^s = 6887\ thousand\ cubic\ meter$. As a result, the estimated production profile makes use of the 4th and 5th reference natural gas wells (Table C.1). Since natural gas volumes were provided in ranges (ER/NEB 2008), a range of production volumes was created: low, mid and high. Figure C.13 displays how this worked for a well found on a quarter section with a predicted reserve range of 7 to 174 thousand cubic meters of gas (R), an estimated well density of 0.065 wells per quarter section (W^s), and a calculated R/W^s equal to 2627 (low), 3694 (mid) and 4789 (high) thousand meters cubed. The low volume estimation is found using reference gas wells 2 and 3 (Table C.1), the mid volume estimation is found using gas wells 3 and 4, and the high volume estimation uses gas wells 4 and 5.

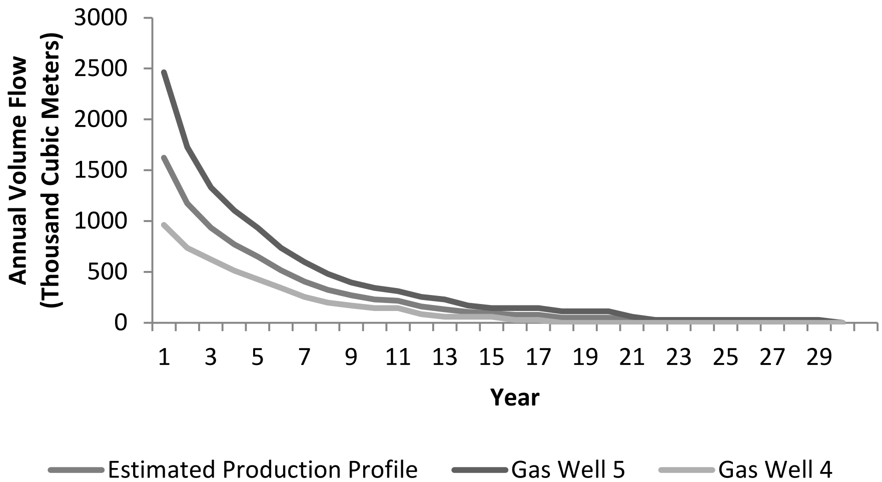

Figure C.12. Production profile for an example natural gas well with a calculated expected lifetime production of 6887 thousand cubic meters of natural gas.

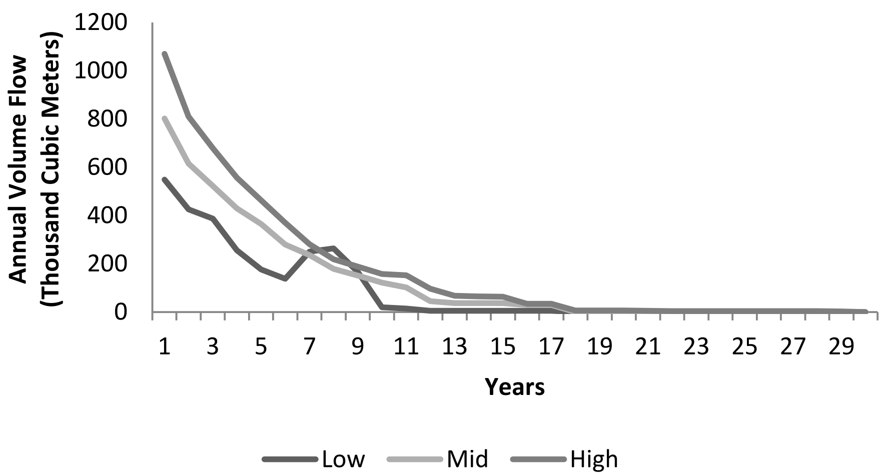

Figure C.13. Production profiles for a natural gas well with an estimated total production range of 2627 (low), 3694 (mid) and 4789 (high) thousand cubic meters of natural gas. The difference in the shapes of the production profiles are due to differences in the reference wells used to estimate each of the production profiles.

C.2.3 Number of Wells per Quarter Section

In the previous sections, W^s, W^{sa}, and W^a were used to represent the number of wells on a quarter section conditional on whether or not the quarter section had been successfully drilled in the past. There are many factors that determine the number of wells drilled to exploit resources, and modelling the number of wells drilled is a complex issue (Hauer *et al.* 2010b). As a result, the best method for determining the number of wells drilled per quarter section in this study was by using past data on wells drilled in the study area. W^s is the average number of successful wells drilled on a quarter section that had at least 1 successfully drilled well (i.e. a 'successful' quarter). W^{sa} is the average number of unsuccessful wells drilled on a quarter section that had at least 1 successfully drilled well (i.e. a 'successful' quarter). W^a is the average number of unsuccessful wells drilled on a quarter section that has never had a successful well drilled (i.e. an 'unsuccessful' quarter). These values were calculated for Equation C-2 and Equation C-3 using the well data provided by the Saskatchewan Ministry of Energy and Resources' InfoMap (Saskatchewan Industry and Resources 2011). The calculation method was slightly different between the natural gas and oil analyses, thus each will be discussed in turn below. In the case of Equation C-1, only W^s is included and it is known (i.e. it is the number of wells currently extracting resource from that quarter section).

C.2.3.1 Natural Gas

W^s, W^{sa}, and W^a were calculated for each natural gas reserve level (Table C.2). Values were calculated using townships rather than quarter sections because using information on quarter sections would have resulted in inflated values for the parameters due to two reasons: 1) reserve information was provided at the township level not at the quarter section level, and 2) there is a low proportion of quarter sections that have been drilled. The number of successfully and unsuccessfully drilled wells was calculated for both successful and unsuccessful townships. W^s, W^{sa}, and W^a were calculated as the average number of successful wells on successful townships, the average number of unsuccessful wells on successful townships, and the average number of unsuccessful wells on unsuccessful townships, respectively. These numbers were then divided by 144 (144 quarter sections per township) to provide the values at a quarter section level (Table C.2).

Table C.2. The average number of natural gas wells drilled on a quarter section in the South of the Divide region.

Remaining Ultimate Potential (000 m^3)	Average # of Successful Wells on Successful Quarter Sections	Average # of Unsuccessful Wells on Successful Quarter Sections	Average # of Unsuccessful Wells on Unsuccessful Quarter Sections
1 - 174	0.007	0.322	0.000
175 - 347	0.019	0.021	0.004
348 - 694	0.088	0.024	0.000
695 - 1736	0.109	0.040	0.010

C.2.3.2 Oil

The use of pool data in the oil analysis, allowed each oil pool to have its own average number of wells calculated. The number of successful and unsuccessful wells and quarter sections were both calculated. Those values were then used to find the average number of wells per quarter section conditional upon both the well's success and the quarter section's success (Table C.3).

Table C.3. The average number of oil wells drilled per quarter section in the South of the Divide region categorized by oil pools.

	Average # of Successful Wells on Successful Quarter Section	Average # of Unsuccessful Wells on Successful Quarter Sections	Average # of Unsuccessful Wells on Unsuccessful Quarter Sections
Battle Creek Upper Shaunavon Pool	1.500	0.500	1.000
Whitemud Shaunavon Pool	1.707	0.122	1.200
Battle Creek West Madison Pool	3.200	0.500	1.000
Rapdan West Shaunavon Pool	1.188	0.313	1.077
Rangeview Madison Pool	1.500	0.000	0.000
Battle Creek Madison Pool	2.250	0.250	1.000
Rangeview East Madison Pool	1.500	0.000	1.000
Eastend Shaunavon Pool	1.458	0.167	1.000
Rapdan Upper Shaunavon Pool	2.053	0.197	1.048
Rapdan South Upper Shaunavon Pool	1.429	0.143	0.000
Divide Madison Pool	3.667	0.000	0.000
Battle Creek South Upper Shaunavon Pool	2.500	0.000	0.000
Eastbrook Shaunavon Pool	1.500	0.308	1.000
Chambery Upper Shaunavon Pool	1.000	0.429	1.000
Rapdan North Lower Shaunavon Pool	1.200	0.000	1.000
Dollard Upper Shaunavon Pool	2.231	0.231	1.000

C.2.4 Assigning Depths to Quarter Sections

The depth to subsurface resources can have a large effect on drilling costs. As such, depth to reserves was estimated for each resource (oil and natural gas) for all quarter sections within the study region. An average depth to natural gas was estimated for each township. First, an average was taken of all well depths within a township and that became the township's assigned depth. However, a second step is required in the case that a township had not yet been drilled (which was the case for 48 of the 190 townships). In the case of a township with no wells (and therefore no depth information), a nearest neighbour principle was used. For each township with adjacent townships with depth data, their depths were averaged and assigned to the township without depth data. Thus, townships with no depth data are assigned a depth based on the average depths of their neighbouring townships. This process would continue through several passes until all township were assigned a depth (Figure C.14). In the case of depth to oil, each pool had information regarding the depth to the formation and these depths were used to estimate the drilling depth required to extract the resource (Figure C.15).

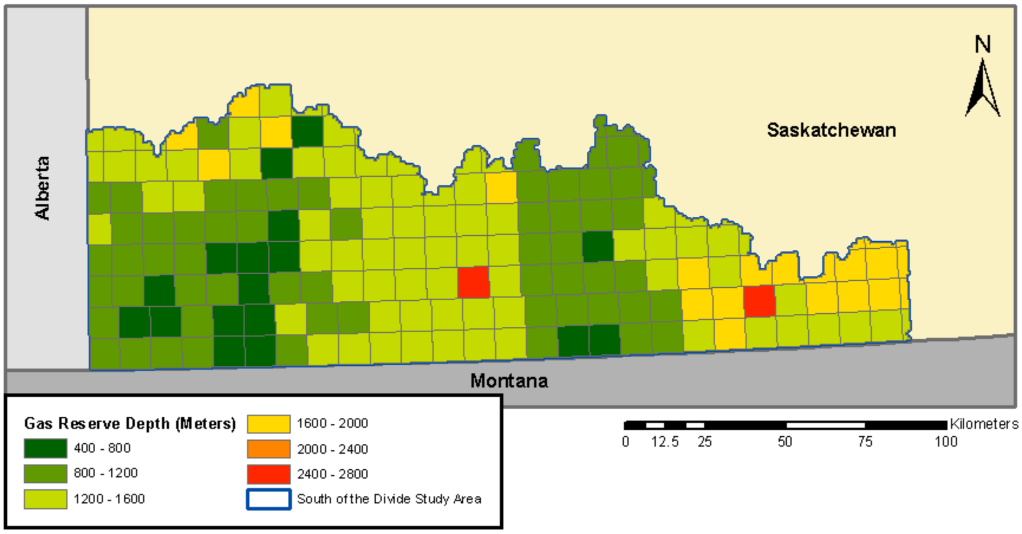

Figure C.14. Depth of discovered and future gas formations within the South of the Divide region (information from Saskatchewan Industry and Resources 2011).

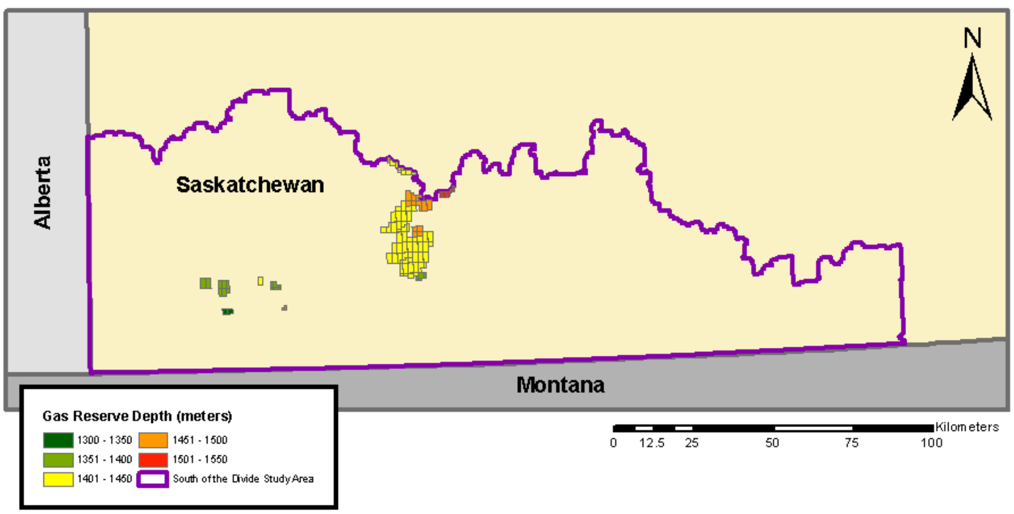

Figure C.15. Depth of oil formations within the South of the Divide region (information from ER 2008).

C.2.5 Costs

Costs can be divided into fixed costs (seismic, drilling, equipment and tie in costs) and variable costs (operating costs). Drilling costs were collected from a PSAC well cost study (Petroleum Services Association of Canada 2007) and costs were assigned to a quarter section based on whether its resources would require a drilling depth less than, or more than, 1000 meters. Seismic, equipment, tie-in, and operating costs were all collected from an Alberta Department of Energy (2007) technical report (Table C.4). The costs collected from the report are for PSAC region AB3, but were used to closely approximate the costs of PSAC region SK2.

Table C.4. The costs used in the NPV model for natural gas and medium oil wells.

	Drill and Complete Costs ($/well)	Drill and Abandon Costs ($/well)		Variable Operating Costs

	Seismic Costs ($/well)	Depth ≤ 1000m	Depth > 1000m	Depth ≤ 1000m	Depth > 1000m	Equipment Costs ($/well)	Tie-In Costs ($/well)	Gas Well ($/ 000m^3)	Oil Well ($/bbl)
Gas	9,000	412,124	690,666	187,204	331,240	39,000	53,000	11.30	-
Oil	9,000	412,124	690,666	187,204	331,240	57,000	-	-	4.79

*Seismic, equipment, tie-in, and variable operating costs taken from Alberta Department of Energy (2007); Drilling costs taken from Petroleum Services Association of Canada (2007).

C.2.6 Price Forecasts

Price forecasts for natural gas (methane) were obtained from GLJ Petroleum Consultants on April 1st, 2011 (GLJ Petroleum Consultants 2011). The analysis makes use of the SaskEnergy Price forecast. This is the provincial gas price that is used in the calculation of royalties. Price forecasts for crude oil were also obtained from GLJ Petroleum Consultants on April 1st, 2011 (GLJ Petroleum Consultants 2011). The analysis makes use of the Medium Crude Oil forecast since the oil pools in the South of the Divide region produce a medium density crude oil.

Prices are reported in current dollars; however, prices were deflated to 2008 dollars using the consumer price index. This calibration allowed the NPV model to be inflation adjusted to reflect 2008 dollars. The price forecast only went up to 2020, however, prices after 2020 were predicted to increase at 2%/year (GLJ Petroleum Consultants 2011). These prices were adjusted by an estimated 2 point increase in CPI/year[59]. Future price predictions are smooth projections into the future (Figure C.16 and Figure C.17). The natural gas prices were reported in \$/mmbtu and therefore required a couple simple conversions to move prices into \$/1000m^3. The first conversion factor is that there are 1.055 GJ/1 mmbtu; and the second conversion is that there are 37 GJ/1000m^3 of methane. Thus, simply by multiplying

$\frac{\$}{mmbtu} \times \frac{1\ mmbtu}{1.055\ GJ} \times \frac{37\ GJ}{1000m^3}$ you get the appropriate pricing units of $\frac{\$}{1000m^3}$.

[59] If a higher inflation rate of 2% were used instead, resource prices past 2020 would remain constant at 2020 levels.

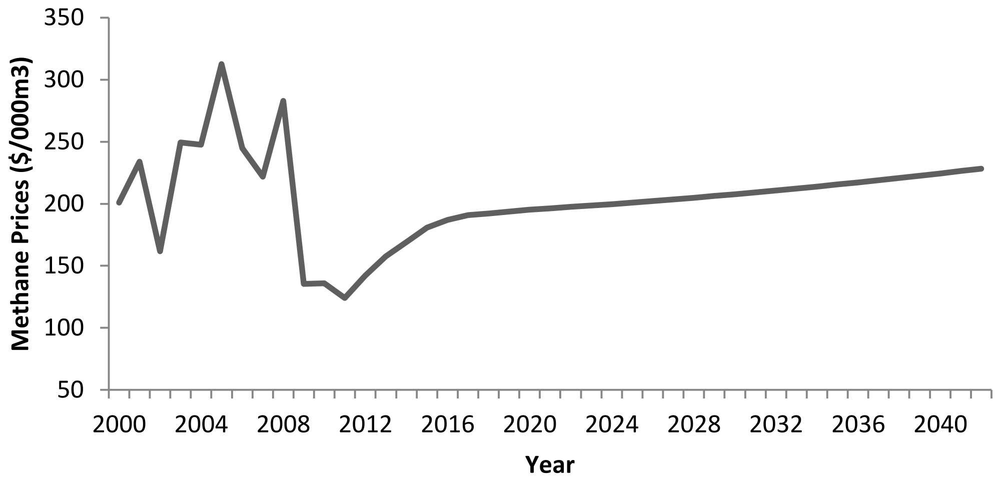

Figure C.16. SaskEnergy prices (constant 2008 prices) for methane gas from 2000 to 2011 and predicted into 2042 (information from GLJ Petroleum Consultants 2011).

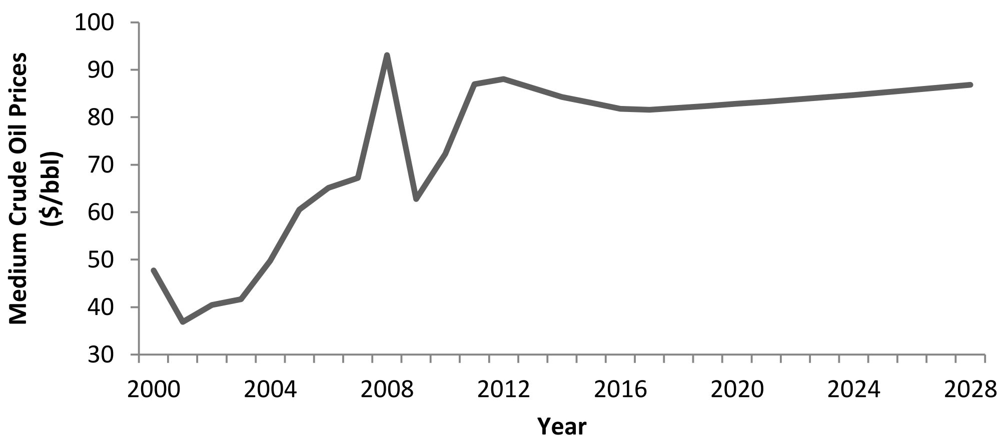

Figure C.17. Medium crude oil prices (constant 2008 prices) from 2000 to 2011 and predicted into 2028 (information from GLJ Petroleum Consultants 2011).

C.2.7 Royalties

Royalties were computed for future natural gas and medium crude oil extraction using the Saskatchewan oil and gas formulas information circular (ER 2011) and the Alberta Department of Energy (2006) report on Oil and Gas Fiscal Regimes of the Western Canadian Provinces and Territories. Computations were simplified by excluding special rates and incentive programs (for example, horizontal well drilling incentives, waterflood project incentives, oil well reactivation incentives, etc.). Due to the lack of detailed formation information, it was impossible to determine the amount of natural gas produced from oil wells (associated gas), and as such, natural gas produced from oil wells was not included in the NPV model. However, this is assumed to have little impact on NPV values because Saskatchewan has very little associated gas (ER/NEB 2008).

C.2.7.1 Natural Gas

Crown royalty rates (R%) are dependent upon the age of the well, the productivity of the well, as well as the provincial average gas price ($/1000m^3). The value of the royalty share is determined by multiplying the crown royalty volume of each well by the wellhead value of the gas for the month (Alberta Department of Energy 2006). Monthly royalties are calculated by the province; however, in our model, annual royalties were calculated for simplicity. In order to alter the calculations to reflect annual royalty rates, annual volume flows replaced monthly flows, and an average annual price replaced monthly natural gas prices. The annual royalty value can be computed using Equation C-12.

Equation C-12

$$Royalty\ Value = V_t C_t^{roy} = V_t R_t^{\%}(P_t - 10)$$

where V_t is the well's annual volume flow in thousand cubic meters, $R_t^{\%}$ is the natural gas royalty rate for year t, $(P_t - 10)$ is the annual wellhead value of the gas[60], and C_t^{roy} is the percentage of the natural gas wellhead value that is collected as royalties for each thousand cubic meters of natural gas collected from a well (also known as the royalty cost).

There are four classifications of wells based on age. Old Gas is produced from wells drilled prior to October 1st 1976; New Gas is produced from gas wells drilled on or after October 1st 1976; Third Tier Gas is produced from gas wells drilled on or after February 9th 1998; and Fourth Tier Gas which is produced from gas wells drilled on or after October 1st 2002. Table C.5 outlines the gas royalty formulas and rates (Alberta Department of Energy 2006) used to calculate royalties within the natural gas NPV model. Kg, Xg, Cg and Dg are constants calculated from the formulas outlined in Table C.6.

Table C.5. The formulas used to calculate crown royalty rates based on natural gas well volumes and age (Alberta Department of Energy 2006).

	MGP* ≤ 25 000 (m^3/month)	25 000 < MGP ≤ 115 400 (m^3/month)	MGP > 115 400 (m^3/month)
Old, New and Third Tier Gas	R%† = (Cg‡ x MGP) – SRC¥	R% = (Cg x MGP) – SRC	R% = (Kg – (Xg/MPG)) – SRC
Fourth Tier Gas	R% = 0	R% = (Cg x MGP) – Dg	R% = (Kg – (Xg/MGP))

*MGP = Monthly Gas Production (m^3/month)[61]
†R% = Crown royalty rate (to a minimum of 0%)
‡Kg, Xg, Cg and Dg are constants calculated from the formulas outlined in Table C.6
¥SRC = Saskatchewan Resource Credit of 2.5% for third tier gas and 1% for old gas and new gas. The SRC does not apply to fourth tier gas.

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[60] The annual wellhead value of gas is the annual provincial price of gas ($/1000m^3) minus the fixed gas cost allowance of $10/1000m^3 set by the province of Saskatchewan.

[61] Volumes from the production profiles are in yearly flows, thus the appropriate royalty rates were determined by multiplying the MGP values by 12. This assumes that flow is evenly distributed throughout the year and the royalty rate is equal in every month throughout the year.

Table C.6. The formulas used to calculate the constants used within the natural gas Crown royalty calculations (Alberta Department of Energy 2006).

	Kg	Xg	Cg	Dg
Old Gas	26 + (32.5 x (PGP* – 35)/PGP)	Kg x 57.69	Kg/230.76	-
New Gas	19.5 + (26 x (PGP – 35)/PGP)	Kg x 57.69	Kg/230.76	-
Third Tier Gas	19.5 + (26 x (PGP – 50)/PGP)	Kg x 57.69	Kg/230.76	-
Fourth Tier Gas	6.75 + (33.73 x (PGP – 50)/PGP)	Kg x 64.7	Kg/205.76	Kg/8.23

*PGP is the provincial average gas price ($/1000m^3) set each month.[62]

C.2.7.2 Oil

The procedure to calculate Crown royalty rates for oil closely parallels the procedure used to calculate rates for natural gas. As in the case of natural gas, oil royalty rates are sensitive to a well's production, the age of the well, the current provincial oil price ($/m^3), but now in addition, royalty rates are sensitive to the type of oil produced (Alberta Department of Energy 2006). Oil production is divided into 3 types of oil – Heavy Oil, Southwest-Designated Oil, and Non-Heavy Oil. The South of the Divide region is encompassed within the zone of Southwest-Designated Oil.

Southwest-Designated Oil has its own unique royalty calculation procedures. The value of the royalty share is determined by multiplying the crown royalty volume of each well by the wellhead value of the oil for the month (Alberta Department of Energy 2006). Monthly royalties are calculated by the province; however, in our model, annual royalties were calculated for simplicity. In order to alter the calculations to reflect annual royalty rates, annual volume flows replaced monthly flows, and an average annual price replaced monthly medium oil prices. The annual royalty value can be computed using Equation C-13.

Equation C-13

$$Royalty\,Value = V_t C_t^{roy} = V_t R_t^{\%} P_t$$

where V_t is the well's annual volume flow in cubic meters, $R_t^{\%}$ is the oil royalty rate for year t, P_t is the annual wellhead value of the oil, and C_t^{roy} is the percentage of the oil wellhead value that is collected as royalties for each cubic meters of medium oil collected from a well (also known as the royalty cost).

There are three classifications of oil wells in the Southwest-Designated Oil region based on age. New Oil is produced from oil wells drilled prior to February 9th, 1998; Third Tier Oil is produced from wells drilled on or after February 9th, 1998; and Fourth Tier Oil is produced from wells drilled on or after October 1st, 2002.

[62] While PGP varies monthly, the price forecast model includes only annual average price, and it is this price that is used to calculate the constants necessary to determine the crown royalty rates.

Table C.7 outlines the gas royalty formulas and rates (Alberta Department of Energy 2006) used to calculate royalties within the oil NPV model. K, X, C and D are constants derived from the formulas outlined in Table C.8.

Table C.7. The formulas used to calculate Crown royalty rates based on oil well volumes and age (Alberta Department of Energy 2006).

	MOP* ≤ 25 (m^3/month)	25 < MOP ≤ 136.2 (m^3/month)	MOP > 136.2 (m^3/month)
New and Third Tier Oil	†R% = (K‡ – (X/MOP)) – SRC¥	R% = (K – (X/MOP)) – SRC	R% = (K – (X/MOP)) – SRC
Fourth Tier Oil	R% = 0	R% = (C x MOP) – D	R% = (K – (X/MOP))

*MOP = Monthly Oil Production (m^3/month)
†R% = Crown royalty rate (to a minimum of 0%)
‡ K, X, C and D are constants derived from the formulas outlined in Table C.8.
¥SRC = Saskatchewan Resource Credit of 2.5% for third tier oil and 1% for new gas. The SRC does not apply to fourth tier oil.

Table C.8. The formulas used to calculate the constants used within the oil Crown royalty calculations (Alberta Department of Energy 2006).

	K	X	C	D
New Oil	16.25 + 29.25 x (SOP* – 50)/SOP	Kg x 23.08	-	-
Third Tier Oil	16.25 + 29.25 x (SOP – 100)/SOP	Kg x 23.08	-	-
Fourth Tier Oil	7.14 + 35.71 x (SOP – 100)/SOP	Kg x 75	Kg/247.48	Kg/9.9

*SOP is the average southwest designated oil wellhead price ($/$m^3$)[63]

C.2.8 Taxes

Hauer *et al.* (2010b) developed a simple model to estimate taxes that overcomes the issue that corporate taxes are paid at the corporate level, and not at the well level which is the scale at which the model has been designed. The model allowed taxes to be calculated per well. Taxes for every year of a well's producing life was calculated by multiplying the corporate sales tax percentage rates by the net revenue which accounted for all operating costs, royalties and depreciation on capital investment (Hauer *et al.* 2010b). The federal corporate tax rate is declining to 15% as of January 1st, 2012, and the Saskatchewan provincial corporate sales tax in 2012 will be 12%. A depreciation rate of 20% was used in the model. Taxes are computed for both natural gas and oil wells using formula Equation C-14.

Equation C-14

$$T_t^{ax} = 0.27\left[V_t\left(P_t - C^{oper} - C_t^{roy}\right) - \delta K_t\right]$$

[63] Future SOP values were estimated using the GLJ Petroleum Consultants (2011) price forecast for medium oil. While SOP varies monthly, the price forecast model includes only annual average price, and it is this price that is used to calculate the constants necessary to determine the Crown royalty rates.

Where K_t is the capital balance in real dollars at the beginning of period t and δ is the depreciation rate. The capital balance is updated annually using Equation C-15.

Equation C-15

$$K_t = K_{t-1}(1 - \delta)$$

In the case of wells that have yet to be drilled in the model, K_1 would equal the sum of equipment, drilling and tie-in costs (if applicable). If instead, wells currently exist as in the case of NPV Equation C-1, K_1would instead equal the initial capital costs multiplied by $(1 - \delta)^{M-1}$ where M is the number of years the well has already been in production. Capital balance would be calculated as normal in subsequent years. It is possible that the tax formula could yield a negative result, and in that case, taxes for that year were set to zero.

C.2.9 Probability of Successful Drilling and Seismic Success

The uncertainty surrounding subsurface resource exploration and discovery is captured in the NPV equations through the use of P^{seis} and $P^{success}$ (Hauer *et al.* 2010b). These probabilities are used in the case of quarter sections that have not yet been drilled. The success rates are based on historic well data collected from the Saskatchewan oil and gas InfoMap (Saskatchewan Industry and Resources 2011) while seismic probabilities for natural gas exploration are derived.

Drilling success rates in this model are computed as the total number of successfully drilled quarter sections divided by the total number of quarter sections drilled, or otherwise represented as

$P^{success} = \frac{Number\ of\ Successfully\ Drilled\ Quarter\ Sections}{Total\ Number\ of\ Quarter\ Sections\ Drilled}$. Each natural gas reserve level has a probability of success calculated, and each oil pool had its own probability of success calculated.

Table C-9 displays the region's probability of success for each oil pool and natural gas reserve level. The high success rates are not unreasonable, as it has been found that the chance of commercial success in Alberta is very high and averages close to 80% (Alberta Department of Energy 2007).

Table C.9. The calculated probability of drilling success for each oil pool and the total natural gas reserve in the South of the Divide region.

	# Successfully Drilled Quarter Sections	Total # of Drilled Quarter Sections	Probability of Success
Gas Reserves 1 000 – 174 000 m^3	2	92	0.02
Gas Reserves 175 000 – 347 000 m^3	98	314	0.31
Gas Reserves 348 000 – 694 000 m^3	115	141	0.79
Gas Reserves 695 000 – 1 736 000 m^3	563	735	0.73
Battle Creek Upper Shaunavon Pool	2	23	0.50
Whitemud Shaunavon Pool	41	79	0.80
Battle Creek West Madison Pool	5	16	0.76
Rapdan West Shaunavon Pool	32	64	0.61
Rangeview Madison Pool	6	6	1.00
Battle Creek Madison Pool	4	23	0.75
Rangeview East Madison Pool	6	10	0.82
Eastend Shaunavon Pool	24	46	0.78
Rapdan Upper Shaunavon Pool	76	129	0.81
Rapdan South Upper Shaunavon Pool	7	9	0.91
Divide Madison Pool	3	3	1.00
Battle Creek South Upper Shaunavon Pool	6	8	1.00
Eastbrook Shaunavon Pool	26	30	0.81
Chambery Upper Shaunavon Pool	7	11	0.58
Rapdan North Lower Shaunavon Pool	10	16	0.92
Dollard Upper Shaunavon Pool	13	20	0.76

The probability of exploration success, P^{seis}, for natural gas was derived using two separate sources of information. One was the probability of successful exploration from the Saskatchewan InfoMap (Saskatchewan Industry and Resources 2011), and the second was an appendix to the ER/NEB (2008) report on Saskatchewan's natural gas potential. The appendix is available online (NEB 2011). Within the appendix, there were 5 natural gas plays found within the South of the Divide region as determined by using natural gas pool information collected from the Saskatchewan oil and gas InfoMap. These 5 play areas had an average reported cumulative success rate of 0.05 over the past 60 years. This success rate is much lower than the success rate expected after successful exploration; thus, it was assumed, as it was in Hauer *et al.* (2010) that these success rates did not account for exploration. As a result, seismic success rates were able to be calculated by comparing these two very different reported success rates. To compute P^{seis} Equation C-16was used, and P^{seis} was found to be 0.09[64].

Equation C-16

$$P^{seis} \times P_{InfoMap}^{Success} = P_{NEB}^{Success} \rightarrow P^{seis} = P_{NEB}^{Success} \Big/ P_{InfoMap}^{Success}$$

The probability of exploration success was not computed for oil reserves because the reserves were already considered discovered and therefore required no further exploration activities to occur.

C.2.10 Final Model Calculations

The previous sections outlined how all the various components of the NPV equations were calculated, derived, or collected. The final step is to calculate the NPV of oil and natural gas for every quarter section within the region and include it in the final opportunity cost model. It is important to recall that with regard to the natural gas calculations each quarter section had a low, mid and high value calculated for royalties, taxes and net present value. The range of values resulted from the initial provision of remaining ultimate potential in ranges of reserve volume.

C.3 Oil and Gas NPV Results

Net present values of profits were calculated for each quarter section using Equation C-1, Equation C-2, and Equation C-3 for natural gas resources, and using Equation C-1 and Equation C-2 for oil resources. Setting the discount rate at 0.04 reflects a risk free real return on capital (Hauer *et al.* 2010). The result is that investing in oil and gas development has a higher return (i.e. higher net present values) than if risk was included through the use of a higher discount rate. It is possible that a higher discount rate may be more representative of the rate used by oil and gas development companies. The result is that oil and gas companies would have slightly lower estimates of NPV.

The NPVs in this model are calculated under the assumption that initial investment proceeds immediately for all quarter sections in the area. This is not a realistic assumption – due to the capacity and time constraints faced by energy producers. Two quarter sections with identical reserves and estimated NPVs would have different realized NPVs if they are developed at different times. The quarter section that is developed later would have a lower NPV due to discounting. In fact, Hauer *et al.* (2011) extend the work done in Hauer *et al.* (2010) to include a 50 year planning horizon for oil and gas development with capacity constraints which resulted in reduced estimates of oil and gas net present value[65]. Adamowicz *et al.* (2009) found that oil and gas NPVs

[64] The calculation uses a region-wide probability of successfully drilling a natural gas well. The probability of success for the region as a whole is 0.57.

[65] The areas of Alberta that had lower natural gas net present values were developed later in the 50 year planning horizon. The idea is that the wealthier deposits are exploited first and poorer reserves are developed after the wealthier reserves have been depleted. Interestingly, the

were 8 – 30% lower than when capacity constraints were included. Consequently, the oil and gas values provided here are an upper bound on the oil and gas NPVs within the South of the Divide region. However, the inclusion of low, mid and high estimates of gas values provides a sensitivity analysis which presents the range of values possible for the region. The oil and gas land values here, while an upper bound, still provide information on relative values of areas and can provide valuable information on priority areas (Hauer *et al.* 2010b).

C.3.1 Spatial Distribution of NPV Values

Each quarter section had its total NPV (profits, taxes and royalties) summed to get the total oil and natural gas value. In the case of oil, only two oil pools overlapped and required their individual NPVs to be summed. In the case of natural gas, only quarter sections that contained discovered and undiscovered reserves without any active wells required their NPVs from Equation C-2 and Equation C-3 (profits); Equation C-6 and Equation C-8 (royalties); and Equation C-7 and Equation C-9 (taxes) to be summed to get their total NPVs. Land values for natural gas were calculated for the low, mid and high natural gas reserve scenarios. Figure 4.2 is a map showing the total land values for oil reserves in the region. Total land values for the low, mid and high remaining ultimate potential reserves are shown in Figure C.19, Figure 4.1, and Figure C.21 respectively. The relatively homogeneous total land values for natural gas are due to the homogeneous natural gas reserves in the region[66] (see Figure C.4).

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regions with natural gas values similar to those found in the South of the Divide region were not exploited at all during the 50 year time horizon as a result of their very low values.

[66] The natural gas values calculated for the South of the Divide (SoD) region can be put to test against the natural gas values calculated by Hauer *et al.* (2010b) for Alberta. The reserves in the SoD region are similar to reserves in northwest Alberta. They are low (in general <4 000 000 m^3/section or equivalently <1 000 000 m^3/quarter section) and primarily undiscovered. The resulting natural gas values are similar between the two regions and range from $2.5/acre to $500/acre. The values greater than $500/acre in the SoD are due to one of three reasons: the quarter section has a higher natural gas reserve potential (as much as 6 400 000 m^3/section in the western part of the region), the quarter section has 'discovered' reserves with a higher probability of success, or the quarter section already has active wells that no longer have to account for drilling and exploration costs. Natural gas values for southeast Alberta may not be the best indicator of gas values for southwest Saskatchewan because in general, natural gas formations are less developed in Saskatchewan than similar formations in Alberta (ER/NEB 2008). As a result, gas reserves are less explored in Saskatchewan and natural gas net present values may be lower than Alberta values because of greater levels of undiscovered reserves and higher levels of uncertainty.

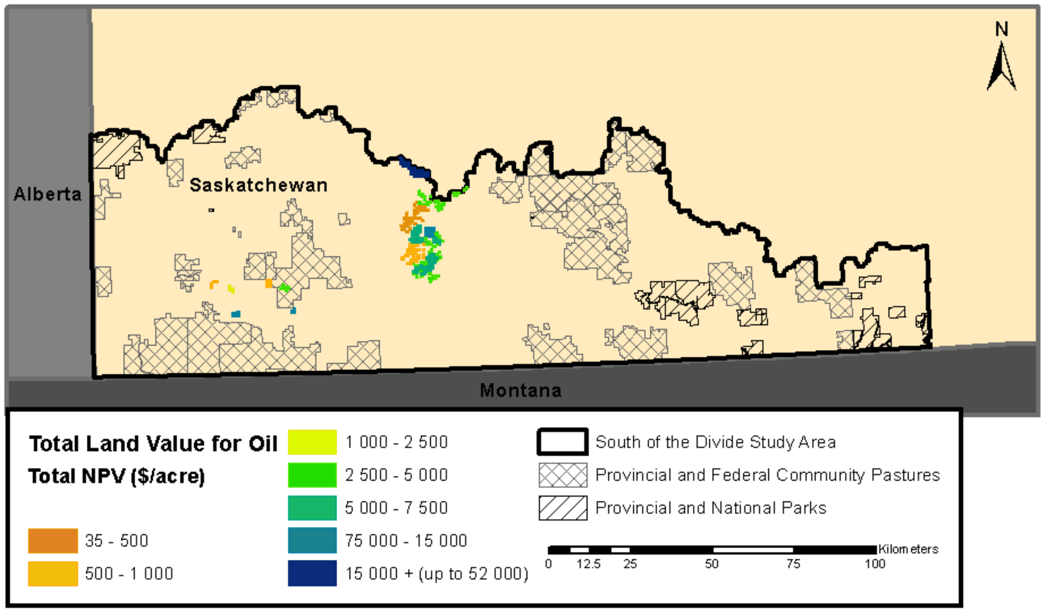

Figure C.18. The South of the Divide oil land values shown for all oil pools in dollars per acre.

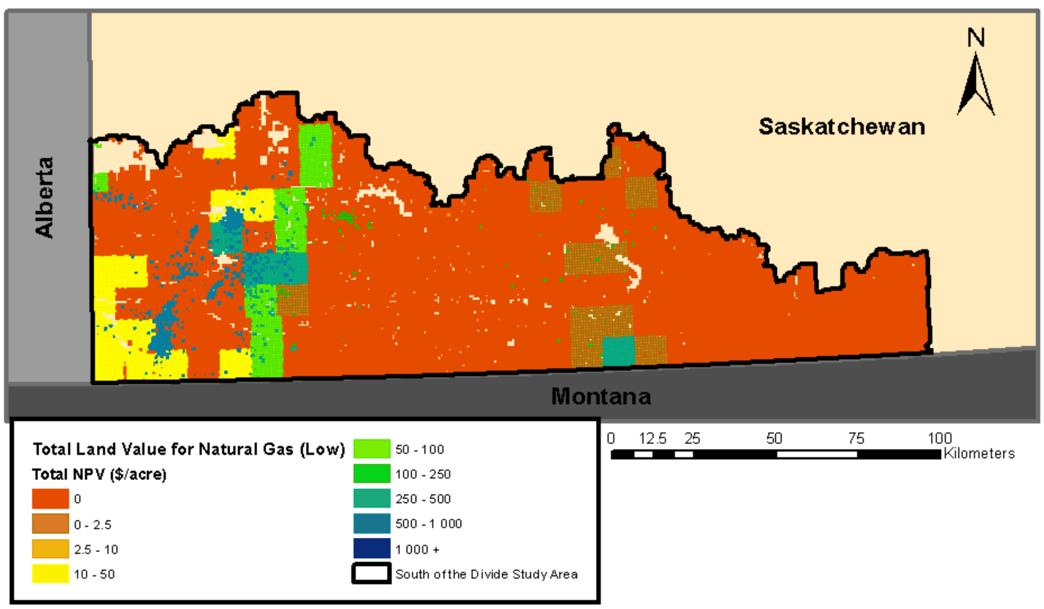

Figure C.19. The South of the Divide natural gas land values for the lower bound of the estimated remaining ultimate potential reserves.

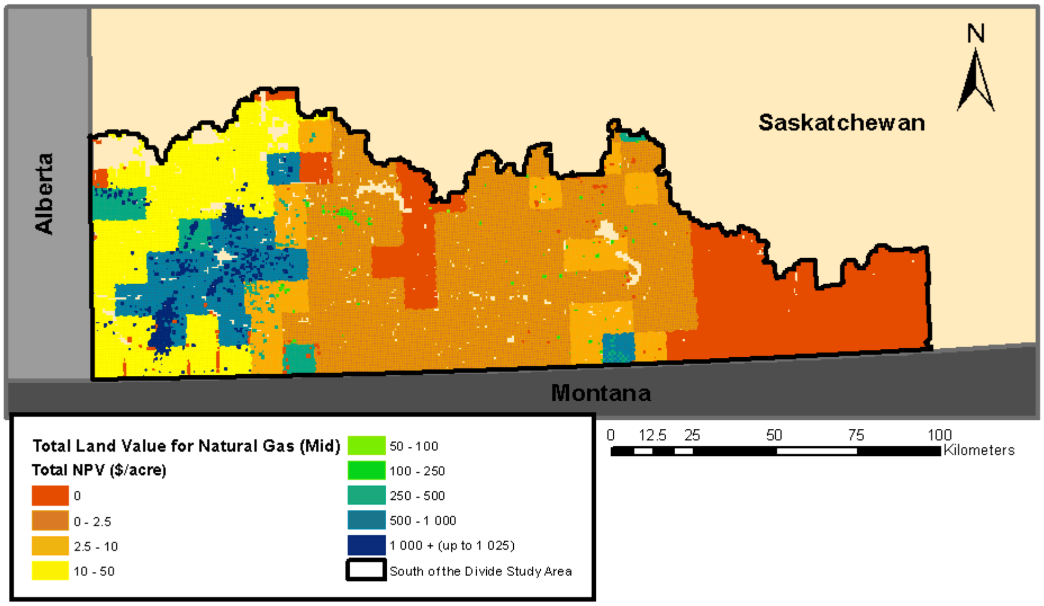

Figure C.20. The South of the Divide natural gas land values for the midpoint of the estimated remaining ultimate potential reserves.

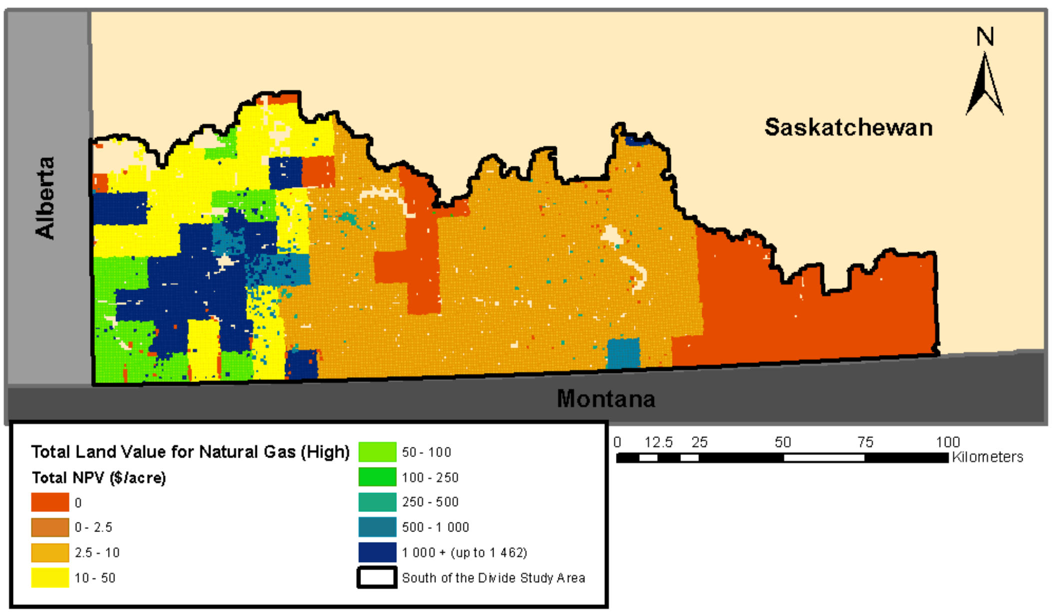

Figure C.21. The South of the Divide natural gas values for the upper bound of the estimated remaining ultimate potential reserves.

C.3.2 The Value of Oil and Gas Resources in Each Species Range and Critical Habitat

The net present value of oil and natural gas can be tallied within each species' range and proposed critical habitat to give an estimate of the relative value of resources in each species' habitat.

Table C.10, Table C.12, and Table C.14 show the NPVs in each species' range broken down by profits (Equation C-1, Equation C-2, and Equation C-3 above), royalties (Equation C-4, Equation C-6, and Equation C-8 above), and taxes (Equation C-5, Equation

C-7, and Equation C-9 above). Total values are also reported. The NPVs are further broken down by resource – oil and natural gas – and by natural gas reserve levels – low, mid and high. Table C.11, Table C.13, and Table C.15 show the same information for species' critical habitat. Table C.10 and Table C.11 provide values for existing wells (Equation C-1, C-4, C-5), Table C.12 and Table C.13 provide values for future wells (Equations C-2, C-3, C-6, C-7, C- 8, C-9), and Table C.14 and Table C.15 provide values for all wells (existing and future). Species have been sorted in the tables so that the species with the largest value in the mid ultimate potential scenario appears first and the smallest value species appears last. Table C.16 and Table C.17 show NPV/acre for each species' range and critical habitat, respectively. Species are listed so that the highest NPV/acre value is listed first, and the lowest NPV/acre value is listed last.

Table C.10. Net present values of profits, royalties and taxes of existing oil and natural gas (low, mid and high reserve levels) wells within each species' range.

	Millions of Dollars															
	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
Species Name	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	50	0	6	55	80	0	15	95	109	0	25	134	155	39	54	248
Burrowing Owl	50	0	6	55	80	0	15	95	109	0	25	134	155	39	54	248
Loggerhead Shrike	50	0	6	55	80	0	15	95	109	0	25	134	155	39	54	248
Swift Fox	49	0	5	55	79	0	15	94	108	0	25	133	96	9	33	138
Greater Sage Grouse	16	0	1	18	26	0	5	31	36	0	8	44	0	0	0	0
Mountain Plover	11	0	1	12	18	0	3	21	25	0	6	30	0	0	0	0
Eastern Yellow-bellied Racer	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Black Footed Ferret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C.11. Net present values of profits, royalties and taxes of existing oil and natural gas (low, mid and high reserve levels) wells within each species' critical habitat.

	Millions of Dollars															
Species Name	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	29	0	3	32	46	0	8	54	62	0	14	76	31	6	11	47
Swift Fox	22	0	2	25	36	0	7	43	49	0	12	61	11	1	4	15
Greater Sage Grouse	7	0	0	7	10	0	2	12	14	0	3	17	0	0	0	0
Burrowing Owl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loggerhead Shrike	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mountain Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eastern Yellow-bellied Racer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Footed Ferret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C.12. Net present values of profits, royalties and taxes of future oil and natural gas (low, mid and high reserve level) wells within each species' range.

	Millions of Dollars															
	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
Species Name	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	20	5	10	35	100	40	53	193	243	107	106	457	48	19	90	157
Burrowing Owl	20	5	10	35	100	40	53	193	243	107	106	457	48	19	90	157
Loggerhead Shrike	20	5	10	35	100	40	53	193	243	107	106	457	48	19	90	157
Swift Fox	18	5	10	32	97	38	52	187	235	103	103	441	5	1	2	8
Greater Sage Grouse	2	0	1	3	25	10	13	48	66	29	28	123	0	0	0	0
Mountain Plover	1	0	1	2	11	4	5	21	25	10	11	47	0	0	0	0
Eastern Yellow-bellied Racer	1	0	1	3	3	1	1	6	5	2	2	9	0	0	0	0
Black Footed Ferret	1	0	1	2	2	1	1	4	4	1	2	6	0	0	0	0

Table C.13. Net present value of profits, royalties and taxes of future oil and natural gas (low, mid and high reserve level) wells within each species' critical habitat.

	Millions of Dollars															
Species Name	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	12	3	7	22	56	22	30	107	134	59	58	251	1	0	0	1
Swift Fox	9	3	5	17	41	16	21	79	95	41	41	178	0	0	0	0
Greater Sage-Grouse	2	0	1	3	5	2	3	10	13	6	6	26	0	0	0	0
Eastern Yellow-Bellied Racer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loggerhead Shrike	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burrowing Owl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mountain Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-Footed Ferret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C.14. Net present values of profits, royalties and taxes of all oil and natural gas (low, mid and high reserve levels) wells within each species' range.

Millions of Dollars

Species Name	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Burrowing Owl	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Loggerhead Shrike	69	5	16	91	180	40	69	288	352	107	132	591	203	58	144	405
Swift Fox	67	5	15	87	176	38	67	281	343	103	128	574	101	10	35	147
Greater Sage Grouse	18	0	2	21	51	10	18	79	101	29	36	167	0	0	0	0
Mountain Plover	13	0	2	15	29	4	9	42	50	10	16	77	0	0	0	0
Eastern Yellow-bellied Racer	2	0	1	3	4	1	2	6	5	2	2	10	0	0	0	0
Black-Footed Ferret	1	0	1	2	3	1	1	4	4	1	2	7	0	0	0	0

Table C.15. Net present values of profits, royalties and taxes of all oil and natural gas (low, mid and high reserve levels) wells within each species' critical habitat.

Millions of Dollars

Species Name	Natural Gas (Low)				Natural Gas (Mid)				Natural Gas (High)				Oil			
	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot	Prof	Roy	Tax	Tot
Sprague's Pipit	41	3	9	54	102	22	38	162	196	59	73	327	31	6	11	49
Swift Fox	32	3	8	42	77	16	29	121	144	41	53	238	11	1	4	15
Greater Sage Grouse	8	0	1	10	15	2	5	22	28	6	9	43	0	0	0	0
Eastern Yellow-bellied Racer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Loggerhead Shrike	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burrowing Owl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mountain Plover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-Footed Ferret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

There are large differences in the size of species' ranges within these eight species, and as a result there are large differences in the value of oil and natural gas NPVs amongst the eight species. Range size is the largest driver for differences in total NPV values. Loggerhead Shrike, Burrowing Owl, and Sprague's Pipit ranges cover the entire South of the Divide study area, and as such they have the largest oil and gas NPVs within their range. The remaining species listed by decreasing range sizes (and also decreasing oil and gas NPVs) are Swift Fox, Greater Sage Grouse, Mountain Plover, Black-footed Ferret and Eastern Yellow-bellied Racer (Table C.16). However, location of range also affects NPVs. Oil values are concentrated in the north-central part of the study area (Figure C.18)), and therefore any ranges that contain this area receive a large increase to their NPV.

For half the species at risk included in this analysis, critical habitat has been designated almost entirely within Grasslands National Park. However, Sprague's Pipit, Swift Fox, Greater Sage Grouse and Loggerhead Shrike have critical habitat designated outside the national park. The park's mineral rights are not available for development (Pat Fargey, pers. comm.); nonetheless, natural gas land values within the park have been included in these tables to provide insight into the true opportunity cost of forgoing oil and natural gas exploration within these eight species' critical habitats and ranges[67]. Species listed from largest to smallest critical habitat designated are Sprague's Pipit, Swift Fox, Greater Sage Grouse, Loggerhead Shrike, Burrowing Owl, Mountain Plover, Black-footed Ferret, and Eastern Yellow-bellied Racer. It's unsurprising that the order of NPVs for oil and natural gas land values closely follow the same order. However, location can also impact the oil and gas NPV for the species. Sprague's Pipit and Swift Fox are the only species whose critical habitat covers any of the South of the Divide's current or potential oil development (Table C.17).

Table C.16. Oil and natural gas (low, mid, and high reserve level) NPVs per unit area ($/acre) for each species' range.

		NPV of Profits ($/acre)			NPV of Profits, Royalties and Taxes ($/acre)		
Species Name	Range Area (10,000 acres)	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil
Sprague's Pipit	343	79	112	162	144	202	290
Burrowing Owl	343	79	112	162	144	202	290
Loggerhead Shrike	343	79	112	162	144	202	290
Swift Fox	304	55	91	146	77	141	237
Mountain Plover	41	31	73	124	36	103	190
Greater Sage Grouse	95	19	54	106	22	83	175
Eastern Yellow-bellied Racer	26	6	14	21	11	24	37
Black Footed Ferret	36	3	7	11	6	12	19

[67] Table 5.1 and Table 5.2 include natural gas land values for each of the species' ranges and critical habitats, respectively, when natural gas land values within Grasslands National Park are excluded.

Table C.17. Oil and natural gas (low, mid, and high reserve level) NPVs per unit area ($/acre) for each species' critical habitat.

		NPV of Profits ($/acre)			NPV of Profits, Royalties and Taxes ($/acre)		
Species Name	Habitat Area (1000 acres)	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil	Natural Gas Low and Oil	Natural Gas Mid and Oil	Natural Gas High and Oil
Sprague's Pipit	1515	48	88	150	68	139	248
Swift Fox	1004	42	87	154	57	136	253
Greater Sage-Grouse	662	12	23	42	15	34	65
Eastern Yellow-bellied Racer	1	1	2	4	1	5	10
Burrowing Owl	3	0	0	4	0	5	11
Mountain Plover	3	0	0	4	0	5	11
Black-footed Ferret	3	0	0	4	0	5	11
Loggerhead Shrike	33	0	0	2	0	3	6

There is the potential to mitigate some of the lost oil and gas revenues through alternative drilling practices, technological advancements in resource extraction, or simply a better understanding of the relationships between resource extraction and species at risk. Subsurface resources can be extracted from areas adjacent to critical habitat location through the use of directional drilling (ER/NEB 2008). Advancements in policy or technology may also be able to mitigate the harmful effects of oil and gas on species at risk and, therefore, reduce lost oil and gas revenues. For example, two of the major drivers behind the avoidance of natural gas well sites by Sprague's Pipits are the creation of lease roads (linear disturbance) and the seeding of lease sites and roadways to non-native species such as crested wheatgrass (Stephen Davis pers. comm.). Policies that promote multiple wells in one location and reseeding to native species would reduce linear disturbances and invasive species without sacrificing the ability to extract subsurface resources.

D Appendix: Agricultural Land Values

Agricultural land is often valued on the real-estate market using a combination of historical land sales in the area and the parcel of land's assessed value. Statements like "land in this area is selling at 2.3 times assessed value" are often reported when a parcel of land is for sale. This simple land valuation technique is employed within this study to determine the market value of agricultural land in the South of the Divide region. The data used and steps taken to determine the agricultural land market values are discussed in detail below.

For completeness, a hedonic land value model was also run. At the end of this appendix, the land values resulting from this model are discussed, and compared to the results obtained using the assessment values. The discussion of this model is simply included to provide additional information. The true value of the hedonic model is discussed in Appendix E with respect to the opportunity cost of land-use conversions in the region.

D.1 The Land Transaction Data

Transaction data were purchased for the South of the Divide region from the Saskatchewan Farmland Security Board (FLSB). Data were able to be purchased based on Rural Municipalities, and as such, information was purchased for the 15 Rural Municipalities (RMs) included within the South of the Divide region (Table D.1). A total of 26 725 land transactions were made in the 15 RMs between the years of 1993 and 2011.

Table D.1.The rural municipalities (RMs) included within the South of the Divide planning area and their 2001 and 2006 rural populations (Saskatchewan Bureau of Statistics 2001).

#	RM Name	RM No.	2006 (2001) Population[68]	#	RM Name	RM No.	2006 (2001) Population
1	Reno	51	462 (457)	9	Lone Tree	18	105 (190)
2	Maple Creek	111	1167 (1156)	10	Wise Creek	77	222 (257)
3	Piapot	110	392 (424)	11	Auvergne	76	329 (355)
4	White Valley	49	418 (470)	12	Glen McPherson	46	112 (126)
5	Frontier	19	323 (319)	13	Mankota	45	382 (430)
6	Arlington	79	413 (371)	14	Waverly	44	422 (444)
7	Grassy Creek	78	305 (401)	15	Old Post	43	394 (475)
8	Val Marie	17	479 (481)				

The information provided by the FLSB included legal land location, RM name and number, acres, price, sale date, purchaser, vendor, and whether the transaction was a

[68] These population numbers do not include populations of towns or villages within the RM and instead reflect the rural population within the study area; the total rural population in these 15 RMs is 5 925. The rural population would be the population most impacted by land-use changes required to protect species at risk. Data source is the 2001 and 2006 Canadian census: http://www.stats.gov.sk.ca/stats/population/SaskCensusPopulation.pdf.

family sale or arm's length transaction. A series of steps was taken to clean the data. The following steps outline the procedure:

1) Removed all transactions with a price less than $5/parcel of land
    a. Most of these were land shuffles between the government, or title changes within families
2) Removed all transactions with a sale value less than $31.25/acre since this was the lowest assessed value present in the South of the Divide area
    a. Again, these were often land shuffles between government or families
3) Removed all transactions that were for parcels of land less than 100 acres
    a. Allowed the removal of any quarter sections divided into multiple subdivisions etc.
    b. Our transactions were supposed to represent the value of an agricultural quarter section, and not smaller parcels of land sold as subdivisions or acreages
4) Removed all transactions that were for debt settlement reasons
    a. Removed due to the inability to ascertain whether or not these values were indicative of market values
5) Removed all transactions that were outside the South of the Divide boundary
    a. The South of the Divide region follows watershed boundaries, and not RM boundaries; thus, some of the transaction data purchased was for land located outside the study region
6) Converted all prices into 2008 dollars using the consumer price index
    a. This allowed the prices to be inflation adjusted between years of land sales

After the six steps stated above were carried out, a total of 6499 usable transactions remained. Of these 6499 transactions, 3600 were arm's length transactions, and 2899 were family sales. Only arm's length data were used in this analysis (see section D.4.1.4.1 for a discussion on the quality of family transactions). The following descriptive statistics provide a snapshot of the arm's length transaction data available (Table D.2). Figure D.1 shows the spatial distribution of land sales throughout the South of the Divide region classified by family and arm's length transactions. The lack of transactions within several key areas of the region is noteworthy. These transaction information gaps include government holdings – parks, community pastures, etc. – that are key habitat areas for many of the species at risk. However, assessed land values are available for these areas and can be used to fill in the gaps.

Table D.2. Summary of the arm's length transactions data (n = 3600) used to calculate the market value of agricultural land in the South of the Divide region.

	Arm's Length Land Transactions			
	Min	**Mean (St. Deviation)**	**Max**	**Number of Transactions (%)**
Price/parcel* ($)	6 662	38 959 (21 102)	442 460	-
Size (Acres)	102	158.80 (3.92)	176	-
Price/Acre	42.44	245.50 (133.97)	2 765.40	-
Year	1993	2001 (4.99)	2011	-
Family Transactions	-	-	-	0 (0%)
Arm's Length Transactions	-	-	-	3600 (100%)
1993	-	-	-	11 (0.31%)
1994	-	-	-	172 (4.78%)
1995	-	-	-	301 (8.36%)
1996	-	-	-	315 (8.75%)
1997	-	-	-	205 (5.69%)
1998	-	-	-	315 (8.75%)
1999	-	-	-	201 (5.58%)
2000	-	-	-	229 (6.36%)
2001	-	-	-	228 (6.33%)
2002	-	-	-	123 (3.42%)
2003	-	-	-	195 (5.42%)
2004	-	-	-	134 (3.72%)
2005	-	-	-	151 (4.19%)
2006	-	-	-	215 (5.97%)
2007	-	-	-	211 (5.86%)
2008	-	-	-	234 (6.50%)
2009	-	-	-	170 (4.72%)
2010	-	-	-	189 (5.25%)
2011	-	-	-	1 (0.03%)

* Prices are adjusted for inflation into 2008 dollars.

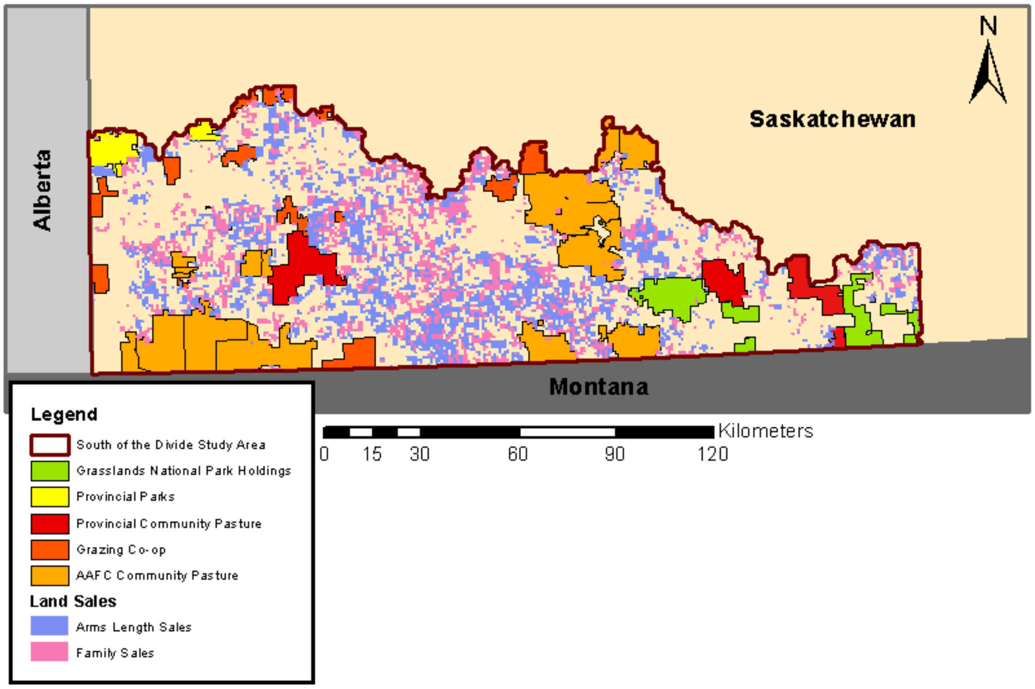

Figure D.1. The spatial distribution of family and arm's length transactions within the South of the Divide region.

D.2 The Assessment Data

Land assessments in Saskatchewan are handled by the Saskatchewan Assessment Management Agency (SAMA). SAMA coordinates a re-valuation of all properties in the province every four years to coincide with a new base date. The 2009 re-valuations used within this study used June 30th 2006 as their base date (SAMA 2007). While residential and commercial properties were valued using a market value standard for the first time in 2009, agricultural property does not use a market value assessment procedure. The assessment process for agricultural land only accounts for the productive capability of the land and does not account for any subsurface resources, or the value of the land for any other competing uses. Arable and pasture land have separate assessment procedures, but both use a regulated property assessment valuation standard. The assessment methods are discussed below.

D.2.1 Arable Land

The assessed value of arable agricultural land is determined by the application of the formula $LV = PR \times E \times PF \times U$ where LV is assessed value of land, PR is productivity rating, E is economic factors, PF is provincial factor and U is the number of land units. The formula can be further broken down into the factors making up its component parts. The final formula for the calculation of the assessed value of arable land is listed first followed by the breakdown of the formula into its sequentially calculated steps (SAMA 2007):

$$LV = \big(C + OM + T\,(P \times PAF)\big) \times A - dep \times Phys \times Econ \times PF \times U$$

$$MR = \big(C + OM + T\,(P \times PAF)\big)$$

$$PR = MR \times (A - dep \times Phys)$$

$$FR = PR \times Econ$$

$$AVR = FR \times PF$$

Where

LV = assessed value of arable land;

C = climate rating;

OM = organic matter rating;

T = texture rating;

P = soil profile rating;

PAF = soil profile adjustment factor;

MR = master rating – this is the base productive capacity calculation for arable land. It is composed of the 5 components listed above. These components, climate, organic matter, soil texture and soil profile, are believed to have a direct effect on soil productivity. The MR units are index points/acre with the maximum score possible being 100 index points/acre;

$A - dep$ = A-depth factor that makes adjustment for the depth of the A soil horizon;

$Phys$ = physical factors that reduce the productivity of the soil;

PR = productivity rating – this is the MR adjusted to depth of A horizons and physical factors that may reduce soil productivity. The rating is in index points/acre;

$Econ$ = economic factors that affect the average cost of production. These factors include stones, topography, natural hazards, tree cover, and miles to market;

FR = final rating – this is the productivity rating adjusted for economic factors. The final rating is in index points/acre;

PF = provincial factor is a conversion factor used to convert index points/acre into $/acre. The provincial factor for arable land is $6.60/index point;

AVR = assessed value rating – this is the final rating multiplied by the provincial factor. The AVR units are $/acre;

U = size of land unit (acres).

Thus, the land assessment process for arable land first calculates productivity (max of 100 index points), and then adjusts the productivity by using physical and economic factors that may reduce productivity. It then convents the index points into a usable $/acre format and then calculates the value of a quarter section based on its size and its $/acre productivity calculation.

D.2.2 Non-arable Land

Calculating the assessed value for non-arable land closely resembles the calculation for arable land. However, there are significant enough differences to warrant a separate discussion of the non-arable procedure. The assessed value of non-arable (pasture and hay land) is determined by the application of the formula $LV = R \times PF \times U$ where LV is assessed value of land, R is a rating factor, PF is provincial factor and U is the number of land units. Pasture land will be discussed first in greater detail followed by a detailed discussion on assessment calculations on hay land.

D.2.2.1 Pasture Land

The following series of calculations outline the calculation of assessed values for pasture land in Saskatchewan (SAMA 2007):

$$CC = Range \times Veg \times Tree \times Water$$

$$CC \rightarrow R$$

$$LV = R \times PF \times U$$

Where

CC = carrying capacity – this is a measure of the potential productivity of pastureland. Carrying capacity measures the capability of a parcel of pasture land to support grazing livestock without degrading the pasture's health;

$Range$ = range site carrying capacity – range sites are determined based on soil moisture (soil texture, soil depth. soil organic matter, topography, and climate), nutrients (soil organic matter, soil texture and soil parent material), and salinity which influence pasture productivity. Each range site is assigned a carrying capacity (AUM/quarter section) based on the ecoregion in which it is found within the province;

Veg = vegetation type adjustment – this adjusts for productivity based on whether or not a pasture is native or non-native species. It is assumed that seeded pastures have higher productivity and thus their carrying capacity is adjusted upwards;

$Tree$ = tree cover adjustment – carrying capacity is adjusted downwards if shrub or tree cover is above a threshold value;

$Water$ = water table adjustment – the presence of a high water table allows the carrying capacity to be adjusted upward by a factor of 2 (ie. It doubles the effective carrying capacity of the pasture);

R = land rate – the land rate is assigned based on the carrying capacity calculated for a parcel of land. A table within the SAMA manual (SAMA 2007) relates carrying capacity (AUM/quarter section) to a land rate;

PF = provincial factor – this is a conversion factor that changes the land rate into a $/acre value. In the case of pasture land this conversion factor is $5.75/acre/land rate;

U = land units (acres);

LV = assessed value of pasture land – this is the product of the calculated $/acre value and the size of the land parcel (acres).

The process for calculating the assessed value of pasture land requires first the calculation of the parcel's carrying (or grazing) capacity and then the conversion of this carrying capacity into a land rate that is then adjusted using the provincial factor of $5.75/acre/land rate.

D.2.2.2 Hay Land

The following set of calculations explains the calculation of the assessed values for hay land in Saskatchewan (SAMA 2007):

$$LV = R \times PF \times U$$

Where

LV = assessed hay land value;

R = land rate – this is based on a table outlining whether a parcel of land is able to be harvested annually or biannually as well as its yield (tons/acre) when it is harvested;

PF = provincial factor – this is a conversion factor that changes the land rate into a $/acre value. In the case of hay land this conversion factor is $5.75/acre/land rate (the same conversion as in the case of pasture land);

U = land unit (acres).

Calculating assessed land values for hay land is relatively straightforward. A land rate is assigned to a parcel of land based on its forage yield and its frequency of harvest. In turn, that land rate is converted to a $/acre value. Each parcel of land can then have its assessed value calculated by multiplying its size (acres) by its unit price ($/acre).

D.2.3 The Location and Values of Land Assessments in the South of the Divide Region

As mentioned briefly above, the assessment data used within this project was re-evaluated in 2009 using a base date of 2006. The data was provided by SAMA to Ed Beveridge at the Saskatchewan Ministry of Environment who had a GIS technician, Barry Otterson, join the data to the South of the Divide Cadastral spatial layer. As a result of the join, a total of 21 532 quarter sections within the study region had assessed values assigned to them.

Table D.3 displays the breakdown of land assessment categories within the region and some simple descriptive statistics of the assessed values assigned to each category. Figure D.2 is a map of the spatial distribution of appraised land values in the region.

Table D.3. Summary statistics of assessed land values (2008 dollars) in the South of the Divide region broken down by land use.

	Arable Land	Hay and Pasture Land	Other Lands*	All Land Uses
Number of Quarters	7 613	13 906	13	21 532
Minimum Assessed Value	941	105	16 625	105
Mean Assessed Value (Std. Deviation)	390929.85 (7 573.26)	20 495.32 (6 794.19)	121 666.85 (145 142.16)	27 427.81 (12 389.37)
Maximum Assessed Value	194 062	166 249	463 825	463 825

*Commercial and Industrial land (n = 9) and mixed agricultural land (n = 4) make up the other category

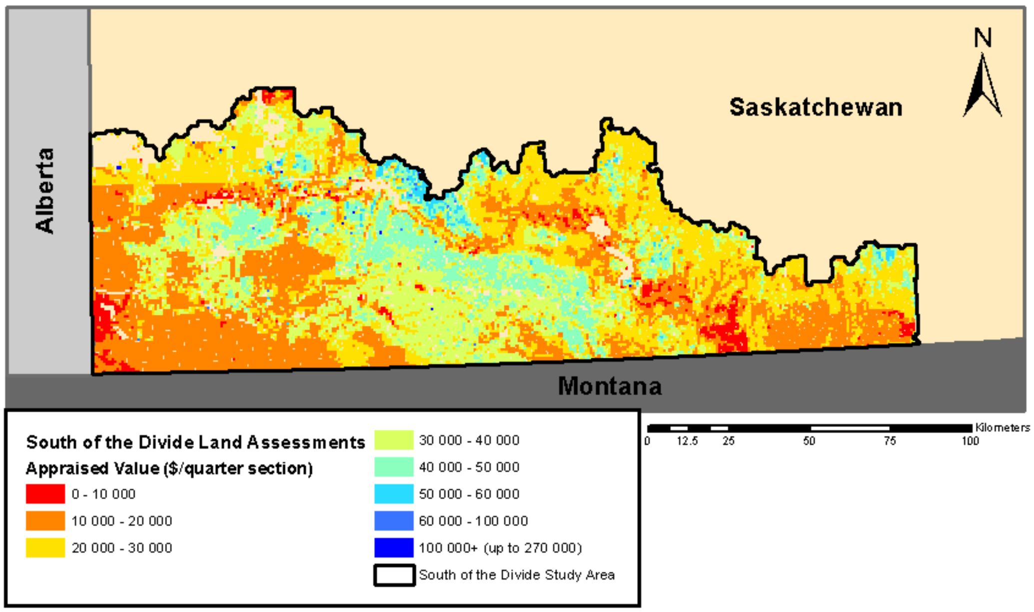

Figure D.2. Appraised land values (2008 dollars) for 21534 quarter sections in the South of the Divide region.

D.3 Calculating the Agricultural Land Market Values

Market values were calculated by taking a ratio of sale prices and assessed values and applying these ratios to the assessed values of all the quarter sections in the region. The methods used to calculate these ratios and market values are presented in the following sections.

D.3.1 Creating the Transaction to Assessment Ratio Spatial Layer

The 3600 quarter sections with transaction data were extracted from the land assessment layer using ArcMap 10.0. The extracted quarter sections – with their assessed land values – were joined with their corresponding transaction data. A total of 3314 matches were made. Once the quarter sections' information was joined, the land assessment values were brought from 2006 dollars into 2008 dollars using the consumer price index. A ratio of assessed value to sale value was then calculated for the 3314 quarter sections using the simple formula ($sale\ price/acre \div assessed\ value/acre$). The result is a map (Figure D.3) of sale price to assessed value ratios for the South of the Divide region.

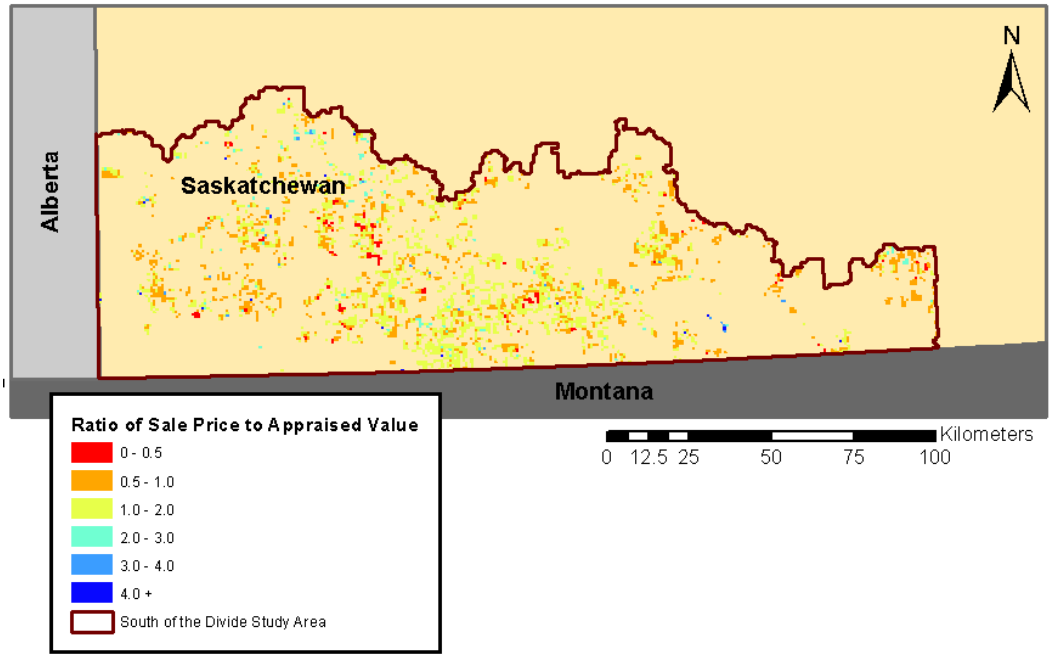

Figure D.3. The spatial location of land value ratios within the study region.

D.3.2 Applying the Ratios to all Quarter Sections

After the 3314 ratios were calculated, the ratios were then spatially joined to all 21 532 quarter sections with assessed land values in the study area (Figure D.4). Quarter sections were assigned the ratio located nearest to them. The result is that all 21 532 quarter sections received a land value ratio that best represented the market surrounding the quarter section.

Table D.4 provides descriptive statistics summarizing ratio values in the region and also provides information on the distances between quarter sections and the quarter sections from which they received their land value ratios.

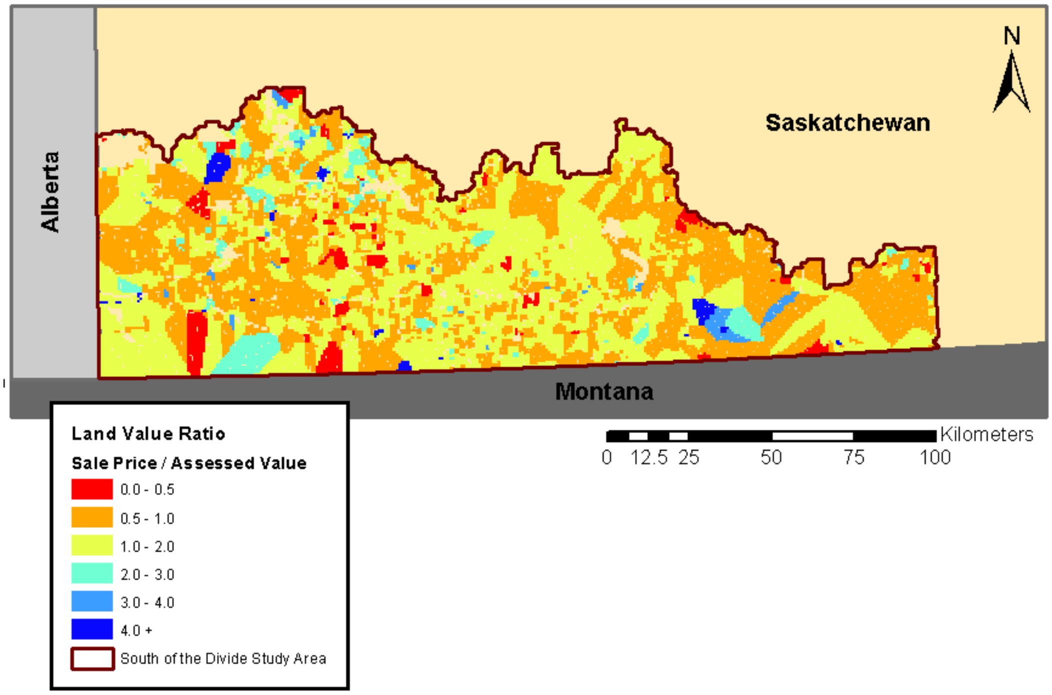

Figure D.4. Map of ratios applied to all quarter sections with assessed values in the South of the Divide region (n = 21 531).

D.3.3 Calculating Land Values for the South of the Divide Region

Land values were calculated within ArcMap 10.0 using the spatial layer containing assessed values and land value ratios. The formula used to estimate land value is simple – $[(ratio \times assessed\ value/acre) \times acres]$ – and resulted in 21 532 quarter sections with estimated market values.

D.3.4 The Land Values

The average land value ratio was 1.15. On average, the ratios were highest for 'other' lands (1.20), and lowest for cultivated lands (1.10; Table D.4). The average distance between a quarter section and a quarter section with a sale price to assessed value ratio was greatest for hay and pasture lands (2.86 km), and lowest for cultivated lands (0.33 km). The greatest distance from a quarter section with a ratio was 18.4 km (Table D.4). The very southwest corner of the study area contains the quarter sections that are the furthest distance from other quarter sections with land value ratios. A total of 6 549 quarter sections were directly adjacent to a quarter with a land value ratio (i.e. distance of zero meters). The average land value in the region is $30 836.91 for all 21 532 quarter sections considered. Arable lands had a higher average market value than hay and pasture lands at $43 519.85 ($271.99/acre) and $23 783.21 ($148.64/acre), respectively. Land values are displayed in Figure D.5.

Table D.4. A summary of the land value ratios, distance between parcels of land and parcels with a land value ratio, and the resulting land market values (2008 dollars) for quarter sections of each land use type within the watershed.

	Arable Land	Hay and Pasture Land	Other Lands*	All Land Uses
Number of Quarter Sections	7 613	13 906	13	21 532
Minimum Ratio	0.2	0.2	0.9	0.2
Mean Ratio (Std. Deviation)	1.10 (0.46)	1.18 (0.85)	1.20 (0.40)	1.15 (0.74)
Maximum Ratio	9.7	26.3	2.4	26.3
Minimum Meters to Ratio	0	0	0	0
Mean Meters to Ratio (Std. Deviation)	328.86 (784.77)	2 865.01 (3064.11)	850.41 (743.20)	1 967.09 (2784.21)
Maximum Meters to Ratio	9 279.2	18 404.6	2 311.5	18 404.6
Minimum Market Value	884.11	89.06	21 422.64	89.06
Mean Market Value (Std. Deviation)	43 519.85 (19 259.92)	23 783.21 (17 544.81)	148 789.47 (20 085.63)	30 836.91 (21 205.20)
Maximum Market Value	306 778.79	480 939.57	658 969.34	658 969.34

*Commercial and Industrial land (n = 9) and mixed agricultural land (n = 4) make up the other category

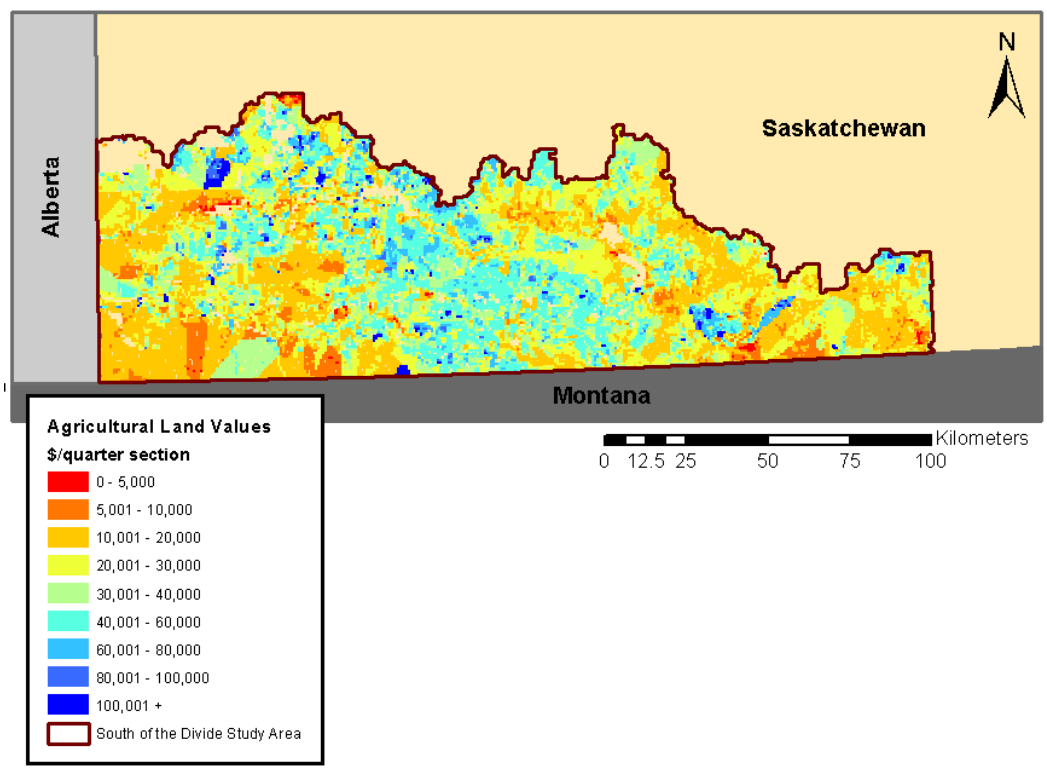

Figure D.5. Agricultural land values calculated using sales transaction and assessment data.

D.4 A Hedonic Model of Agricultural Land Values

A hedonic land value model was run using land transaction data for the region. This section outlines in detail the information used, the steps taken and the results of the hedonic land value analysis. The land values resulting from this model are discussed, and compared to the results obtained using the assessment values. The discussion of this model is simply included to provide additional information. The true value of the hedonic model is discussed in Appendix E with respect to the opportunity cost of land-use conversions in the region.

D.4.1 Hedonic Valuation

Hedonic models are commonly used in microeconomics to determine the values of individual characteristics of a whole, or in turn to estimate the value of a whole if information on its individual parts are known but its overall value is not. The most commonly cited example in econometric textbooks is the example of a house. A house can be broken down into its characteristic parts – number of bathrooms, bedrooms, the square footage, the neighbourhood in which it is located, and so forth. Houses that have been sold in the market and their characteristics can be used to make a simple multiple linear regression model that provides a formula allowing market value to be calculated based on the house's characteristics. As mentioned above, this can allow two useful things to result. One, the value of a bathroom or garage can be determined, but also, the market value of a house with a specific set of characteristics can be estimated using the resulting formula.

Rather than use a hedonic model to determine the value of houses, the hedonic valuation technique will be employed here in another commonly used manner, the estimation of the value of agricultural land. In competitive markets, the price of land equals the discounted sum of expected net returns obtained through the allocation of land to its highest valued use (Plantinga *et al.* 2002). In this way, land prices reflect the value of current land uses, as wells as the value of potential land uses (Plantinga *et al.* 2002). In the case of agricultural land, potential uses can include any number of potential land use changes including, but not limited to, urban development.

According to Shi *et al.* (1997), there are two broad categorizes into which econometric studies of agricultural land prices can be placed. The first category includes the 'rent capitalization models' which use net returns (or proxies for net returns) to agricultural activities along with other explanatory variables. The second category includes models that attempt to explain urban-rural fringe areas through the use of primarily nonfarm factors. A few models have combined the two approaches. Urban-rural fringe studies gain their importance in areas where it is desired to convert agricultural land into residential developments, second homes (or cottages etc.), recreational enterprises etc. Unlike the study conducted by Shi *et al*. (1997), there are no urban areas affecting land values in the South of the Divide region. There is only a scattering of small towns (populations less than 1000) within the region. Therefore, a rent capitalization model will be used.

The greatest source of development within the area is resource extraction which is concentrated in the central part of the region. However, surface and subsurface resources are owned separately within the province of Saskatchewan, and subsurface resource considerations are not included here, but rather left to be discussed in

Appendix C. Resource extraction only affects land values to the extent that land managers are compensated for surface disturbance by the subsurface rights holder during the production life of a well. As such, it is likely that the expected best use of land for the vast majority of the area will remain to be agricultural production. Thus, market values should closely approximating agricultural use values (Shi *et al.* 1997; Phipps 1984). As a result, this rent capitalization hedonic model will be able to closely estimate the value of agricultural land.

Land markets are complex and the variables that should be included within a land valuation model, or even the number of variables that should be included within the model, are never easily decided upon (Xu *et al.* 1993). Shi *et al.* (1997) provides a summary of regression models used to estimate farmland values. They found that the suite of variables often used within cross sectional studies include seller characteristics, buyer characteristics, farm income, yield or production, capital gains, parcel size, other land characteristics, and location. Xu *et al.* (1993) included land characteristics such as the proportion of total acres that was used as pasture, land capability ratings, and length of windbreak in feet per acre. Other characteristics that have been included are variables indicating population density and growth (Palmquist and Danielson 1989). The variables included are a function of data availability as well as the bigger question that is being addressed through the use of the model.

D.4.1.1 The Transaction Data

The same transaction data were used for the hedonic model as were used for the assessment method of land value calculations discussed above. However, after the data was cleaned (following the same six steps listed above), all 6499 usable transactions were used in the hedonic model. A total of 3600 arm's length transactions remained, and 2899 family sales remained in the data set. It was decided that family transactions would be kept in the data set until a model could be run to determine whether or not they should be excluded from the data set.

The following descriptive statistics provide a snapshot of the transaction data available (Table D.5). Figure D.6 shows the spatial distribution of land sales throughout the South of the Divide region classified by family and arm's length transactions. The lack of transactions within several key areas of the region is noteworthy. These transaction information gaps include government holdings – parks, community pastures, etc. – that are key habitat areas for many of the species at risk. As a result, the ability of the model to predict the value of government lands is limited.

Table D.5. Summary of the transaction data used within the hedonic land model broken down between all transactions (n = 6499) and arm's length transactions only (n = 3600).

	Arm's Length Land Transactions			
	Min	**Mean (St. Deviation)**	**Max**	**Number of Transactions (%)**
Price/parcel* ($)	6 662	38 959 (21 102)	442 460	-
Size (Acres)	102	158.80 (3.92)	176	-
Price/Acre	42.44	245.50 (133.97)	2 765.40	-
Year	1993	2001 (4.99)	2011	-
Family Transactions	-	-	-	0 (0%)
Arm's Length Transactions	-	-	-	3600 (100%)
1993	-	-	-	11 (0.31%)
1994	-	-	-	172 (4.78%)
1995	-	-	-	301 (8.36%)
1996	-	-	-	315 (8.75%)
1997	-	-	-	205 (5.69%)
1998	-	-	-	315 (8.75%)
1999	-	-	-	201 (5.58%)
2000	-	-	-	229 (6.36%)
2001	-	-	-	228 (6.33%)
2002	-	-	-	123 (3.42%)
2003	-	-	-	195 (5.42%)
2004	-	-	-	134 (3.72%)
2005	-	-	-	151 (4.19%)
2006	-	-	-	215 (5.97%)
2007	-	-	-	211 (5.86%)
2008	-	-	-	234 (6.50%)
2009	-	-	-	170 (4.72%)
2010	-	-	-	189 (5.25%)
2011	-	-	-	1 (0.03%)

* Prices are adjusted for inflation into 2008 dollars.

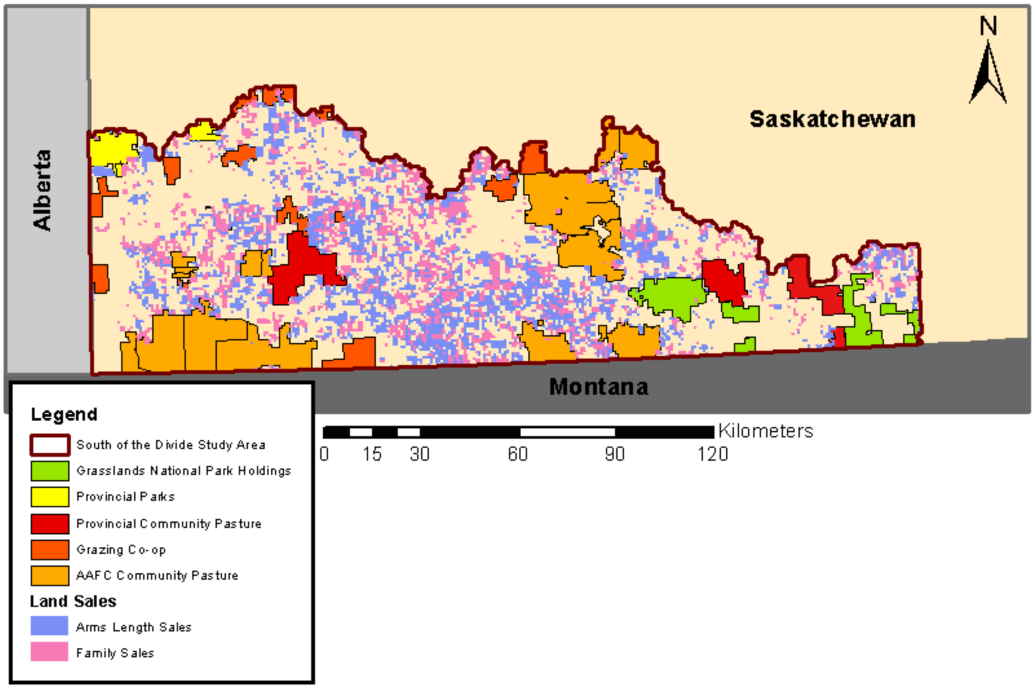

Figure D.6.The spatial distribution of family and arm's length transactions within the South of the Divide region.

D.4.1.2 Additional Characteristics Used within the Hedonic Model

The transaction data provides information on year of sale, size of land parcel, and the price of land parcel; however, in order to run an informative and useful land model, there is a need for additional land characteristics. These additional land characteristics were collected from GIS layers provided by the Saskatchewan Ministry of Environment and the Canadian Wildlife Service. The overall categories of explanatory variables were: type of sale, time of sale, size of parcel, location of parcel, oil and gas development, population trends, land ownership, land cover/use, and land quality. The land characteristics used within the model are outlined in more detail in Table D.6 below.

Table D.6. Land characteristics and explanatory variables used within the hedonic agricultural land model.

Characteristic	Variable Name	Description	Source
Sale type	FAM	Dummy variable indicating that the sale of the quarter section was between family members	Farmland Security Board (Transaction Quarters)
Legal land location	LLD	Legal land location of all quarter sections in the area	Farmland Security Board (Transaction Quarters) SOD_Land_Ownership GIS Layer SK Ministry of Environment (All Quarters)
Price per acre	PRICEAC	Unit price of land ($/acre) for all quarter sections with sale data available	Farmland Security Board (Transaction Quarters)
Parcel size	ACRE	The size of the land parcel in acres	Farmland Security Board (Transaction Quarters) SOD_Land_Ownership GIS Layer SK Ministry of Environment (All Quarters)
Year of sale	YEAR1, YEAR2, … YEAR 18, YEAR19	Dummy variables representing year of sale (Year1 = 1993, Year2 = 1994, …Year18 = 2010, Year19 = 2011)	Farmland Security Board (Transaction Quarters)
Location (north – south and east – west)	TWN, RNG	Twn is the township in which a quarter section is located; acts as a north – south control Rng is the range in which a quarter section is located; acts as an east – west control	Farmland Security Board (Transaction Quarters) SOD_Land_Ownership GIS Layer SK Ministry of Environment (All Quarters)
Oil and gas development	GWELL, OWELL	A count of the number of active wells on a quarter section GWell = active gas wells, Owell = active oil wells	Saskatchewan Ministry of Energy and Resources InfoMap
Rural municipality (RM) population	POSGWTH	A dummy variable that equals 1 if there was positive rural population growth (2001 to 2006) in the RM in which the quarter section is located	Rural_Municipality GIS Layer SK Ministry of Environment SK Bureau of Statistics Saskatchewan
Land ownership	AC, NP, IP, IR, CE, PF	Dummy variables indicating land ownership (AC = agricultural crown land, NP = national park, IP = irrigation project, IR = Indian reserve, CE = conservation easement, PF = private farmland and all other minor categories)	SOD_Land_Ownership GIS Layer SK Ministry of Environment (All Quarters)
Land cover and use	HP, CRP, NG	Dummy variables indicating the quarter sections predominant land use (HP = hay and tame pasture, CRP = annual crops, NG = native grasslands)	Land_Cover GIS Layer from the Canadian Wildlife Service
Land cover and use	WTRPCNT, WDPCNT, HPPCNT, CRPPCNT, NGPCNT	Variables representing the percentage of the quarter sections surface area that is made up of different land covers (WtrPcnt = % water, WdPcnt = % woody vegetation, HpPcnt = % hay or tame pasture, CrpPcnt = % annual crops, NgPcnt = % native grass)	Land_Cover GIS Layer from the Canadian Wildlife Service
Land capability	MS, S, VS, NC	Dummy variables indicating the predominant land capability classifications of each quarter section (MS = moderately severe or 3, S = severe or 4, VS = very severe or 5, NC = no annual crop capability or 6)	Land_Capability GIS Layer from the Canadian Wildlife Service
Ecosite classification	SALTY, HILLY, WET, OVERFLOW, LOAMY, OTHER	Dummy variables indicating the predominant ecosite of each quarter section (Salty = all solonetzic and saline ecosites, Hilly = thin and badland ecosites, Wet = marsh, dry meadow and wet meadow ecosites, Overflow = overflow ecosite, Loamy = loam and sandy loam ecosites, Other = clay and gravel ecosites)	Rangeland_Ecosite GIS Layer from the Canadian Wildlife Service

The land characteristics were joined to the transaction data using several different methods. The transaction data already included the variables FAM, LLD, PRICEAC, ACRE, YEAR1,...,YEAR19, TWN, and RNG. GWELL and OWELL variables were linked to the transactions using their legal land description (LLD) since the Saskatchewan Oil and Gas InfoMap (Saskatchewan Industry and Resource 2011) provides the legal land description for all oil and gas wells within the province. POSGWTH was linked to transaction quarter sections using their rural municipality name. Land ownership (AC, NP, IP, IR, CE and PF) information was linked to transaction quarter sections using their legal land descriptions. Within the SOD_Land_Ownership GIS layer, each quarter section is given a legal land description as well as information regarding its land management type (private, public etc.). Land cover, land capability and ecosite classification variables were linked to the transaction quarters within ArcMap 10.0 using the Tabulate Area function. This function calculates the area of each land cover, land capability and ecosite type included within each quarter section. Percentage and dummy variables were then created.

A quick summary of the land characteristics used in the hedonic model (in addition to that provided by the Saskatchewan Farmland Security Board) is included in Table D.7. There were three parcels within the data that clearly had errors in the size of the quarter section (SW 21-05-30 W3, SE 24-02-27 W3, and SW 29-02-26 W3) and the quarter section acres were simply set at 160 acres. Otherwise, parcel size was calculated based on the land ownership file provided by the Canadian Wildlife Service.

Table D.7. Summary of land characteristic data used to estimate the hedonic model and the land characteristics used to predict land values from the estimated model.

	Quarter Sections with Arm's Length Transaction Data					All Quarter Sections within the South of the Divide Study Region				
Name	**N**	**Mean**	**St. Dev**	**Min**	**Max**	**N**	**Mean**	**St. Dev**	**Min**	**Max**
ACRES	3600	158.800	3.924	102.00	176.00	23934	154.610	32.320	0.00	329.00
GWELL	3600	0.036	0.190	0.00	2.00	23989	0.033	0.189	0.00	5.00
OWELL	3600	0.022	0.201	0.00	4.00	23989	0.020	0.215	0.00	7.00
POSGWTH	3593	0.403	0.491	0.00	1.00	20948	0.410	0.492	0.00	1.00
PF	3600	0.903	0.297	0.00	1.00	23908	0.424	0.494	0.00	1.00
AC	3600	0.040	0.196	0.00	1.00	23908	0.293	0.455	0.00	1.00
NP	3600	0.002	0.044	0.00	1.00	23908	0.036	0.186	0.00	1.00
IP	3600	0.004	0.060	0.00	1.00	23908	0.004	0.061	0.00	1.00
IR	3600	0.028	0.164	0.00	1.00	23908	0.005	0.073	0.00	1.00
CE	3600	0.016	0.125	0.00	1.00	23908	0.005	0.074	0.00	1.00
WDPCNT	3588	1.841	8.551	0.00	92.57	23963	4.904	16.822	0.00	100.71
WTRPCNT	3588	3.154	6.420	0.00	89.94	23963	3.412	9.005	0.00	100.59
NGPCNT	3588	23.080	32.933	0.00	100.38	23963	52.865	42.244	0.00	104.93
HPPCNT	3588	21.783	33.012	0.00	100.28	23963	13.275	26.784	0.00	105.77
CRPPCNT	3588	48.526	43.697	0.00	100.12	23963	23.244	38.138	0.00	100.98
NG	3588	0.249	0.433	0.00	1.00	23963	0.611	0.488	0.00	1.00
HP	3588	0.229	0.420	0.00	1.00	23963	0.146	0.353	0.00	1.00
CRP	3588	0.524	0.499	0.00	1.00	23963	0.262	0.440	0.00	1.00
MS	3360	0.751	0.433	0.00	1.00	22260	0.541	0.498	0.00	1.00
S	3360	0.204	0.403	0.00	1.00	22260	0.357	0.479	0.00	1.00
SALTY	3594	0.133	0.340	0.00	1.00	23908	0.149	0.356	0.00	1.00
HILLY	3594	0.047	0.212	0.00	1.00	23908	0.104	0.305	0.00	1.00
WET	3594	0.001	0.029	0.00	1.00	23908	0.000	0.006	0.00	1.00
OTHER	3594	0.003	0.053	0.00	1.00	23908	0.011	0.106	0.00	1.00

The average parcel size for the study area is 154.61 acres which is very close to the average parcel size (158.80) for the quarter sections used in the linear regression. The average number of gas wells and oil wells per parcel are 0.033 and 0.020 respectively for the entire study area and 0.036 and 0.022 respectively for the quarter sections used in the model (Table D.7). Within the model, private farmland is overrepresented and makes up 90% of the quarter sections; however, within the study area, only 42% of the quarter sections are classified as private farmland by the Canadian Wildlife Service. Agricultural crown land, community pastures and grazing coops were all underrepresented within the hedonic model. Agricultural crown land makes up 30% of the study area, and Grasslands National Park makes up approximately 4% of the area. The remaining 24% of the study area is divided amongst irrigation projects (0.4%), conservation easements (0.5%), Indian reserves (0.5%), community pastures (17%), grazing cooperatives (3%), provincial parks (1%), and small contributions by town sites (0.03%), fish and wildlife lands (0.07%), historic parks, properties and sites (0.05%), regional parks and recreational areas (0.01%), and migratory bird sanctuaries (0.02%).

The quarter sections with sales transactions underrepresented the area of grazing lands in the study area (agricultural crown lands, community pastures and grazing cooperatives), and as a result overrepresented the amount of cropland within the study area. The land base used within the regression model had a total annual cropland cover of 48% compared to the entire study area which only has an annual crop land cover of 23%. Hay lands and tame pastures were also overrepresented in the model with 22% of the land cover compared to an actual cover of only 13% in the study area. The result is that native grasslands are underrepresented in the model with only 23% land cover compared to an actual land cover in the study area of 53%. The dummy variables closely mirror the percentage variables. In the models, cropland, hay and tame pasture lands, and native grasslands make up 52%, 23% and 25% of the quarter sections respectively. However, in the entire study area, cropland, hay and tame pasture lands, and native grasslands make up 26%, 15% and 61% of the quarter sections respectively.

Higher quality land is overrepresented in the models. The highest land capability classification (class 3 meaning moderately severe limitations to crops) makes up 75% of the land in the models, but only makes up 54% of the land in the study area. Class 4 land makes up 20% of the land in the models, and 36% in the study area. Class 5 land makes up a very small portion of the land in both the model and the study area (0.03% and 0.07% respectively). Class 6 land (not capable of supporting annual cropland and limited to the production of native or tame perennial species) makes up 5% of the land base in the hedonic model and 10% of the actual study area's land base.

Loam and overflow ecosites make up the majority of the land base in the regression sample (75%) and in the entire study area (66%). Saline and solonetzic ecosites make up the second largest portion of land in the model and entire study area (13% and 15% respectively). Bandlands and thin soils make up 5% of the model's quarter sections, and a total of 10% of the quarter sections in the entire South of the Divide region. Very small portions of the landscape are made up of clay, gravel, wet and dry meadow, and marsh ecosites.

D.4.1.3 The Models

The hedonic models were run in SHAZAM Professional Edition. A multiple linear regression was run that made use of the Ordinary Least Squares (OLS) estimator. The models that were run included a large number of dummy variables. Working with dummy variables restricts the functional forms that can be used because it is impossible to take the log of 0. Thus, a linear functional form has been selected because of 1) the inability to take the logarithmic of many of the variables, and 2) the variables and interpretation are best suited to a linear form.

The following equations outline the variables used within the models. Both models include a constant, time dummies (years 2010 and 2011 together act as the base case since 2011 had only 1 observation), a gas well count variable, an oil well count variable, township and range variables, a positive growth dummy (negative growth as the basecase), land ownership dummies (private farmland as the basecase), variables indicating the percentage of the quarter section made up of water or woodlands (shrubs and trees), ecosite dummies (using loam and overflow ecosites as the basecase), and land capability variables (using land capabilities of 5 and 6 as the basecase). Each model also contains variables used to indicate the quarter section's land use (native grassland, annual cropland, or hay/tame pasture). The difference between Model D-1 and Model D-2 is in the form that the land use variables take. Model D-1 includes the percentage of each quarter section made up of each land use (native grassland, cropland, and hay/tame pasture), whereas Model D-2 uses land use dummies to indicate the quarter sections' predominant land use (native grasslands as the basecase).

Model D-1

$$\begin{aligned} PRICEAC = {} & CONSTANT + YEAR1 + \cdots + YEAR17 + GWELL + OWELL + TWN \\ & + RNG + POSGWTH + AC + NP + IP + IR + CE + WTRPCNT \\ & + WDPCNT + NGPCNT + HPPCNT + CRPPCNT + SALTY \\ & + HILLY + WET + OTHER + MS + S \end{aligned}$$

Model D-2

$$\begin{aligned} PRICEAC = {} & CONSTANT + YEAR1 + \cdots + YEAR17 + GWELL + OWELL + TWN \\ & + RNG + POSGWTH + AC + NP + IP + IR + CE + WTRPCNT \\ & + WDPCNT + HP + CRP + SALTY + HILLY + WET + OTHER + MS \\ & + S \end{aligned}$$

The models were run with all transaction data (N = 6113) and again with only arm's length transaction data (N = 3360). The lower number of observations (compared to 6499 transactions and 3600 arm's length transactions reported above) is due to the removal of any observations with missing data. When all 6113 transactions were used, one additional variable was added to each model. This variable is FAM and is a dummy variable indicating that the transaction data comes from a land sale that took place between family members (arm's length transactions are used as the basecase). The two models were compared using their goodness of fit measures (R^2) and the coefficient on the FAM sale variable. The more appropriate model was used to calculate both the value of land and the value of land use changes within the study region.

The models were tested for heteroskedasticity using two tests (Whistler *et al.* 2004). The first is a Lagrange Multiplier test that requires a simple auxiliary regression to be run. The auxiliary regression required for the heteroskedasticity test regresses the squared OLS residuals on the model's predicted dependent variable values ($e^2 = constant + \hat{y}$)[69]. The test statistic is the number of observations used in the regression (N = 6113 and 3360) multiplied by the auxiliary regression's R^2. The test statistic is χ^2 distributed with 1 degree of freedom. The second test is the Breusch-Pagan-Godfrey test (Whistler *et al.* 2004). This test regresses the squared OLS residuals on all of the explanatory variables included within the model and a constant ($e^2 = constant + year1 + \cdots + year17 + \cdots + wet + other + ms + s$. The resulting test statistic is the

[69] Where e^2 is the estimated error variance and $\hat{y}$ is the predicted dependent variables.

computed by $\frac{ESS}{2\left(\frac{e^2}{N}\right)^2}$ where ESS is the regression's explained sum of squares, N is the number of observations, and e^2 is the estimated error variance. The test statistic is χ^2 distributed with degrees of freedom equal to $2[K-1]$ where K is the number of explanatory variables in the regression.

Both models were found to have significant heteroskedasticity using the Lagrange Multiplier (LM) and Breusch-Pagan-Godfrey (B-P-G) tests (see Table D.8 and Table D.9) whether they were run with all transaction data or with only the arm's length transaction data. Despite the presence of heteroskedasticity, OLS remains an unbiased estimator. However, the OLS estimator is not efficient (Whistler *et al.* 2004) and the coefficients' variances are biased. Therefore, the initially estimated standard errors are incorrect for the models and hypothesis tests cannot be conducted. Heteroskedasticity can sometimes be an indicator of a model's misspecification (e.g. incorrect functional form). In the case that the model is not misspecified, or its current functional form is desired, the biased standard errors can be corrected by computing White's heteroskedasticity-consistent covariance matrix and recalculating the standard errors. If an efficient estimator is desired, a third option is to use a Generalized Least Squares (GLS) estimator (Whistler *et al.* 2004). Model D-1 and Model D-2 were estimated using an OLS estimator that made use of White's heteroskedasticity-consistent covariance matrix. As such, conclusion can be made regarding the significance of the estimated coefficients.

D.4.1.4 The Results

Table D.8. Summary of results from hedonic land value models run using arm's length transaction data.

	MODEL 1			MODEL 2		
Variable	Estimated Coefficient	Standard Error	P-Value	Estimated Coefficient	Standard Error	P-Value
ACRE	-1.57	0.74	0.03**	-1.38	0.73	0.06*
YEAR1	-59.63	76.45	0.44	-63.22	74.40	0.40
YEAR2	-125.41	20.59	0.00***	-123.94	20.55	0.00***
YEAR3	-106.17	20.30	0.00***	-103.91	20.27	0.00***
YEAR4	-91.63	20.62	0.00***	-92.39	20.47	0.00***
YEAR5	-74.54	20.37	0.00***	-74.57	20.30	0.00***
YEAR6	-36.65	22.37	0.10*	-36.00	22.06	0.10*
YEAR7	-92.97	20.98	0.00***	-91.82	21.09	0.00***
YEAR8	-60.22	20.53	0.00***	-58.53	20.49	0.00***
YEAR9	-38.35	21.27	0.07*	-38.57	21.26	0.07*
YEAR10	-67.83	21.22	0.00***	-67.81	21.20	0.00***
YEAR11	-90.23	20.44	0.00***	-88.56	20.37	0.00***
YEAR12	-61.07	21.71	0.01***	-59.83	21.54	0.01***
YEAR13	-53.04	23.23	0.02**	-54.92	22.91	0.02**
YEAR14	-63.76	21.56	0.00***	-64.61	21.24	0.00***
YEAR15	-58.98	20.29	0.00***	-57.80	20.06	0.00***
YEAR16	-56.78	19.16	0.00***	-57.30	18.93	0.00***
YEAR17	-32.61	19.52	0.10*	-33.24	19.42	0.09*
GWELL	-13.31	6.54	0.04**	-10.28	6.55	0.12
OWELL	35.65	13.50	0.01***	38.84	13.44	0.00***
TWN	4.51	1.64	0.01***	3.32	1.56	0.03**
RNG	-1.17	0.55	0.03**	-0.81	0.55	0.14
POSGWTH	9.23	5.89	0.12	8.14	5.94	0.17
AC	-51.79	10.76	0.00***	-56.44	9.87	0.00***
NP	-21.79	10.67	0.04**	-36.44	9.25	0.00***
IP	7.23	40.47	0.86	-14.05	50.01	0.78
IR	11.83	16.06	0.46	6.83	16.25	0.67
CE	-8.55	18.03	0.64	-11.25	18.11	0.54
WTRPCNT	0.47	0.38	0.23	-0.27	0.33	0.42
WDPCNT	0.78	0.40	0.05**	0.16	0.40	0.70
NGPCNT	0.23	0.28	0.41	-	-	-
HPPCNT	0.95	0.25	0.00***	-	-	-
CRPPCNT	1.19	0.26	0.00***	-	-	-
HP	-	-	-	50.29	7.38	0.00***
CRP	-	-	-	71.03	6.71	0.00***
SALTY	-19.86	7.45	0.01***	-19.61	7.48	0.01***
HILLY	-14.49	9.50	0.13	-17.83	9.48	0.06*
WET	-124.48	44.59	0.01***	-117.71	47.83	0.01***
OTHER	31.42	55.02	0.57	23.50	56.37	0.68
MS	34.14	9.06	0.00***	39.67	8.96	0.00***
S	6.58	9.94	0.51	9.26	9.99	0.35
CONSTANT	452.68	120.20	0.00***	453.95	125.50	0.00***
N		3360			3360	
R^2		0.16			0.15	
ADJUSTED R^2		0.15			0.14	
LOG LIKELIHOOD		-20800.90			-20814.80	
HET TESTS	Test Stat	DF	P-Value	Test Stat	DF	P-Value
LM	4.14	1	0.04**	6.61	1	0.01***
BPG	2513.72	39	0.00***	2361.46	38	0.00***

Note: * significant at 10% level; ** significant at the 5% level; *** significant at the 1% level

Table D.9. Summary of select results from hedonic land value models run using all transaction data (family and arm's length transactions).

	MODEL 1			MODEL 2		
Variable Name	**Estimated Coefficient**	**Standard Error**	**P-Value**	**Estimated Coefficient**	**Standard Error**	**P-Value**
FAM	-28.56	3.71	0.00***	-27.957	3.749	0.00***
N		6113			6113	
R^2		0.11			0.10	
ADJUSTED R^2		0.10			0.10	
LOG LIKELIHOOD		-38943.10			-38962.40	
HET TESTS	**Test Stat**	**DF**	**P-Value**	**Test Stat**	**DF**	**P-Value**
LM	6.13	1	0.01***	7.59	1	0.01***
BPG	16032.47	40	0.00***	15259.64	39	0.00***

Note: * significant at 10% level; ** significant at the 5% level; *** significant at the 1% level

D.4.1.4.1 All transactions versus only arm's length transactions

In general, arm's length transactions are used in models predicting the value of land. Here, family transactions were included in one set of models to determine whether or not they could be included and improve model performance by providing the benefit of additional sales observations. Unfortunately, the ability of the model to predict the variability in land prices was considerably reduced when family transactions were included. The goodness of fit measures were noticeably smaller with the inclusion of the family sales data. The models had R^2s of 10 – 11% when family sales were included as compared to 15 – 16% when only arm's length transactions were considered (Table D.8 and Table D.9). The coefficient on FAM (the sale dummy indicating a family sale) is large, negative and significant (Table D.9) indicating that, on average, parcels of land are sold below market value within families. The results discussed from this point forward are from the results of the two models when only arm's length transactions are used (Table D.8).

D.4.1.4.2 Model D-1 versus Model D-2

Several different criteria were considered when choosing between Model D-1 and Model D-2. The first was model fit. Both models had similar goodness of fit measures and in both models the explanatory variables had coefficients of the expected sign and significance. Moreover, many of the coefficients were nearly identical in magnitude between the two models. The second criterion was quality of the land use data – percentage of a quarter section's area in each land use versus dummy variables indicating a quarter section's predominant land use. However, the dummy variables and the percentage variables closely mirrored each other in their ability to explain the quarter sections in the model (see Table D.7 and its discussion). The third and final criterion was the ease of interpretation, calculation of land-use changes, and calculation of land values. In this respect, Model D-2 which makes use of the land use dummy variables prevails. This model provides a constant $/acre conversion estimate, allows the calculation of land values, and is easily interpreted.

D.4.1.4.3 Model D-2

Model D-2's results are quite similar to Model D-1. The primary difference is in the form that the land use variables take (dummy variables for cropland and hay land rather than percentage variables). When all variables in Model D-2 are set to zero, the average price/acre for a quarter section in the study area is $453.95/acre (p-value < 0.01). Taking into account only parcel size (assumed to be 160 acres/quarter section) and the fact that price/acre decreases at a rate of $1.38/acre (p-value = 0.06), an average quarter section would be valued at $452.57/acre and would cost a total of $72 411.20 for 160 acres (under the assumption that all variables other than ACRE are set at zero within the model).

The year of sale dummies are all negative, and are often found to be significantly different from the basecase years of sale (2010 and 2011). The time dummies are able to pick up variations in all factors that would change by year (land market trends, interest and inflation rate trends, etc.).

The impact of resource development on land values depends on whether the resource is oil or gas. The presence of a gas well on a quarter section does not significantly impact the unit price of a quarter section (p-value = 0.12). However, the presence of an oil well on a quarter section significantly increases the unit price ($/acre) of a quarter section by $38.84/acre (p-value < 0.01).

The location variable TWN is signification but the variables RNG and POSGWTH are not (p-values of 0.14 and 0.17 respectively). The price/acre of land parcels increases by $3.32/acre (p-value = 0.04) with each 10 km movement north from the US border. Location of parcels east to west in the study area, and the population growth or decline of rural municipalities does not significantly affect land values in the area.

Irrigation land[70], Indian reserve land and conservation easement lands were not found to be significantly different in value as compared to the basecase of private farmland (p-values of 0.78, 0.67 and 0.54 respectively). However, land classified as national park land and agricultural crown land had significantly lower unit land prices. Agricultural crown land sold for $56.44/acre (p-value < 0.01) lower than private farmland on average and national park land (lands acquired by the national park) were sold for $36.44/acre (p-value < 0.01) less than private farmland on average.

The percentage of a quarter section made up of water or wooded areas does not significantly impact its price (p-values of 0.42 and 0.70 respectively); however, whether the majority of a quarter section is made up of annual cropland, or hay/tame pasture does impact the quarter section's value. A quarter section that is made up of a majority of cropland has its unit price ($/acre) increase by $71.03/acre (p-value < 0.01) relative to a quarter section that is made up of a majority of native grassland. With respect to a quarter section made up of a majority of hay or tame pastureland, its unit price ($/acre) would be $50.29/acre(p-value < 0.01) higher than a quarter section made up of a majority of native grassland.

Land quality variables, such as land capability and ecosite type significantly impacted sale prices. If a parcel of land was classified as salty (saline or solonetzic) the unit price of land ($/acre) would decrease by $19.61/acre (p-value = 0.01) relative to loamy or

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[70] The lack of significant results regarding irrigation land is somewhat surprising, but is likely driven by the very small percentage of quarter sections in the study region (0.5% of all quarter sections), and in the transaction data (2.8% of all quarter sections) that are irrigation lands.

overflow lands, and if a parcel of land was classified as hilly (badlands and thin soils) the unit price of land ($/acre) would decrease by $17.83/acre (p-vlaue = 0.06). If a parcel of land was classified as wet (wet meadow, dry meadow or marsh) the unit price of land would decrease by $117.71/acre (p-value = 0.01). While this result seems counter intuitive in the case of grazing lands (where wet and dry meadows have greater production values and can stock a greater number of cattle), most of the transactions observed were from the central part of the study region (Figure D.6) where cultivation is the primary agricultural use. In the case of cultivation and hay lands, dry and wet meadows are areas of lost production. Land classified as other (gravel and clay) were not found to be significantly different from loam or overflow lands (p-values = 0.68). The highest quality land (MS) – class 3 under the Canadian land classification system – resulted in significantly higher unit land prices ($39.67/acre; p-value < 0.01) than the lowest two land classes – class 5 and 6 – found in the area. Class 4 land (S) was not found to have a value above that of class 5 or 6 land (p-value = 0.35).

D.4.1.4.4 Land Values

The observed average value of quarter sections with arm's length sales data (n = 3600) was $38 989 with a unit price of $245.50/acre. Land values were estimated for all quarter sections in the study area using Model D-2. A total of 19 620 quarter sections (82% of the quarter sections in the study region) had all the data required to calculate land values and their unit price ($/acre) and total land value ($/quarter section) were calculated (Table D.10). The estimated average value of these quarter sections was $41 339 with a unit price of $267.77/acre. Figure D.7 shows the price per acre values for the study area's quarter sections. Quarter sections with missing variables are coloured red.

In order to calculate land values for the 4369 quarter sections with missing data, the variables with missing data were set to zero (i.e. the basecase for that set of variables). The variables with the greatest number of missing entries are POSGWTH, MS and S (Table D.7). The POSGWTH variable is missing a large number of entries because the provincial and national parks are not classified as part of a rural municipality. However, by setting the variable to zero, Grasslands National Park is properly represented because the three RMs in which it is located – Val Marie, Waverley and Mankota – all have shown population declines between 2001 and 2006 (Table D.1). The land capability variables have missing data due to an incomplete data layer. The quarter sections in that region likely have a land capability rating of 3 (MS) or 4 (S) since these capability ratings make up 90% of the region, and setting the variable to the basecase of a more severe land rating will underestimate the land value. Recognizing these calculation limitations, the estimated average unit land price for all quarter sections in the region is $268.11/acre and the average value of a quarter section is $39 929 (Table D.10). Figure D.8 shows the price/acre for all quarter sections in the study area including the quarter sections for which variables were estimated. Figure D.9 shows the price per quarter section for the entire study area.

Table D.10. Descriptive statistics of observed (left column) and estimated (right column) land values in the South of the Divide Study region.

	Quarter Sections with Arm's Length Transaction Data					All Quarter Sections with the South of the Divide Study Region				
Name	**N**	**Mean**	**St. Dev**	**Min**	**Max**	**N**	**Mean**	**St. Dev**	**Min**	**Max**
Priceac[1]	3600	245	133	42	2765	19620	267	70	16	611
Price	3600	38959	21102	6662	442460	19620	41339	11576	0	89535
Priceac2[2]						23989	268	75.55	16	614
Price2						23989	39929	12433	0	402220

[1]Priceac ($/acre) and Price ($/quarter section) estimations are calculated using only quarter sections with no missing variables
[2]Priceac2 and Price2 estimations are calculated setting all missing variables to the base case (= 0) and calculating the value of an acre and quarter section

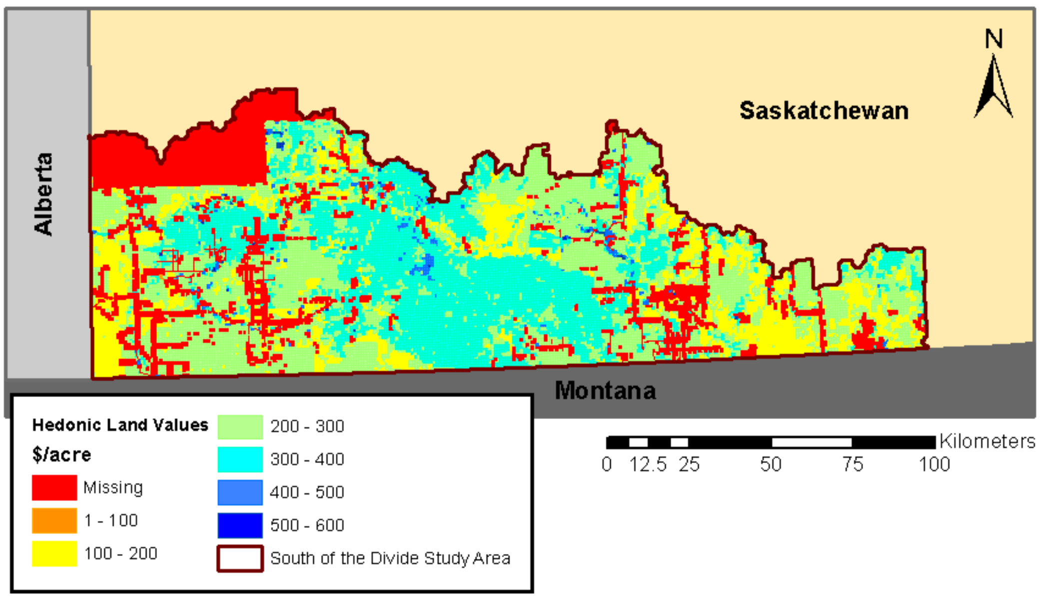

Figure D.7. Estimated prices per acre are shown for each quarter section within the study area. Quarter sections with missing input variables are coloured in red.

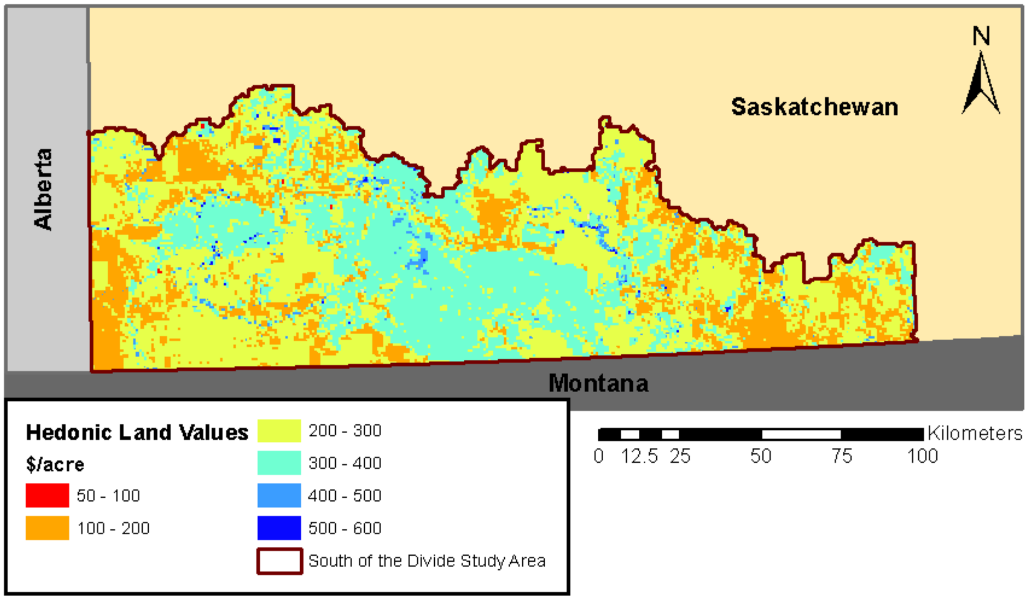

Figure D.8. Estimated price/acre is shown for each quarter section within the study area. Price/acre for quarter sections with missing input variables were calculated by setting the missing input variable equal to zero.

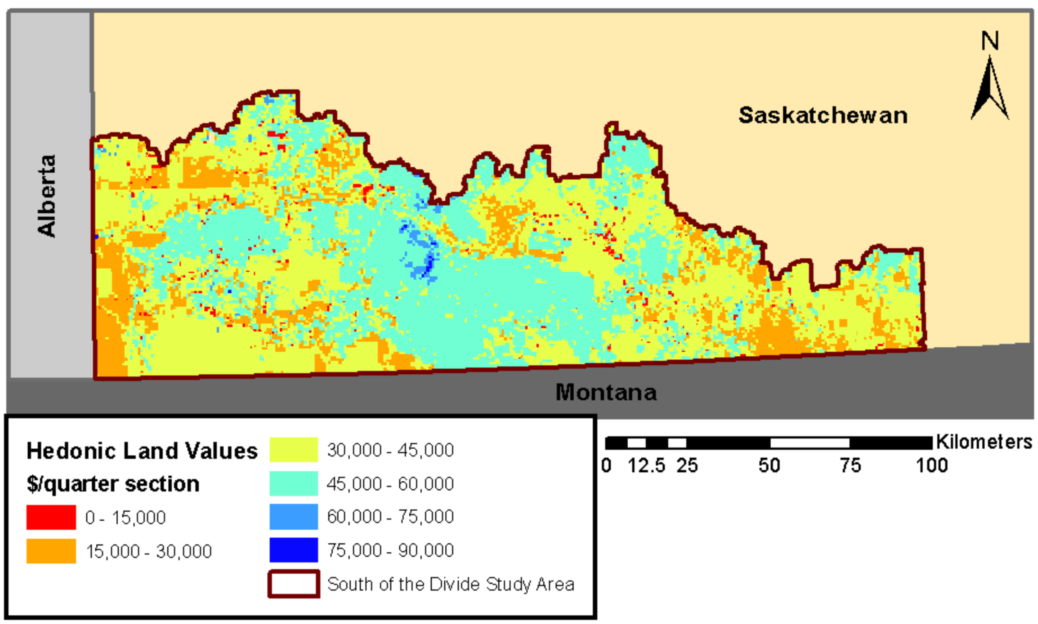

Figure D.9. Estimated price/quarter section land values for the South of the Divide region. Prices for quarter sections with missing input variables were estimated by setting the missing input variable equal to zero.

D.5 A Comparison of the Two Land Value Methods' Results

Within the final opportunity cost model, only one set of agricultural land values will be used. The land values calculated using the appraised value of land are a more robust estimate of land values, and will, therefore, be the values used. It is still interesting to consider the differences in the estimated land values between the hedonic model and the land assessment method. Table D.11 includes summary statistics for each of the methods of calculating land value. The first column summarizes the observed sale information from the 3600 parcels of land sold through arm's length transactions in the region between 1993 and 2011. The average sale price per acre was $245.50.This is lower than the average price per acre estimated using the hedonic model ($267.77/acre and $268.11/acre).However, the observed sales prices were higher than the average price per acre for the appraised parcels, and the parcels' whose appraised value was adjusted using the land value ratios ($179.36/acre and $191.94/acre, respectively). The higher values for the observed sale prices versus the assessed values may be for the reasons discussed above in regards to Table D.7. The sale transactions data overrepresented cropland (and higher quality agricultural land) and underrepresented native grassland grazing lands. Therefore, the assessed values would be lower on average due to their inclusion of representative areas of grazing lands.

Table D.11. Summary of agricultural land values found using market transaction data, assessment land values and hedonic valuation.

	Observed	Assessment Method		Hedonic Method	
	Observed Sales	**Appraised**	**Ratio Adjusted**	**Estimated Sale Price***	**Estimated Sale Price – All Quarters****
Number of quarter sections	3600	21 532	21 532	19 620	23 989
Average Price per Acre	$245.50	$170.37	$191.94	$267.77	$268.11
Average Price per Quarter Section	$38 959.00	$27 265	$30 718	$41 339.00	$39 929.00

* These predicted sales prices only include quarter sections with complete land characteristic information
** These predicted sales prices include all quarter sections – variables with missing information were set to zero in order to calculate predicted land values

Simple descriptive statistics were run on the estimated land values. A correlation was run between the ratio adjusted price/acre and the predicted sale price per acre (all quarters). The correlation coefficient is 0.424. Simple t-tests and F-tests were run to test for equal means and equal variances, respectively, of the estimated price/acre values for each estimation methods. In Table D.12, the results of a t-test of equal means are reported above the results of an F-test for equal variances for each pair of estimation techniques.[71] The ratio adjusted average price/acre is significantly higher than the appraised price/acre (p-value = 0.000). The predicted hedonic average price/acre is significantly higher than the appraised price/acre (p-values = 0.000 and 0.002) and the ratio adjusted price/acre (p-values = 0.000). The average price/acre is not

[71] The calculation of the t-statistic is as follows: $t_{stat} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\hat{\sigma}_1^2/n_1 + \hat{\sigma}_2^2/n_2}}$, where degrees of freedom is equal to $n_1 + n_2 - 2$.

The calculation of the F-statistics is as follows:

$$F_{stat} = \begin{cases} \hat{\sigma}_1^2/\hat{\sigma}_2^2 \ if \ \hat{\sigma}_1^2 > \hat{\sigma}_2^2 \ (df1 = n_1 - 1; df2 = n_2 - 1) \\ \hat{\sigma}_1^2/\hat{\sigma}_2^2 \ if \ \hat{\sigma}_2^2 > \hat{\sigma}_1^2 \ (df1 = n_2 - 1; df2 = n_1 - 1) \end{cases}$$

significantly different between the two hedonic methods (p-value = 0.637) suggesting that setting the input variables to zero in order to calculate land values is not erroneous. Figure D.10 shows the difference between the ratio adjusted price/acre and the predicted hedonic price/acre for all quarters. The majority of the landscape shows that the hedonic estimated land values are greater than the land values estimated using assessed values (light orange, yellow and light green).

Table D.12. Tests to compare equality of means (top box) and variances (bottom box) between land value estimation techniques.

	Appraised	Ratio Adjusted	Estimated Sale Price	Estimated All Quarters
Appraised –Means				
Appraised – Variance				
Ratio Adjusted – Means	20.84 (0.000) DF = 35 297			
Ratio Adjusted – Variances	2.96 (0.000) DF = 21 531, 21 531			
Estimated Sale Price – Means	134.12 (0.000) DF = 41 151	73.720 (0.000) DF = 34 349		
Estimated Sale Price – Variances	1.18 (0.000) DF = 21 531, 19 619	3.50 (0.000) DF = 21 531, 19619		
Estimated All Quarters – Means	137.02 (0.000) DF = 45 423	74.70 (0.000) DF = 34 193	0.472 (0.637) DF = 42 785	
Estimated All Quarters – Variances	1.04 (0.002) DF = 21 531, 23 988	3.08 (0.000) DF = 21 531, 23 988	1.13 (0.000) DF = 23988, 19 619	

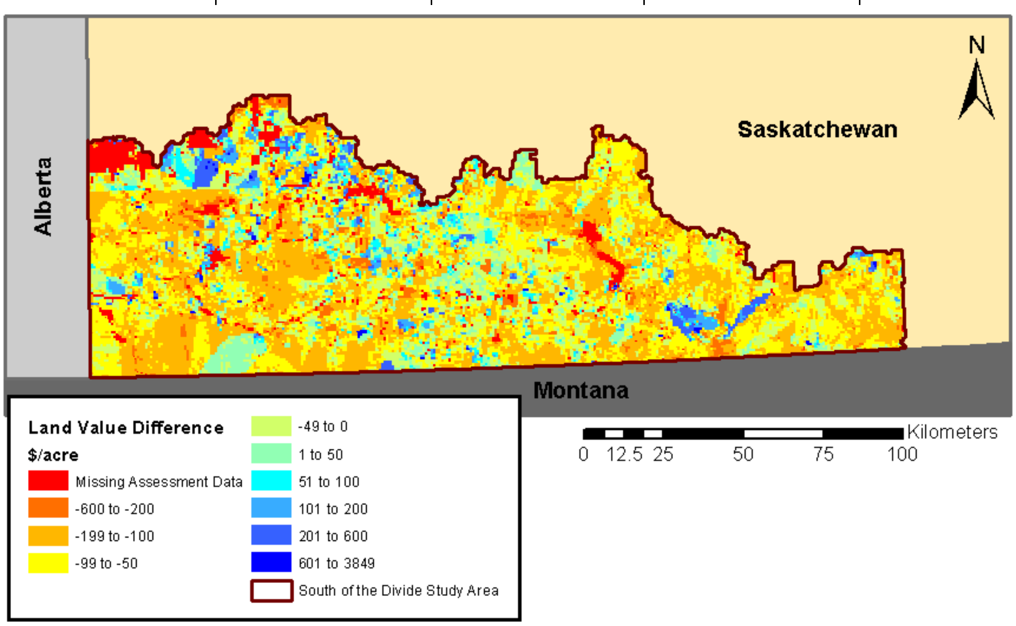

Figure D.10. The difference in estimated price per acre between the assessment method and the hedonic method. This figure displays the value of the Assessment Estimated Sale Value minus the Hedonic Estimated Sale Value.

E Appendix: Agricultural Land Conversion Costs

The price of a parcel of land is equal to the discounted sum of expected net returns obtained from the use of that land in its most profitable form (Plantinga *et al.* 2002). Within the South of the Divide region, agriculture is the highest valued use and the price of the land reflects the value that would be received if the land were to remain in agriculture indefinitely. So, what is the foregone cost if land is removed from agriculture and placed into a biological reserve? The opportunity cost would simply equal the land's market value (Polasky *et al.* 2001). The hedonic land value model presented in Appendix D, Section D.4 is able to provide information on these land values, but more importantly it can also provide information on the value of individual characteristics of each parcel of land. In turn these values can inform the opportunity cost of altering land characteristics.

E.1 Land Conversion Opportunity Costs

The hedonic land value model not only allows the calculation of a parcel of land price, but it can also be used to calculate the value of changes in land characteristics (Palmquist and Danielson 1989). The accuracy with which land changes can be valued depends on how many parcels of land within the market are affected by the land changes (Palmquist and Danielson 1989). If many parcels are affected, not only will the price of the directly affected parcels change, but the overall market equilibrium price can also shift. In this case, the hedonic equation can still provide an upper bound on the value of land improvements (Palmquist and Danielson 1989; Freeman 1975; Lind 1975).

Model D-1 and Model D-2 were designed to allow the calculation of the value of a change in the quarter section's land use (or cover). Just as the opportunity cost of removing land completely from production (i.e. its price) can be calculated from a hedonic model, so too can the opportunity cost of changing land characteristics (i.e. change in price) be calculated from a hedonic land model. Model D-1 allows changes to be made based on percentages and Model D-2 allows a quarter section to be changed from one land use entirely to another land use. It intuitively makes the greatest sense to have a constant $/acre opportunity cost (i.e. a constant marginal opportunity cost) for the conversion of land between uses and Model D-2 is therefore used to calculate land conversion opportunity costs[72]. While marginal costs are constant, total opportunity costs would still increase linearly with the number of acres converted and would, therefore, vary across the landscape. Model D-2 which uses dummy variables to indicate the land use of a quarter section, would permit the calculation of a constant marginal opportunity cost of land conversion through the use of the following formulas:

Equation E-1

$$\Delta PRICEAC = \hat{\beta}_{CRP} * (CROP_2 - CROP_1)$$

Equation E-2

$$\Delta PRICEAC = \hat{\beta}_{HP} * (HAY\ or\ TAME\ PASTURE_2 - HAY\ or\ TAME\ PASTURE_1)$$

Quarter sections that are currently cropland would calculate their marginal opportunity cost of converting to native grasslands using Equation E-1 where $\Delta \mathrm{PRICEAC} = -\hat{\beta}_{\mathrm{CRP}} * (1) = -71.03$. As a result, the conversion cost is \$71.03/acre. Quarter sections that are currently hay or tame pasture would calculate their marginal opportunity cost of converting to native grasslands using Equation E-2 where $\Delta \mathrm{PRICEAC} = -\hat{\beta}_{\mathrm{HP}} * (1) = -50.29$. The conversion cost would as a result be \$50.29/acre. It is also worth noting that if the goal were to turn annual cropland into tame hay or pasture lands, the opportunity cost of conversion would be \$20.74/acre.

Opportunity costs of land conversion were calculated for all quarter sections in the study area. The number of acres of cropland for each quarter section was multiplied by \$71.03/acre to give the total opportunity cost of converting cropland to native grassland. The number of acres in hay and tame pasture for each quarter section was multiplied by \$50.29/acre to give the total opportunity cost of converting hay and tame

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[72] Model D-1 which uses percentage variables for land use would also permit the calculation of the opportunity costs of land conversion. However, the opportunity cost of land conversion (\$/acre) would increase linearly (i.e. marginal opportunity costs are linear) based on a quarter section's land use percentages. The greater the proportion of land that is converted, the larger the opportunity cost per acre. This would result in a total cost curve that increases at an increasing rate (i.e. a convex total cost curve). The following equations can be used to calculate the marginal opportunity cost of conversion.

$$\Delta \mathrm{PRICEAC} = [\hat{\beta}_{\mathrm{NGPCNT}} * \%\ \mathrm{NATIVE\ GRASS}_2 + \hat{\beta}_{\mathrm{CRPPCNT}} * \%\ \mathrm{CROP}_2] - [\hat{\beta}_{\mathrm{NGPCNT}} * \%\ \mathrm{NATIVE\ GRASS}_1 + \hat{\beta}_{\mathrm{CRPPCNT}} * \%\ \mathrm{CROP}_1]$$

$$\Delta \mathrm{PRICEAC} = [\hat{\beta}_{\mathrm{NGPCNT}} * \%\ \mathrm{NATIVE\ GRASS}_2 + \hat{\beta}_{\mathrm{HPPCNT}} * \%\ \mathrm{HAY\ or\ TAME\ PASTURE}_2] - [\hat{\beta}_{\mathrm{NGPCNT}}\ \%\ \mathrm{NATIVE\ GRASS}_1 + \hat{\beta}_{\mathrm{HPPCNT}} * \%\ \mathrm{HAY\ or\ TAME\ PASTURE}_1]$$

If it is assumed that land use is being changed from a quarter section with 100% cropland or hay/tame pasture cover to a quarter section with 100% native grassland cover, then the above formulas simplify even further to become the following equations that are comparable to the results of Model D-2 (total conversion of a quarter section with constant marginal opportunity cost).

$$\Delta \mathrm{PRICEAC} = \hat{\beta}_{\mathrm{NGPCNT}} * (100) - \hat{\beta}_{\mathrm{CRPPCNT}} * (100) = 0.23(100) - 1.19(100) = -96.00$$

$$\Delta PRICEAC = \hat{\beta}_{NGPCNT} * (100) - \hat{\beta}_{HPPCNT} * (100) = 0.23(100) - 0.95(100) = -72.00$$

pasture to native grass. The total opportunity cost of converting a quarter section to native grass is the sum of the opportunity cost of converting both cropland and hay and tame pastures to native grassland. Figure E.1 shows the total opportunity cost of conversion to native grassland for all quarter sections in the study area. If conversion to hay or tame pasture is desired, then the cost of converting a quarter section of cropland to tame pasture is $20.74 multiplied by the number of acres of cropland (Figure E.2).

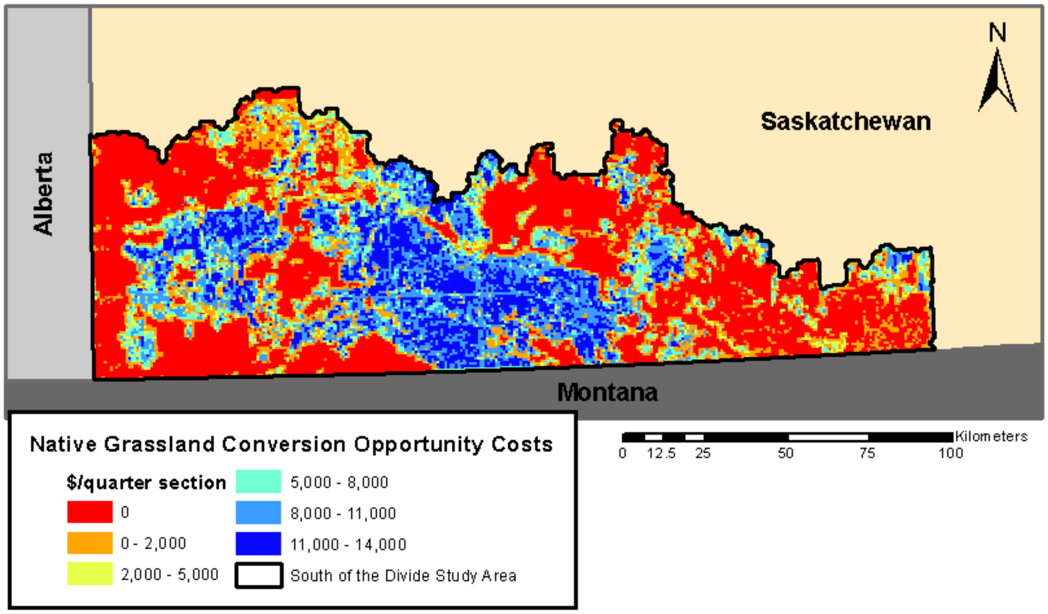

Figure E.1. The opportunity cost of converting land from annual cropland and perennial forages (tame pasture or hay land) into native grasslands.

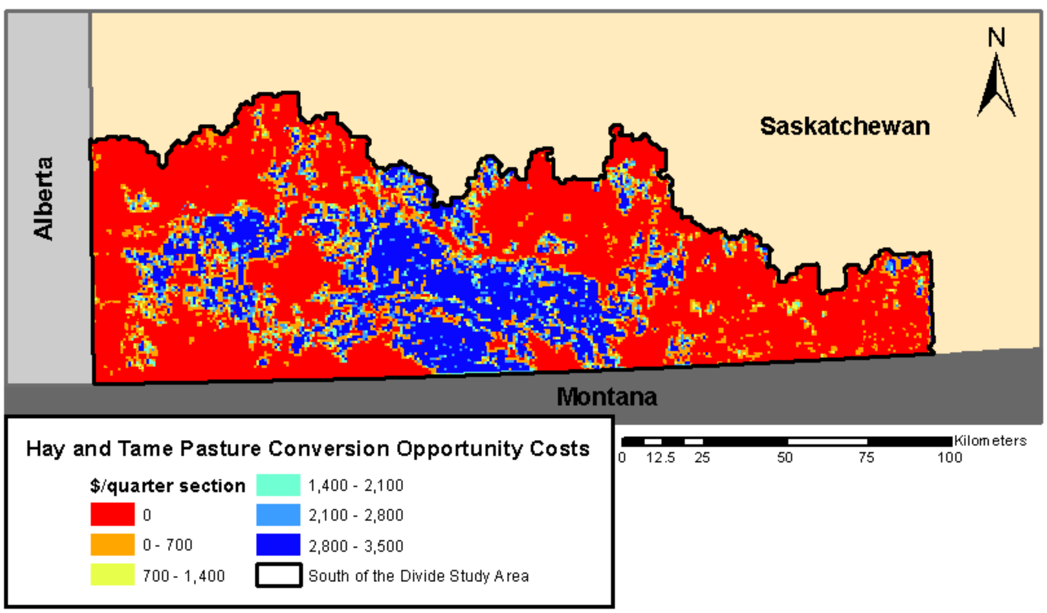

Figure E.2. The opportunity cost of converting land from annual cropland to perennial forages (tame pasture or hay land).

E.2 Land Conversion Establishment Costs

The direct financial cost of conversion between cropland and perennial cover is largely dependent on the type of perennial cover desired. Conversion to native grasslands is more expensive than seeding to tame grasslands because seed is more expensive (there are fewer producers due to lower demand) and germination success is lower (and, therefore, a higher seeding rate or reseeding is often required). The following table (Table E.1) highlights the potential direct cost per acre to return cropland into perennial cover.

Table E.1. Direct costs of converting cropland into perennial cover.

	Cost ($/acre)	Cost (2008$/acre)	Source
Cropland to Hay or Tame Pasture	$53.09/acre*	$54.34/acre	Saskatchewan Ministry of Agriculture 2006
Cropland to Native Pasture	$375/acre	$373.88/acre	Tannas 2009 (in Dollevoet 2010)
Hay or Tame Pasture to Native Pasture	$400/acre	$391.84/acre	Pat Fargey pers. comm. 2011

* Assumes breaking and glyphosate application not required since converting cropland into tame pasture, and not breaking tame pasture in order to reseed.

E.3 The Total Cost of Land Conversion

The total cost of conversion used within the final reserve network model is the sum of direct costs and opportunity costs (Table E.2). The total costs of converting cropland or hay land into native grasslands closely correspond to the $421/acre value found by Dollevoet (2010) when farms in southeastern Saskatchewan convert cropland into tame hay.

Table E.2. Total costs of converting between land uses within the South of the Divide region.

	Direct Cost ($/acre)	Opportunity Cost ($/acre)	Total Cost ($/acre)*
Cropland to Hay or Tame Pasture	$54.34/acre	$20.74/acre	$75.08/acre
Cropland to Native Pasture	$373.88/acre	$71.03/acre	$444.91/acre
Hay or Tame Pasture to Native Pasture	$391.84/acre	$50.29/acre	$442.13/acre

*Total cost is in 2008 dollars

F Appendix: Grazing Management Costs

Approximately 60% of the quarter sections within the South of the Divide region are made up of a majority of native grasslands, and about 50% of the area in total is native grasslands (Table D.7). These native grasslands are owned and managed several different ways. There are community pastures (provincial and federal), grazing cooperatives, crown lease land, and privately owned land. Community pastures are owned and operated by the federal and provincial governments. Ranchers in the area pay for the right to graze their cattle in these pastures. Grazing cooperative land is leased from the provincial government and privately managed. Cooperatives are managed by a board, and ranchers pay a fee per animal to graze in the cooperative. They are not for profit and the fees only cover the cost of managing the land. Crown lease land is leased from the provincial government by ranchers in the area. The leases are long term, and managers are allowed to manage the land as if it is private land. There are recommended stocking rates provided to land managers, but there is no monitoring or enforcement conducted by the provincial government to ensure management of the land aligns with the recommendations of the province (Jessica Williams, pers. comm.). Privately owned land is owned and managed by individual ranchers and land managers in the area.

There is no single grazing strategy that benefits all of the species at risk within the South of the Divide. However, there is recognition that grazing management practices can often be improved to better suit species. Grazing management improvements will undoubtedly come at a cost to land managers. If grazing strategies that are optimal for species at risk provided the greatest return from the land, managers would already be managing their land in such a manner. The fact that grazing changes are required is strong proof that optimal grazing for species at risk is not optimal for ranch revenues.

The optimal scenario for grazing management on the South of the Divide landscape would be the provision of a heterogeneous grassland landscape that is sustainably grazed over the long run. Heterogeneity would account for species with tall, mid and short grass requirements. The problem lies in determining where this heterogeneity should be located, and what percentage of the landscape should be made up of each grassland type. The simplest way to tackle this issue is to assume that by following the provincial stocking guidelines, there will be a natural provision of heterogeneity due to topography, climate, soils, and livestock grazing preferences. Thus, this section will attempt to measure the cost of moving from current stocking rates within the region to the recommended stocking rates provided by the province (Thorpe 2007). Of course some land managers will already stock at the recommended rates, some will stock below, and some will stock above. However, spatial information on rangeland health and stocking rates is not available; therefore, simplifying assumptions about average stocking rates will be used in the analysis.

F.1 The Ecoregions and Ecosites of the South of the Divide and their Associated Stocking Rates

The southwest corner of Saskatchewan is often divided into two ecoregions: the Cypress Upland and the Mixed Grassland (Figure F.1). It is less common to find the very southwest corner designated as a third ecoregion: the Dry Mixed Grassland. However, the stocking rate guidelines for Saskatchewan use this third ecoregion (Thorpe 2007).

Therefore, in this analysis, while we only use the two ecoregions, the stocking rates used for the Mixed Grassland ecoregion will be an average between the stocking rates of the Dry Mixed Grasslands and the Mixed Grasslands which make up about equal portions of the area.

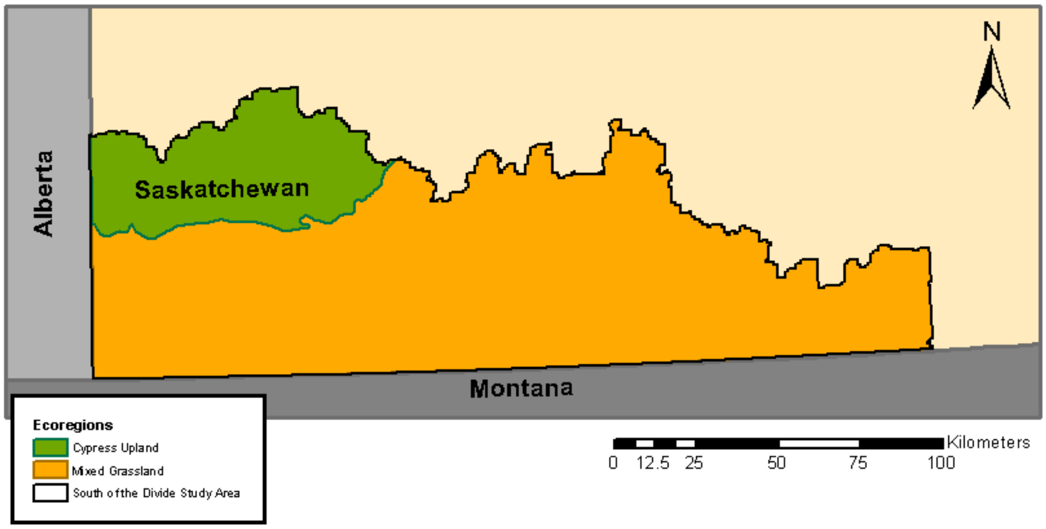

Figure F.1. The ecoregions of the South of the Divide. An additional ecoregion is sometimes included: the Dry Mixed Grasslands. The Dry Mixed Grasslands would traditionally occupy the bottom half (southern most part) of the study area.

Within the two ecoregions of the South of the Divide region, there are 16 ecosites. The primary ecosite of the region by far, is the loam ecosite (Figure F.2). This ecosite is upland in nature, and is found on loam (moderate texture) soils. The reference grassland communities that grow on the loam soils include Northern Wheat Grass – Needle-and-thread communities on the driest areas, Northern Wheat Grass – Western Porcupine Grass or Western Porcupine Grass – Northern Wheat Grass communities on moister sites, and Plains Rough Fescue grasslands on the Cypress Uplands. These are the key grassland communities of the South of the Divide region. Other major ecosites include the solonetzic ecosite found in the extreme southwest corner of the province. This ecosites is characterized by solonetzic – or salty – soils. They have lower grazing tolerances and capacities than loam ecosites. Their reference communities are often composed of Wheat Grass – Needle Grass (Needle-and-thread in the drier sites and Western Porcupine Grass in moister sites) – June Grass. Other ecosites with unique management needs include gravelly sites, clay sites, thin sites, and badland sites. These sites often have recommended stocking rates much lower than the loam ecosites.

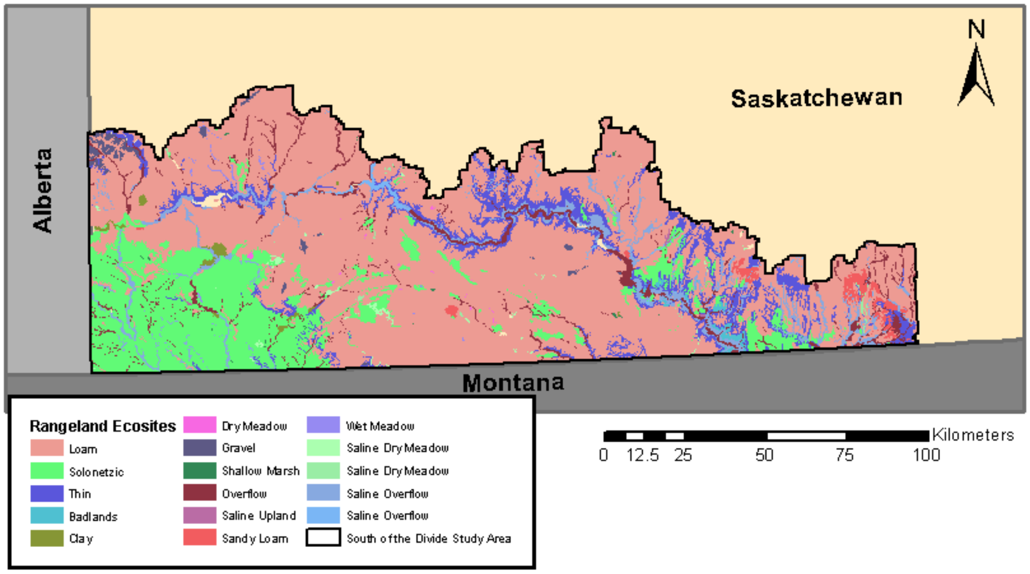

Figure F.2. The sixteen rangeland ecosites making up the South of the Divide region.

Recommended stocking rates are calculated using the loam ecosite as a reference community. The loam ecosite recommendations for the Dry Mixed Grasslands, Mixed Grasslands and Cypress Uplands are 0.20 AUM/acre, 0.29 AUM/acre, and 0.56 AUM/acre, respectively. The complete list of recommended stocking rates is calculated and displayed in Table F.1 below. The loam reference used for the Mixed Grassland ecosites in Table F.1 is the average of the Dry Mixed Grassland and the Mixed Grassland grazing capacities. This table also only displays grazing capacities for reference communities (communities in excellent to good condition). As such, they are the maximum expected grazing capacity possible on these ecosites. If historic management has resulted in grassland degradation, grazing capacities can be diminished. A moderately altered community would provide 0.8 times the grazing capacity as the reference communities shown in Table F.1, and a significantly altered community would provide only 0.6 times the grazing capacity of the reference community.

Table F.1. Recommended stocking rates for the Mixed Grassland Ecoregion and the Cypress Upland Ecoregion within the South of the Divide study area.

Ecosite	Ratio to Loam	Mixed Grassland Ecoregion Stocking Rate (AUM/acre)* (Loam = 0.245 AUM/acre)	Cypress Upland Ecoregion Stocking Rate (AUM/acre) (Loam = 0.56 AUM/acre)
Shallow Marsh	2.69	0.66	1.51
Wet Meadow	2.59	0.64	1.45
Dry Meadow	2.34	0.57	1.31
Overflow	1.54	0.38	0.86
Saline Overflow	1.37	0.34	0.77
Saline Dry Meadow	1.11	0.27	0.62
Loam	1.00	0.25	0.56
Sandy Loam	0.97	0.24	0.54
Clay	0.96	0.24	0.54
Sand	0.94	0.23	0.53
Dunes	0.73	0.18	0.41
Thin	0.73	0.18	0.41
Solonetzic	0.66	0.16	0.37
Gravelly	0.60	0.15	0.34
Saline Upland	0.52	0.13	0.29
Badlands	0.29	0.07	0.16

* The Mixed Grassland numbers in this table are an average of the Dry Mixed Grassland grazing capacity (Loam = 0.20 AUM/acre) and the Mixed Grassland grazing capacities (Loam = 0.29 AUM/acre) found in Thorpe 2007.

Actual stocking rates often differ from recommended stocking rates, and it is this difference that is of primary interest in this project. Tara Davidson (pers. comm.), the Range Management Specialist for Agriculture and Agri-Food Canada in southwest Saskatchewan, was able to provide detailed information on how federal community pastures in the area are stocked, and was also able to provide some insight into private land management in the area[73]. Communications with Jessica Williams, a Resource Agrologist with the Saskatchewan Ministry of Agriculture in southwest Saskatchewan, provided the information that lessees of crown lease land are provided with recommended stocking rates, but at no time during the duration of their lease does the provincial government monitor or enforce those stocking rates. Thus, crown lease land is managed essentially as if it is privately owned and the lessees have the opportunity to manage and stock the land using their own management philosophies.

Federal community pastures in the regions are largely concentrated in the southern half of the study area, with the exception of the Auvergne-Wise Creek, Beaver Valley and Val

[73] Tara Davidson provided professional and personal insight into stocking rates in the region. Tara manages the federal community pastures in the region and owns and manages a ranch just north of the South of the Divide study region.

Marie pastures (Figure F.3). The average loam stocking rates for each of the federal community pastures is listed in Table F.2. All of the community pastures are stocked at or below the recommended stocking rates except for Auvergne – Wise Creek. The higher rate in the Auvergne – Wise Creek pasture is because this pasture has higher elevations (more akin to the Cypress Uplands), good production potential, no major slope issues, and fairly good precipitation (Tara Davidson pers. comm.). Tara Davidson also provided long term average stocking rates for the solonetzic, thin, gravel and badland ecosites. These long term averages were 0.10 AUM/acre, 0.12 AUM/acre, 0.12 AUM/acre and 0.08 AUM/acre respectively. In general, the federal community pastures are stocked according to the stocking rates suggested by the Saskatchewan Research Council (Thorpe 2007). While detailed information on the stocking rates of the provincial community pastures was not obtained, it is assumed that they – like the federal pastures – are stocked according to the recommended stocking rates for the region. As such, the loam ecosites of the provincial community pastures of Arena, Dixon and Mankota are assumed to be stocked at or below 0.25 AUM/acre on average. All other ecosites are also assumed to be stocked at or below their recommended rates.

Table F.2. The loam ecosite stocking rates used for the federal community pastures of the South of the Divide region.

Community Pasture	Actual Loam Stocking Rate (AUM/acre)	Recommended Loam Stocking Rate (AUM/acre)
Auvergne – Wise Creek	0.36	0.25
Beaver Valley	0.20	0.25
Val Marie	0.25	0.25
Lonetree	0.16	0.25
Masefield	0.20	0.25
Battle Creek*	0.18	0.25
Govenlock	0.14	0.25
Nashlyn	0.16	0.25
Reno 1	0.16	0.25
Reno2**	-	0.25
Overall Long Term Average	0.20	0.25

* Battle Creek, Govenlock, and Nashlyn in the southwest corner of the study area do not have pure loam ecosites, but instead have areas of solonetzic-loam mixed soils. It is from these areas that the loam stocking rates in this table come from. The long term average stocking rate for these areas is 0.15 AUM/acre (Tara Davidson pers. comm.) which is a conservative stocking rate below the recommended solonetzic stocking rate of 0.16 AUM/acre.
** Reno 2 does not have any loam ecosites, but its solonetzic sites are stocked at 0.10 AUM/acre – much below that of the recommended stocking rate of 0.16 AUM/acre.

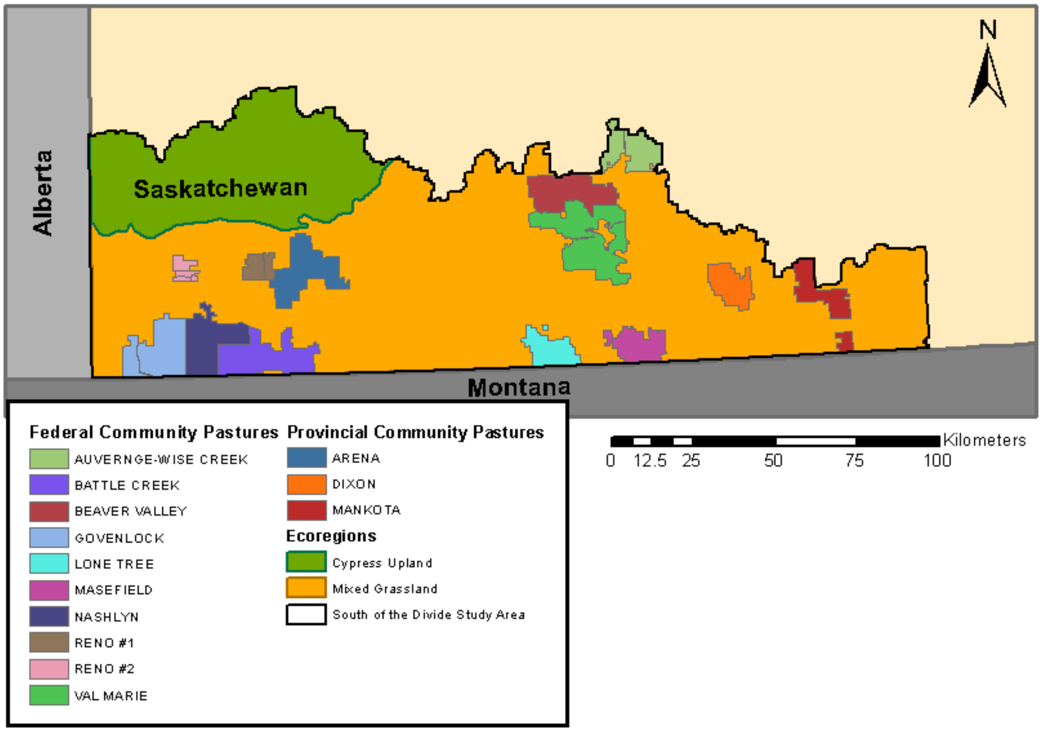

Figure F.3. The provincial and federal community pastures located within the South of the Divide region.

There are management differences between publicly managed and privately managed grazing lands in the South of the Divide region. While the community pastures have similar goals to private operations – manage a productive, bio-diverse rangeland; promote environmentally responsible land use practices; and utilize the pasture in a manner that complements livestock production – there is not the same pressure to be able to make land or lease payments at the end of the year (Tara Davidson pers. comm.). As a result, the Agriculture and Agri-Food Canada (AAFC) community pastures have quite conservative stocking rates and carrying capacities relative to private ranches in the area on average (Tara Davidson pers. comm.).

Grazing cooperatives are another interesting grassland and grazing management design. Most grazing cooperatives are leased from the provincial government and adhere closely to the provincial recommended stocking rates in order to not risk losing the rights to continue to graze their cattle. The larger area of the grazing cooperatives and their ability to limit grazing permits allows the cooperative the ability to better manage the variability in production that comes with good and bad growing years (Randy Currence[74] pers. comm.)

[74] Randy Currence is a lifelong rancher and member on the board of the Scottsguard Grazing Cooperative. The Scottsguard Grazing Cooperative is located along the northern border of the study area.

Privately managed land within the South of the Divide includes privately owned land and crown lease land. Estimates of private stocking rates are found in Table F.3. In personal communications with Tara Davidson, it was found that private loam stocking rates in the Mixed Grassland region ranged from 0.27 AUM/acre on the low end, to 0.35 AUM/acre on the high end, with 0.30 AUM/acre being a moderate stocking rate for private ranches. Thus, compared to the recommended stocking rate for a reference (i.e. excellent to good condition) loam ecosite, the high stocking rate is 43% higher, the moderate stocking rate is 22% higher, and the low stocking rate for private ranches is still 10% higher. Tara Davidson's estimate of heavy stocking rates being 43% higher than the recommended rates is similar to the 33% higher estimate that is commonly cited in the literature for heavy grazing in the Mixed Grasslands of the United States (Lecain *et al.* 2000; Reeder and Schuman 2002; Abdel-Magid *et al.* 1987; Schuman *et al.* 1999). Tara Davidson also estimated that the more fragile ecosites (gravel, bandland, thin, solonetzic etc.) which have an average recommended stocking rate of 0.14 AUM/acre are likely stocked at 0.20 AUM/acre on the high end (43% higher than recommended), 0.15 AUM/acre on the low end (7% higher than recommended), and around 0.18 AUM/acre as a moderate stocking rate (29% higher than recommended).

The estimated stocking rates used on private ranches in the South of the Divide region are displayed in Table F.3. Calculations of the estimated stocking rates are based on the information discussed in the previous paragraph. The stocking rates of the first nine ecosites for each ecoregion were calculated by multiplying the recommended stocking rate for their reference community by 110% (low stocking rate), 122% (moderate stocking rate), and 143% (high stocking rate). The last six ecosites listed for each ecoregion had their actual stocking rates calculated by multiplying the recommended stocking rate for their reference community by 107% (low stocking rate), 129% (moderate stocking rate), and 143% (high stocking rate). These calculations make several simplifying assumptions. The first major assumption is that private land managers stock all ecosites (divided only into two groups: productive ecosites and fragile ecosites) at the same relative rates (i.e. the percentages calculated from communications with Tara Davidson). The second major assumption is that the relative stocking rates hold not only across ecosites, but also across ecoregions (Mixed Grassland and Cypress Upland). While these assumptions may seem restrictive, detailed information on stocking rates are not available. The ideal situation would be the availability of detailed spatial information on stocking rates and rangeland health across the entire study area.

Table F.3. Comparison of the recommended stocking rates for the region (for reference communities in excellent to good condition, communities with moderate alterations in fair condition, and communities with significant alteration in poor condition) and the actual stocking rates observed on privately managed land.

		Recommended Stocking Rates (AUM/acre)			Actual Stocking Rates (AUM/acre)		
Ecoregion	**Ecosite**	**Reference Community**	**Moderate Alterations**	**Significant Alterations**	**Low**	**Moderate**	**High**
Mixed Grassland	Shallow Marsh	0.66	0.53	0.40	0.73	0.81	0.94
	Wet Meadow	0.63	0.51	0.38	0.70	0.78	0.91
	Dry Meadow	0.57	0.46	0.34	0.63	0.70	0.82
	Overflow	0.38	0.30	0.23	0.42	0.46	0.54
	Saline Overflow	0.34	0.27	0.20	0.37	0.41	0.48
	Saline Dry Meadow	0.27	0.22	0.16	0.30	0.33	0.39
	Loam	0.25	0.20	0.15	0.27	0.30	0.35
	Sandy Loam	0.24	0.19	0.14	0.26	0.29	0.34
	Clay	0.24	0.19	0.14	0.26	0.29	0.34
	Sand	0.23	0.18	0.14	0.25	0.28	0.33
	Dunes	0.18	0.14	0.11	0.19	0.23	0.26
	Thin	0.18	0.14	0.11	0.19	0.23	0.26
	Solonetzic	0.16	0.13	0.10	0.17	0.21	0.23
	Gravelly	0.15	0.12	0.09	0.16	0.19	0.21
	Saline Upland	0.13	0.10	0.08	0.14	0.16	0.18
	Badlands	0.07	0.06	0.04	0.08	0.09	0.10
Cypress Upland	Shallow Marsh	1.51	1.21	0.90	1.66	1.84	2.15
	Wet Meadow	1.45	1.16	0.87	1.60	1.78	2.07
	Dry Meadow	1.31	1.05	0.79	1.44	1.60	1.87
	Overflow	0.86	0.69	0.52	0.95	1.06	1.23
	Saline Overflow	0.77	0.61	0.46	0.85	0.94	1.10
	Saline Dry Meadow	0.62	0.50	0.37	0.69	0.76	0.89
	Loam	0.56	0.45	0.34	0.62	0.69	0.80
	Sandy Loam	0.54	0.43	0.33	0.60	0.67	0.78
	Clay	0.54	0.43	0.32	0.59	0.66	0.77
	Sand	0.53	0.42	0.32	0.58	0.64	0.75
	Dunes	0.41	0.33	0.25	0.44	0.53	0.58
	Thin	0.41	0.33	0.25	0.44	0.53	0.58
	Solonetzic	0.37	0.30	0.22	0.40	0.48	0.53
	Gravelly	0.34	0.27	0.20	0.36	0.43	0.48
	Saline Upland	0.29	0.23	0.17	0.31	0.37	0.42
	Badlands	0.16	0.13	0.10	0.17	0.21	0.23

F.2 Calculating the Cost of Reduced Stocking Rates

Calculating the opportunity cost of a reduced stocking rate is relatively straightforward if the adjustment is made for just a year. In that case, pasture rental rates can be used to estimate the value of an AUM/acre, and opportunity costs can be calculated. The difficulty of calculating opportunity costs for grazing management changes comes when the opportunity cost is required to portray a change in management that will exist in perpetuity.

The Saskatchewan Assessment Management Agency (SAMA) calculates the value of pasture land using carrying capacities (AUM/acre) which are a measure of the productive capacity of a pasture and its ability to support grazing herbivores (see Section D.2.2.1 for a thorough discussion on SAMA's pasture assessment calculations). Carrying capacities are then translated into a land rate and, then, ultimately a land value in dollars per acres ($/acre). Carrying capacity is an inherent measure of the land and results from the soils, topography, climate, etc. of a land parcel. Carrying capacity of a land parcel is not dependent on the number of cattle stocked in a pasture, but rather the reverse is true (the number of cattle capable of being stocked depends on the parcel's carrying capacity). Carrying capacity is nonetheless measured in the same units as stocking rate. Therefore, SAMA's assessment calculations provide information on the value of an additional AUM/acre. And while this is intended to estimate the difference in value between parcels of land with varying carrying capacities, it will be used here to estimate the difference in value between stocking rates.

If it is assumed that private land managers in the area are able to continually stock their land at a certain level above the recommended stocking rate, the difference in the two stocking rates can be calculated (AUM/acre), and the value of being able to utilize those additional animal unit months can be calculated using SAMA's land rate chart (Table F.4). These calculations rely on the fact that the actual stocking rates used in the region are in fact sustainable and are, therefore, possible indefinitely[75]. In this case, the actual stocking rates (which are higher than recommended) reflect some sort of hypothetical 'carrying capacity' that is higher than the recommended stocking rates would portray is possible for the pasture. This assumption requires the actual stocking rates of the region to have no measurable detrimental effect on the plant communities and, as a result, the grassland communities under these stocking rates will continue to be in good to excellent condition. Thus, the appropriate stocking rates to compare these higher private stocking rates with are the recommended stocking rates for the reference plant communities. Table F.5 contains the information on differences in stocking rates (between actual and recommended) for both ecoregions, and all sixteen ecosites. Differences in stocking rates are provided for the low, mid and high stocking rates used in the region by private landowners. The land ratings and opportunity costs associated

[75] In all likelihood, the higher than recommended stocking rates would have a detrimental impact on the plant communities of the South of the Divide region. Therefore, even though the stocking rates are currently sustainable, it is unlikely that they would be into the long run. As a result, assuming these higher stocking rates can be maintained will result in an upper bound on the opportunity cost of changing stocking rates to reflect the recommended rates.

with the stocking rate differences are also included in the table. The opportunity costs are highest for the most productive ecosites and lowest for the least productive ecosites.

Table F.4. Saskatchewan Assessment Management Agency (SAMA) land rating chart used to determine the $/acre value of grazing lands in Saskatchewan.

	Application Range				
Stocking Rate (AUM/acre)	**Min**	**Max**	**Land Rating**	**$/acre**	**2008$/acre**
0.03	0.00	0.04	5	28.75	30.06
0.05	0.04	0.06	7	40.25	42.09
0.08	0.07	0.09	9	51.75	54.11
0.10	0.09	0.11	11	63.25	66.13
0.13	0.12	0.14	13	74.75	78.16
0.15	0.14	0.16	15	86.25	90.18
0.18	0.17	0.19	17	97.75	102.21
0.20	0.19	0.21	19	109.25	114.23
0.23	0.22	0.24	21	120.75	126.26
0.25	0.24	0.26	23	132.25	138.28
0.28	0.27	0.29	25	143.75	150.30
0.30	0.29	0.31	27	155.25	162.33
0.33	0.32	0.34	29	166.75	174.35
0.35	0.34	0.36	31	178.25	186.38
0.38	0.37	0.39	33	189.75	198.40
0.40	0.39	0.41	34	195.50	204.41
0.43	0.42	0.44	35	201.25	210.43
0.45	0.44	0.46	36	207.00	216.44
0.48	0.47	0.49	37	212.75	222.45
0.50	0.49	0.51	38	218.50	228.46
0.53	0.52	0.54	39	224.25	234.47
0.55	0.54	0.56	40	230.00	240.49
0.58	0.57	0.59	41	235.75	246.50
0.60	0.59	0.61	42	241.50	252.51
0.63	0.62	0.64	43	247.25	258.52
0.65	0.64	0.66	44	253.00	264.54
0.68	0.67	0.69	44	253.00	264.54
0.70	0.69	0.71	45	258.75	270.55
0.73	0.72	0.74	45	258.75	270.55
0.75	0.74	0.76	45	258.75	270.55
0.78	0.77	0.79	46	264.50	276.56
0.80	0.79	0.81	46	264.50	276.56
0.83	0.82	0.84	46	264.50	276.56
0.85	0.84	0.86	46	264.50	276.56
0.88	0.87	0.89	47	270.25	282.57
0.90	0.89	0.91	47	270.25	282.57
0.93	0.92	0.94	47	270.25	282.57
0.95	0.94	0.96	47	270.25	282.57
0.98	0.97	0.99	47	270.25	282.57
1.00	0.99	1.01	48	276.00	288.58
1.03	1.02	1.04	48	276.00	288.58
1.05	1.04	1.06	48	276.00	288.58
1.08	1.07	1.09	48	276.00	288.58
1.10	1.09	1.11	48	276.00	288.58
1.13	1.12	1.14	48	276.00	288.58
1.15	1.14	1.16	49	281.75	294.60
1.18	1.17	1.19	49	281.75	294.60
1.20	1.19	1.21	49	281.75	294.60
1.23	1.22	1.24	49	281.75	294.60
1.25	1.24	1.26	49	281.75	294.60
1.28	1.27	1.29	49	281.75	294.60
1.30	1.29	1.31	49	281.75	294.60
1.33	1.32	1.34	50	287.50	300.61
1.35	1.34	1.36	50	287.50	300.61
1.38	1.37	1.39	50	287.50	300.61
1.40	1.39	1.41	50	287.50	300.61

Table F.5. The difference in actual (low, moderate and high) stocking rates, and the recommended references stocking rates for the South of the Divide and the associated opportunity costs of moving management in line with the recommended rates.

		Difference between Actual and Recommended Reference Stocking Rates (AUM/acre)			Land Rating Associated with the Differences in Stocking Rate			The Opportunity Cost (2008$/acre) of Changing Stocking Rates to the Recommended Reference Rates		
Ecoregion	**Ecosite**	**Low**	**Moderate**	**High**	**Low**	**Moderate**	**High**	**Low**	**Moderate**	**High**
Mixed Grassland	Shallow Marsh	0.07	0.15	0.28	7	15	25	42.09	90.18	150.30
	Wet Meadow	0.06	0.14	0.27	7	13	25	42.09	78.16	150.30
	Dry Meadow	0.06	0.13	0.25	7	13	23	42.09	78.16	138.28
	Overflow	0.04	0.08	0.16	5	9	15	30.06	54.11	90.18
	Saline Overflow	0.03	0.08	0.14	5	9	15	30.06	54.11	90.18
	Saline Dry Meadow	0.03	0.06	0.12	5	7	11	30.06	42.09	66.13
	Loam	0.03	0.06	0.11	5	7	11	30.06	42.09	66.13
	Sandy Loam	0.02	0.05	0.10	5	7	11	30.06	42.09	66.13
	Clay	0.02	0.05	0.10	5	7	11	30.06	42.09	66.13
	Sand	0.02	0.05	0.10	5	7	11	30.06	42.09	66.13
	Dunes	0.01	0.05	0.08	5	7	9	30.06	42.09	54.11
	Thin	0.01	0.05	0.08	5	7	9	30.06	42.09	54.11
	Solonetzic	0.01	0.05	0.07	5	7	9	30.06	42.09	54.11
	Gravelly	0.01	0.04	0.06	5	5	7	30.06	30.06	42.09
	Saline Upland	0.01	0.04	0.05	5	5	7	30.06	30.06	42.09
	Badlands	0.01	0.02	0.03	5	5	5	30.06	30.06	30.06
Cypress Upland	Shallow Marsh	0.15	0.34	0.65	15	29	44	90.18	174.35	264.54
	Wet Meadow	0.15	0.33	0.62	15	29	43	90.18	174.35	258.52
	Dry Meadow	0.13	0.29	0.56	13	27	40	78.16	162.33	240.49
	Overflow	0.09	0.19	0.37	9	17	33	54.11	102.21	198.40
	Saline Overflow	0.08	0.17	0.33	9	17	29	54.11	102.21	174.35
	Saline Dry Meadow	0.06	0.14	0.27	7	13	23	42.09	78.16	138.28
	Loam	0.06	0.13	0.24	7	13	21	42.09	78.16	126.26
	Sandy Loam	0.06	0.12	0.23	7	13	21	42.09	78.16	126.26
	Clay	0.05	0.12	0.23	7	13	21	42.09	78.16	126.26
	Sand	0.05	0.12	0.23	7	11	21	42.09	66.13	126.26
	Dunes	0.03	0.12	0.18	5	11	17	30.06	66.13	102.21
	Thin	0.03	0.12	0.18	5	11	17	30.06	66.13	102.21
	Solonetzic	0.03	0.11	0.16	5	11	15	30.06	66.13	90.18
	Gravelly	0.02	0.10	0.14	5	11	15	30.06	66.13	90.18
	Saline Upland	0.02	0.08	0.12	5	9	13	30.06	54.11	78.16
	Badlands	0.01	0.05	0.07	5	7	9	30.06	42.09	54.11

F.3 Spatially Assigning Grazing Opportunity Costs

Opportunity costs were spatially applied to all grasslands within the South of the Divide region. Quarter sections predominantly covered by grasslands (calculated using the Tabulate Area command in ArcMap 10.0 and a land cover raster received from the Canadian Wildlife Service) were included in the analysis. Quarter sections were then separated out based on whether they are publicly or privately managed, and which ecoregion they are located. Finally, opportunity costs were calculated for each region by multiplying the area (acres) of a quarter section made up by each ecosite (determined using the Tabulate Area command within ArcMap 10.0 and an rangeland ecosite shapefile provided by the Canadian Wildlife Service) with the corresponding opportunity cost ($/acre) for that ecosite in the appropriate ecoregion. Figure F.4 is a simple diagram outlining the process.

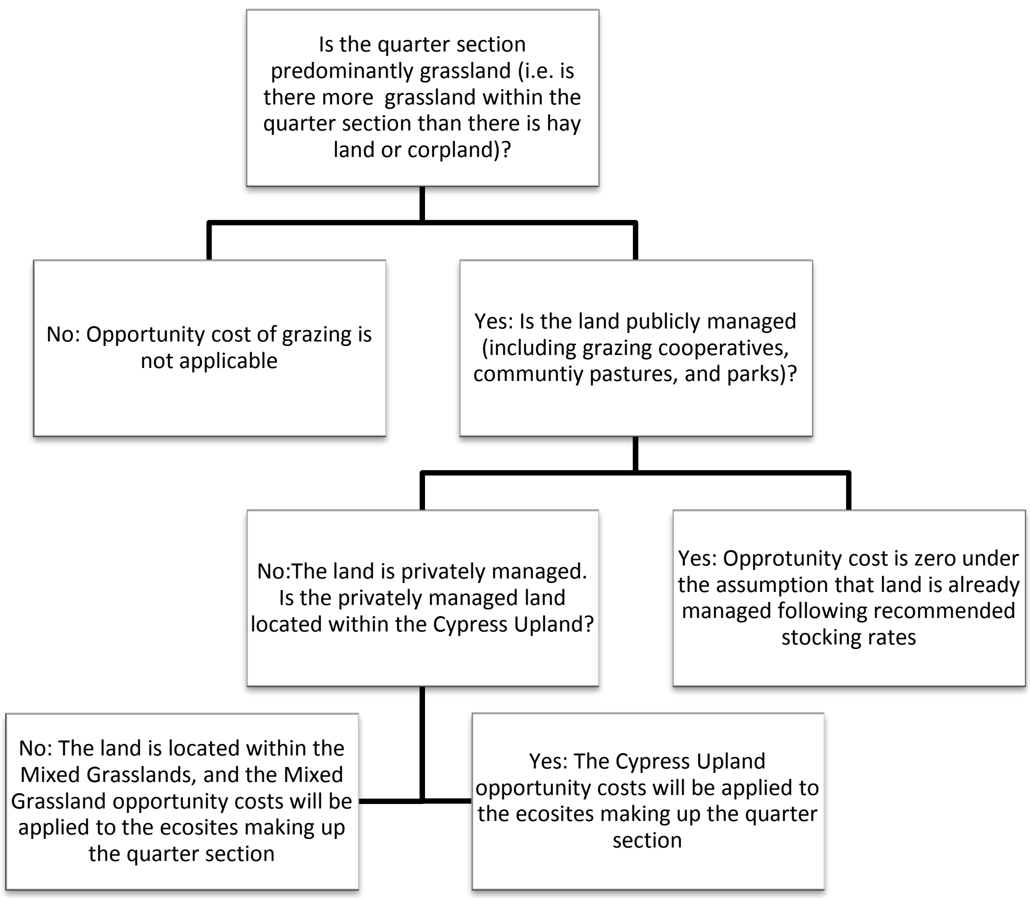

Figure F.4. Decision tree showing how stocking rates were spatially applied to quarter sections within the South of the Divide study regions.

F.4 The Grazing Management Opportunity Cost Results

Grazing management opportunity costs were only calculated for quarter sections covered predominantly with native grasslands (compared to cropland and hayland). In that way, only land already managed as grazing land would have grazing management opportunity costs calculated. A total of 22,964 quarter sections had sufficient information on ecoregion, ecosite, land cover and land ownership, and are, therefore, included within this analysis. A total of 18,790 quarter sections had some amount of native grassland on them, 14,770 were composed of over 50% native grasslands, and 14,950 had a larger proportion of their area covered by native grasslands than by hayland or cropland. Opportunity costs of grazing were calculated for all 14,950 quarter sections with grassland as their primary land use.

Information in Table F.6 includes public and private land to provide a complete picture; however, in the final opportunity cost model public land is assumed to have an opportunity cost of zero due to its current management being in line with recommended stocking rates for the region. The average quarter section size is very close to the commonly used value of 160 acres per quarter section. Within both samples, the minimum cost per acre is set by the lowest producing ecosites in the Mixed Grasslands, and the highest cost per acre is set by the highest producing ecosites in the Cypress Upland. The average costs per quarter section and per acre are likely lower when public land is included due to the high proportion of the Mixed Grassland – which has lower values than the more productive Cypress Uplands – that is represented by public grazing lands.

Table F.6. Summary statistics for grazing management opportunity costs in the South of the Divide region.

	Private Land	**Public and Private Land**
Average Number of Acres per Quarter Section	158.85	159.12
Number of Quarter Sections (% of total quarters in region)	9228 (40%)	14,950 (65%)
Average Cost per Quarter Section (Standard Deviation)	8838.30 (3236.50)	8452.47 (3071.90)
Minimum Cost per Acre	30.06	30.06
Average Cost per Acre (Standard Deviation)	55.79 (16.13)	53.24 (14.60)
Maximum Cost per Acre	174.35	174.35

Figure F.5 displays the spatial distribution of grazing management opportunity costs for privately managed land within the South of the Divide. Higher opportunity costs arise in the Cypress Upland where land is more productive and the potential difference between actual AUM/acre and recommended AUM/acre is higher.

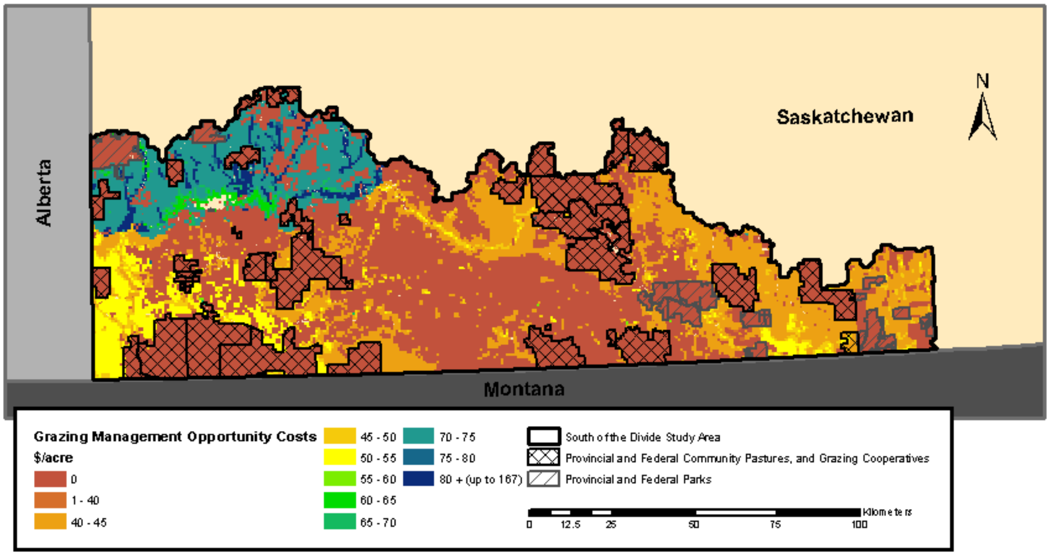

Figure F.5. The spatial distribution of grazing management opportunity costs in the South of the Divide region.

G Appendix: Buffer Strip Cost

Buffer strips are a common BMP on agricultural land. Often they are used to protect the quality of riparian areas and wetlands (Koeckhovern 2008); however, permanent vegetation cover can also provide habitat to grassland species at risk. In fact, the Canadian Wildlife Service suggest leaving strips of uncut hay in hay fields to provide shelter for bird species like as Sprague's Pipits and Burrowing Owls (Environment Canada 2011c). There could also be a benefit to providing buffer strips of perennial cover around the outside perimeter of a quarter section of cropland. Providing strips of permanent cover around crop fields and leaving uncut vegetation strips in hay field is a lower cost option to provide habitat for species at risk on already modified landscapes within the South of the Divide region.

G.1 Calculating the Cost of Buffer Strips

Calculating the cost of the buffer strips was necessary in order to include them into the opportunity cost model of habitat protection. The methods for calculating total costs of buffer strips in hay fields and croplands are discussed below. After costs were calculated, the applicable costs were spatially linked to all quarter sections that were either predominantly cropland or tame pasture/hay. All costs were calculated in 2008 dollars in order to promote consistency with the oil and gas values, agricultural land values, grazing management costs and land conversion costs.

G.1.1 Cropland

Leaving a 12 m perimeter of native grassland around a quarter section of cropland removes a total of 9.35 acres (3.78 ha) of land from production assuming a square, 160 acre quarter section. Assuming this land is lost to production, the opportunity cost per acre equals the value of an average acre of cropland in the South of the Divide – $271.99/acre (Section D.3.4). The cost of converting cropland to native grassland is $373.88/acre (see Table 4.7). Therefore, the total cost per acre is $645.87/acre for native grasslands, and the total cost to plant a 12 m perimeter buffer strip around a quarter section is $6038.88. Koeckhovern (2008) found that leaving buffer strips that would not be used for haying or grazing purposes cost $1482.18/acre. This higher value is likely due to several factors, but the most relevant would be the higher productivity of the land used in his study. A second factor is that the buffer strips could occur anywhere within the quarter section and would therefore have higher opportunity costs due to the nuisance of having to manoeuvre around them.

G.1.2 Hay Fields

BMP recommendations for hay fields in the region include cutting after July 15th in the Mixed Grasslands and July 21st in the Cypress Uplands, not cutting a second cut, and leaving strips of uncut hay within the hay field (Environment Canada 2011c). Within the South of the Divide, 95% of hay fields will receive only one cut due to limited moisture during the growing season and the threat of winter kill in years of low snowfall (Trevor Lennox pers. comm.). Due to the rarity of second cuts in the region, waiting later for the first cut does not jeopardize being able to harvest a second cut, and all that is potentially risked is a loss of quality which varies year to year due to weather conditions. As such, the only BMP considered here is leaving patches of hay uncut in the field. The pattern of uncut hay is depicted in Figure G.1 below. A 2 meter buffer strip around the perimeter of the quarter section is left, and then a 2 meter buffer strip every 100 meters working toward the centre of the field. The result is total of 3.94 acres of remaining standing hay. Assuming an average yield of 1.5 tonnes/acre (Saskatchewan Ministry of Agriculture 2007) and a value of $30/tonne for standing hay (Saskatchewan Forage Council 2010), the value of the standing hay in one quarter section is $173.68 in 2008 dollars ($177.30 in 2010 dollars) for one year. Moving that value into perpetuity results in a value of $1736.80/quarter section using a discount rate of 0.10 (the same as that used in the shelterbelt analysis).

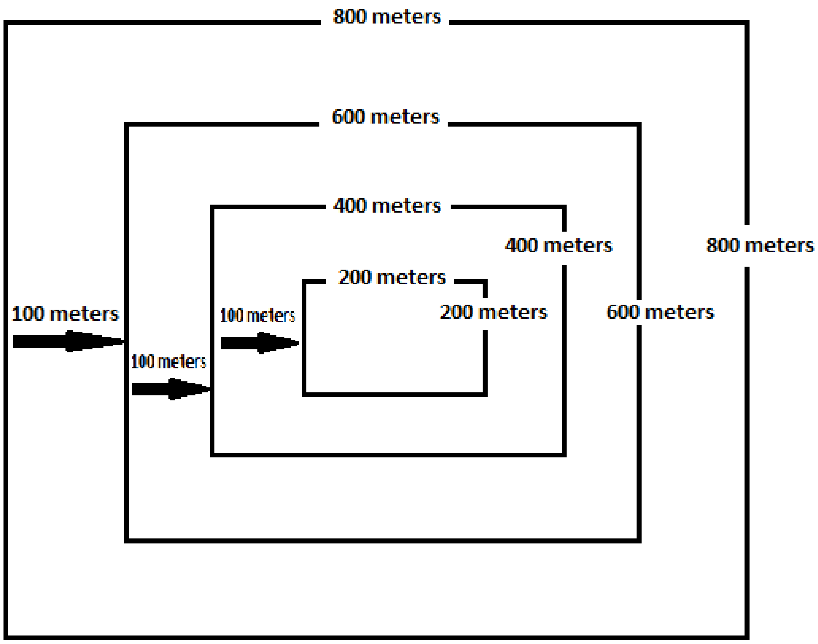

Figure G.1. Diagram showing the buffer strips of remaining standing hay left on a quarter section.

H Appendix: Shelterbelt Cost

Shelterbelts are a fairly common agricultural practice, especially within more arid farming regions. While shelterbelts are often cited to be detrimental to grassland species (as they provide perching spots for avian predators), Loggerhead Shrikes within the South of the Divide region nest within shelterbelts. As a result, shelterbelts are considered a possible BMP on already modified agricultural land (i.e. cropland or hay fields) that would benefit Loggerhead Shrike populations.

H.1 Calculating the Cost of Shelterbelts

Information on the total cost (opportunity and establishment) of shelterbelts in cropland came from a Masters' thesis completed at the University of Alberta's Department of Resource Economics and Environmental Sociology. Trautman-Laslop (2011) investigated the costs of BMPs, one of which was the planting of shelterbelts, on farms in Alberta. The results of the study were tailored to fit the South of the Divide region. Detailed calculation information is presented below. After costs were calculated, the applicable costs were spatially linked to all quarter sections that were either predominantly cropland or tame pasture/hay. All costs were calculated in 2008 dollars in order to promote consistency with the other costs included within the opportunity cost model.

H.1.1 Establishment Costs

Within her Masters' thesis, Trautman-Laslop (2011) created a model that provides information on direct and opportunity costs of shelterbelts within four soil zones – brown, dark brown, black, and dark grey. The brown soil zone model was used to represent the Mixed Grassland ecoregion within the South of the Divide study area, and an average of the dark brown and black soil zone models was used to represent the Cypress Upland ecoregion. The tree species planted are Caragana (*Caragana arboescens*) and Green Ash (*Fraxinus pennsylvanica*). The trees can be ordered at only the cost of shipping from the Agri-Environment Services Branch (AESB) formerly known as the Prairie Farm Rehabilitation Administration (PFRA). Site preparation, planting, and maintenance costs are discussed in detail in the thesis. The total establishment cost for a shelterbelt is $798/acre[76] ($1972/ha) assuming that the shelterbelt is 12 meters wide, and has a 2:1 Caragana to Green Ash planting ratio with all trees planted 60 cm apart.

H.1.2 Opportunity Costs

While establishment costs are the same regardless of soil zone, the total cost of a shelterbelt varies between zones due to its impact on crop yields (Trautman-Laslop 2011). Shelterbelts compete with crops directly adjacent to the shelterbelts, but provide wind protection and increased soil moisture (by acting as a snow fence in the winter) for vegetation outside the area of direct competition (Trautman-Laslop 2011). The brown soil zone as compared to either the dark brown or black soil zone, receives the largest yield loss in crops in direct competition with the trees, but also receives the greatest yield boost in crops protected by the trees (Trautman-Laslop 2011). The loss of crop acreage also hits the better soil zones harder financially because higher value crops can

[76] Costs in Trautman-Laslop (2011) are in 2010 dollars. Therefore, all costs have been converted into 2008 dollars using the consumer price index.

be grown on the higher soils (Trautman-Laslop 2011). There will also be differences in opportunity costs between cropland and hay fields. While Trautman-Laslop (2011) only examines cropland shelterbelts, a simple conversion was used to adjust these results to also apply to hay fields in the South of the Divide region. The applicable shelterbelt costs were spatially linked to all quarter section that were either predominantly cropland or tame pasture.

H.1.2.1 Cropland

The total cost (net present value[77] in perpetuity) – direct and opportunity – of shelterbelts on cropland are $772.22/acre ($1908.18/ha), $719.19/acre ($1777.11/ha), and $1568.92/acre ($3876.80/ha) for the brown, dark brown and black soil zones. If three 12 m wide shelterbelts with a length of 750 m are planted on a quarter section, the total cost per quarter section in the Mixed Grassland ecoregion would be $5152.09 and in the Cypress Uplands, the total cost would be $7632.79 (which uses the average value between the dark brown and black soil zones).

The opportunity cost of planting shelterbelts is the difference between the total and direct costs of implementing shelterbelts. In the Mixed Grasslands, there is no opportunity cost, but rather a benefit, from planting shelterbelts. The establishments costs are $798/acre while the total cost is $772.22 which suggests a negative opportunity cost of $25.78/acre ($63.70/ha). This negative cost is the result of productivity increases as a result of the tree rows. This benefit is approximately 9.5% of the value of an average acre of cropland in the South of the Divide region ($271.99/acre). In the Cypress Upland, the opportunity cost of shelterbelts is $346.06/acre ($855.11/ha). This cost is approximately 127% of the value of an average acre of cropland in the South of the Divide region.

H.1.2.2 Hayland

The establishment costs for shelterbelts are the same between hay fields and cropland – $798/acre ($1972/ha); however the opportunity costs will differ. If it is assumed that the ratio of opportunity cost to land value is transferable between cropland and hay fields a simple calculation can be done to determine opportunity costs, and ultimately the total cost of planting three 12 m wide, 750 m long shelterbelts on a quarter section of perennial forages can be calculated. The average value of an acre of hay or pasture land in the South of the Divide region is $148.64/acre. As such, the opportunity costs for the Mixed Grassland region is a negative opportunity cost (i.e. improved productivity) of $14.12/acre and for the Cypress Upland is a cost of $188.77/acre. The total cost per acre then becomes $783.88/acre – $5229.81/quarter section – for the Mixed Grasslands, and $986.77/acre – $6583.43/quarter section – for the Cypress Uplands.

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[77] The net present values were calculated using a discount rate of 0.10.

I Appendix: Calibrating the Marxan Parameters

Simple calibrations for the Marxan input parameters (the weighting factors on the species target and boundary length terms in the objective function) were run in Zonae Cogito prior to running the final models. Zonae Cogito was designed by Matthew Watts and Romola Stewart from The Ecology Centre at the University of Queensland to work with the family of Marxan software (Watts *et al.* 2010). It is a decision support system and database management system, and also incorporates open source GIS software. The weighting factor on the species penalty term within the objective function is known as the species penalty factor (SPF). The weight factor on the boundary length term within the objective function is known as the boundary length modifier (BLM). SPFs were selected so that all species' habitat targets were required to be met within the final solutions, and BLMs were selected to promote spatial clumping while not overwhelming the planning unit cost term within the objective function.

I.1 Marxan Models

The following three graphs illustrate the selection of the species penalty factor (SPF) for the three Marxan models. The vertical axis illustrates the number of conservation features that did not meet their targets using the SPF outlined on the horizontal axis. These calibrations were run using a boundary length modifier of zero, running all species simultaneously in the model, and using a habitat target of 70%. The ultimate SPF for each model was chosen so that all conservation targets were met (i.e. the vertical axis is at zero). The final SPFs for Models 1, 2, and 3 were 20, 40 and 130 respectively.

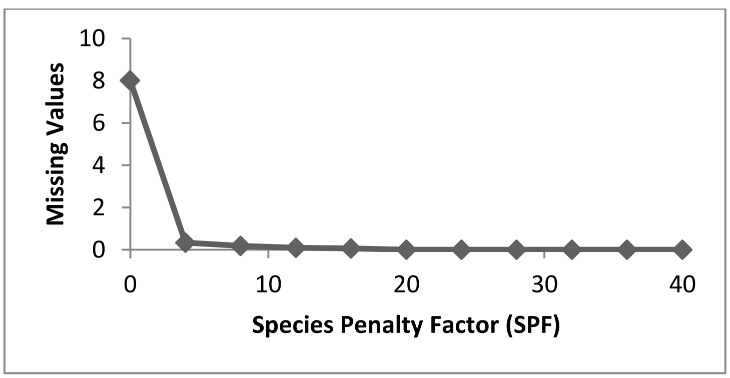

Figure I.1. Calibrating the SPF for Marxan Model 1. Final SPF = 20.

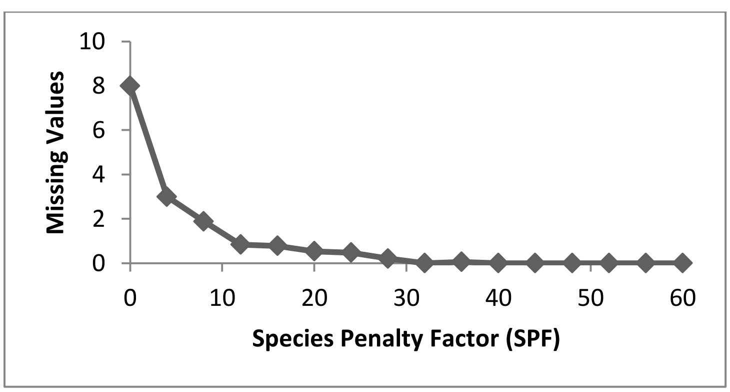

Figure I.2. Calibrating the SPF for Marxan Model 2. Final SPF = 40.

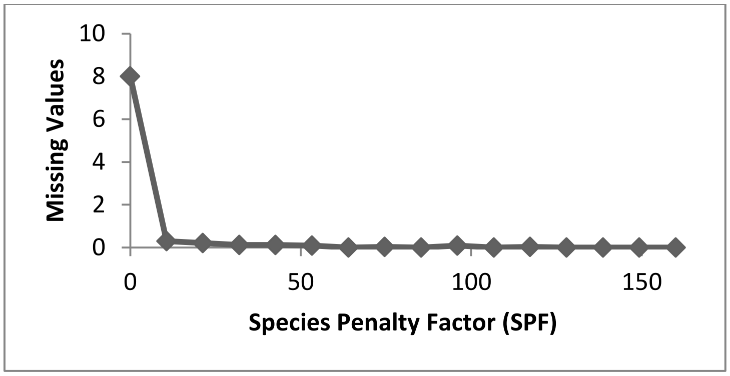

Figure I.3. Calibrating the SPF for Marxan Model 3. Final SPF =130.

The following three graphs illustrate the selection of the boundary length modifier (BLM) for the three Marxan models. The vertical axis illustrates the boundary length included within the protected area network using the BLMs presented on the horizontal axis. These calibrations were run using the calibrate SPF for each model (20, 40 and 130 for Models 1, 2 and 3), running all species simultaneously in the model, and using a habitat target of 70%. The ultimate BLM for each model was chosen where boundary length began to receive little improvements as a result of increasing the BLM, and that the number of planning units was not increased. If too large of a BLM is chosen, it can overwhelm the objective function forcing the objective function to solely minimize boundary length with no regard to actual planning unit cost. This effect can be observed by the number of planning units contained within each calibration run. Thus, it is important to choose a BLM that promote spatially contiguous habitat without overwhelming the objective function and forcing it to include extra planning units simply to reduce boundary area. The final BLMs for Models 1, 2, and 3 were 1000, 400 and 100 respectively.

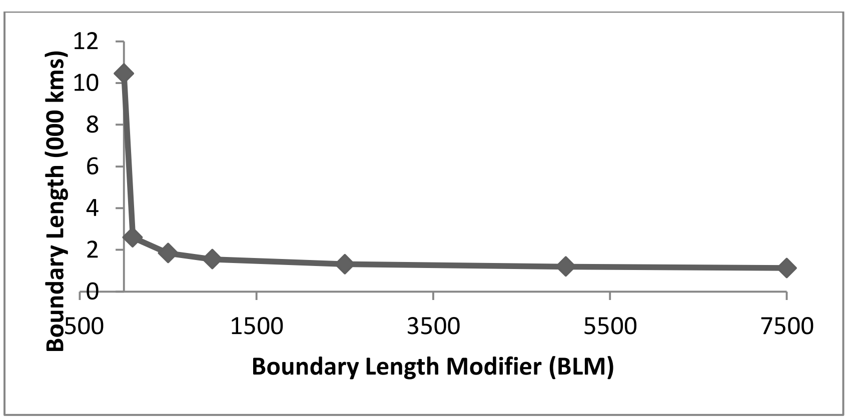

Figure I.4. Calibrating the BLM for Marxan Model 1. Final BLM = 2500.

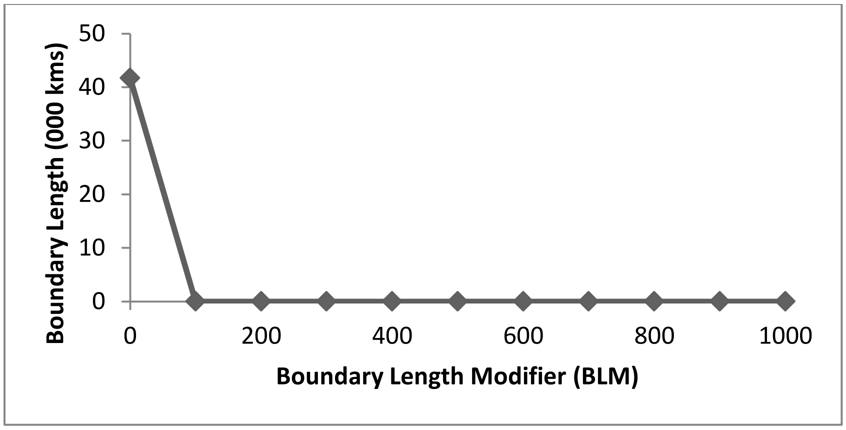

Figure I.5. Calibrating the BLM for Marxan Model 2. Final BLM = 400.

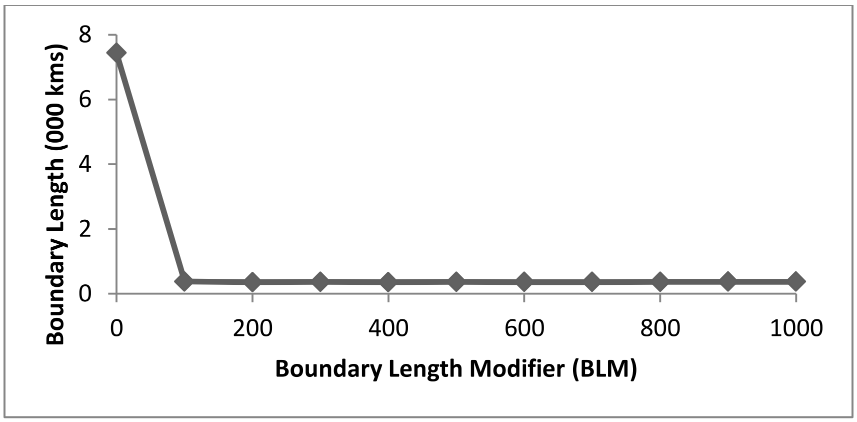

Figure I.6. Calibrating the BLM for Marxan Model 3. Final BLM = 100.

I.2 Marxan with Zones Model

The same method was used to calibrate the Marxan models was used to calibrate the Marxan with Zones model. The SPF calibrations were run using a boundary length modifier of zero, running all species simultaneously in the model, and using a habitat target of 70%. The ultimate SPF for each model was chosen so that all conservation targets were met (i.e. the vertical axis is at zero). The final SPF for the model was 50. The BLM calibrations were run using an SPF of 50, running all species simultaneously in the model, and using a habitat target of 70%. The final BLM for the model was 20.

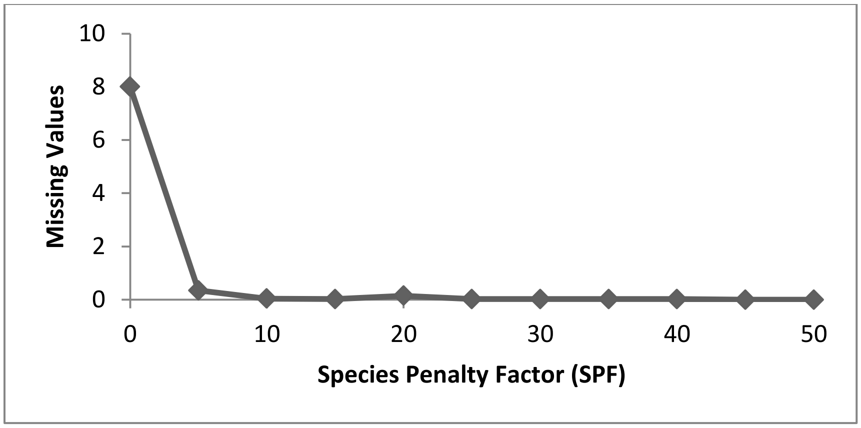

Figure I.7 Calibrating the SPF for the Marxan with Zones Model. Final SPF = 50.

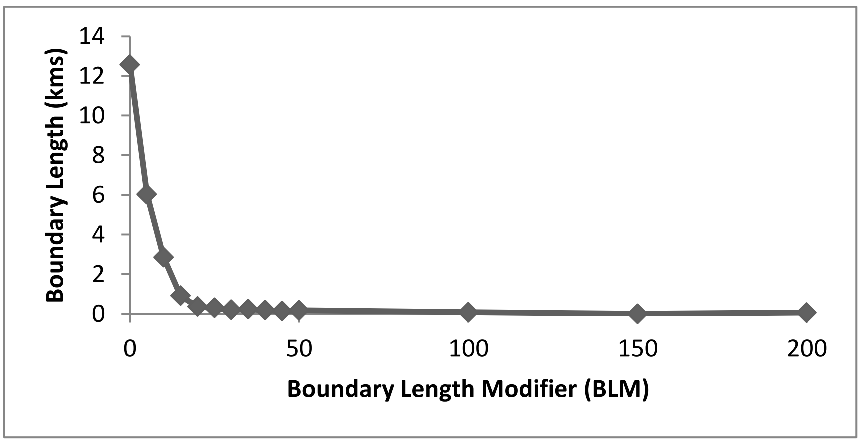

Figure I.8 Calibrating the BLM for the Marxan with Zones Model. Final BLM = 20.