University of Alberta

Integration of Wildlife into the Process of Selection and Evaluation of Protected Areas in Alberta.

by

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A thesis submitted to the Faculty of Graduate Studies and research in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Protected Areas and Wildlands Management.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled INTEGRATION OF WILDLIFE INTO THE PROCESS OF SELECTION AND EVALUATION OF PROTECTED AREAS IN ALBERTA submitted by IWONA PAWLINA in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in PROTECTED AREAS AND WILDLANDS MANAGEMENT.

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ABSTRACT

Alberta joined the international community in efforts to conserve biodiversity by protecting a representative sample of province's natural regions in a system of protected areas (PA). The assumption was that if we protect diverse landscapes we should also be able to protect wildlife associated with those landscapes. This study was undertaken to determine if the landscape approach addresses the representation needs of wildlife and evaluate other methods that could allow integrating wildlife into the process of selection of PA in Alberta.

In Alberta, almost 10% of the province is allocated in 241 PA. Many of the current PA are dispersed and very small. Assuming species continuous distribution throughout their range, a minimum of 80% of all known birds, mammals, butterflies, fishes, amphibians, and reptiles in Alberta could potentially be found in more than three of the PA .The species representation is most likely overestimated. Among the represented species are species that are experiencing population declines, suggesting that representation does not constitute protection. Those species not represented or underrepresented are rare breeders, migrants, highly localized species, species endangered or threatened in Canada, or species on the fringe of their distribution. These analyses also identified gaps in our knowledge on species presence and distribution in Alberta.

In search of efficient strategies to locate additional reserves to improve the representation of species and natural regions in the PA system in Alberta, first I tested the assumption that centers of species richness and centers of species rarity of birds, mammals, fishes, and butterflies coincide. The correlation was moderate (r=0.60,

p=0.001), therefore, various richness and rarity heuristic algorithms and random selection algorithm were evaluated to determine which of them would be suitable to complete the species representation in the PA. The richness algorithm that selected sites based of high number on species and within a buffer of 10 grid cells (if cells were otherwise of equal conservation value), selected sites efficiently and in less dispersed configuration than other algorithms. The rarity algorithm was equally efficient but resulted in more dispersed configuration of cells. Both algorithms were applied to assess their suitability to complete wildlife and landscape representation in the PA system.

For the purpose of this evaluation, the goal was to represent 10% of provincial ranges of birds, mammals, fishes, butterflies, and natural regions in the reserve system. Both algorithms showed a similar performance in terms of efficiency and configuration; however, the rarity algorithm selected more cells already in the PA. These analyses provide basis for the development of future heuristic algorithms as tools for establishing new PA and monitoring the PA network in Alberta. They could assist with future land negotiations and help establish corridors among protected areas to reduce their isolation. Iterative methods could be applied anywhere because they are scale independent, using any type of criteria as long as they are quantitative.

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Table of Contents

Chapter Page

INTRODUCTION 1

1. References 3

I. CONSERVATION IN PRACTICE - FROM RESERVES TO PROTECTED AREAS SYSTEMS. 4

1. The beginnings of protected areas 4
2. National efforts in conservation 5
3. Alberta's contribution to national efforts in conservation 6
4. Alternative reserve selection strategies – a review 7
5. Why should we implement a systematic site selection strategy based on heuristic algorithms in Alberta? 9
6. References 10

II. BIOLOGICAL DIVERSITY IN ALBERTA AND ITS REPRESENTATION WITHIN THE EXISTING SYSTEM OF PROTECTED AREAS. 13

1. Introduction 13

2. Methods 13
   2.1 Confirmed species locations - sources and data retrieval 14
   2.2 Species distribution - sources and data retrieval 15
   2.3 How recent was the data ? 15
   2.4 Species included in the analysis 16
   2.5 Taxonomy 16
   2.6 Species status 16
   2.7 Protected areas (PA) in Alberta 17
   2.8 Criteria for PA evaluation 17
   2.9 Analytical approach - Gap analysis 17

3. Results 17
   3.1 Information on confirmed species locations in Alberta 17
   3.2 Representation of Alberta's biological diversity in the existing system of PA. 20
   3.3 Evaluation of protected areas 24

4. Discussion 30

III. RESERVE SELECTION STRATEGIES FOR PROTECTED AREAS NETWORK IN ALBERTA. 34

1. Introduction 34

2. Methods 37
2.1 Surrogates of Alberta's biodiversity 37
2.2 Ecological criteria for determining conservation values of grid cells 38
2.3 Distribution patterns of rarity and richness 38
2.4 Criteria for tie breaking in site selection process 38
2.5 Spatial Data in support of site selection process 40
2.6 Computational techniques for reserve selection 41
2.7 Application of selected algorithms to complete the representation of the natural features in the existing system of PA 44

3. Results 44
3.1 Distribution patterns of species richness and rarity in Alberta. 44
3.2 Effect of selection algorithms on efficiency 46
3.3 The effect of ties on efficiency 46
3.4 The effect of algorithms and ties on reserve system configuration 49
3.5 Complementary analysis - selecting sites to complete species representation in the existing system of protected areas. 50

4. Discussion 58

4.1 Diversity and rarity - distribution patterns 58
4.2 Site selection methods 58
4.2 Spatial configuration 59
4.3 Complementary analysis 59
4.4 Recommendations 60

5. References 62

IV. CONCLUSIONS 66

1. References 69

Appendices

APPENDIX 1 71
APPENDIX 2 88
APPENDIX 3 96
APPENDIX 4 107

List of Tables

Table		Page
2-1	Census of Alberta's taxonomic diversity and summary of data used in gap analysis.	18
2 -2	Summary of representation of Alberta's biodiversity in the existing system of Protected Areas (PA).	23
2-3	Species not represented or with limited representation in protected areas (PA) in Alberta.	24
2-4	Protected areas required to represent species once listed in order as they were selected.	26
2-5	Additional protected areas required to represent species two times listed in order as they were selected.	27
2-6	Additional protected areas required to represent species three times listed in order as they were selected.	28
2-7	Protected areas (PA) required to represent Species of Special Status (SST) once, twice, or three times listed in order as they were selected.	29
3-1	Classification of selected land disturbances in Alberta.	40
3-2	Summary of iterative algorithms and rules to guide selection process.	43
3-3	Relationship among centers of species richness in Alberta.	45
3-4	Relationship among total rarity scores of wildlife species in Alberta.	45
3-5	Relationship among distribution of centers of species richness and centers of species total rarity for different taxonomic groups in Alberta.	46
3-6	Efficiency of site selection algorithms in representing natural features among 10km by 10km grid cells in Alberta.	48
3-7	Frequency of grid cells based on level of disturbance and current protection.	49
3-8	Cell aggregation to represent 10% of range of all features resulted	49

from various reserve selection approaches.

3-9 Results of complementary analyses using data set with and without bird data. 57

Appendix 1 71

Table 1 - List of Alberta mammals included in the analysis. 72
Table 2 - List of Alberta butterflies included in the analysis. 74
Table 3 - List of Alberta fishes included in the analysis. 78
Table 4 - List of Alberta birds included in the analysis. 80
Table 5 - List of Alberta Amphibians included in the analysis. 87
Table 6 - List of Alberta reptiles included in the analysis. 87

Appendix 4 107

Table. 1. List of natural features underrepresented in the current protected areas system based on 10% provincial species range representation goal. 108

List of Figures

Figure		Page
2-1	Distribution of known species locations in Alberta.	19
2-2	Distribution of protected areas (National Parks, Provincial Parks, Wilderness Areas, and Ecological Reserves) in Alberta by size.	20
3-1	A total of 768 grid cells selected by the richness algorithm (R6) based on the distribution of birds, mammals, butterflies, fishes and natural regions in Alberta.	52
3-2	A total of 763 grid cells selected by the rarity algorithm (TR) based on the distribution of birds, mammals, butterflies, fishes and natural regions in Alberta.	53
3-3	A total of 796 grid cells selected by the richness algorithm (R6) based on the distribution of mammals, butterflies, fishes and natural regions in Alberta.	54
3-4	A total of 863 grid cells selected by the richness algorithm (R6) based on the distribution of mammals, butterflies, fishes and natural regions in Alberta.	55
3-5	A total of 798 grid cells selected by the richness algorithm (R6) based on the distribution of birds, mammals, butterflies, fishes and natural regions in Alberta with special preference to cells consistently selected by other algorithms.	56

Appendix 2

Figure 1. Number of people per 100km^2 grid cell based on 1991 population census.	89
Figure 2. Provincial pipelines per 100km^2 grid cell (January 28, 1997).	90
Figure 3. Provincial gas wells per 100km^2 grid cell (January 28, 1997).	91
Figure 4. Forestry cutover in 1997 per 100km^2 grid cell.	92
Figure 5. Grid cells that intersect with major Alberta's highways (1997).	93
Figure 6 . Land ownership in Alberta in 1997 per 100km^2 grid cell.	94
Figure 7. Protected areas in Alberta based on 100km^2 grid.	95

Appendix 3

Figure 1. Distribution of birds species richness in Alberta per 100km^2 grid cell.	97
Figure 2. Distribution of total rarity score of birds in Alberta per 100km^2 grid cell.	98
Figure 3. Distribution of mammals species richness in Alberta per 100km^2 grid cell.	99

Figure 4. Distribution of total rarity score of mammals in Alberta per 100km^2 grid cell. 100
Figure 5. Distribution of butterflies species richness in Alberta. 101
Figure 6. Distribution of total rarity score of butterflies in Alberta per100km^2 grid cell. 102
Figure 7. Distribution of fishes species richness in Alberta per 100km^2 grid cell. 103
Figure 8. Distribution of total rarity score of fishes in Alberta per 100km^2 grid cell. 104
Figure 9. Distribution of centers of species richness of birds, mammals, butterflies and fishes in Alberta per 100km^2 grid cell. 105
Figure 10. Distribution total rarity scores of birds, mammals, butterflies and fishes in Alberta per 100km^2 grid cell. 106

INTRODUCTION

The decline of biodiversity is one of the most serious global environmental threats (Grehan 1996). Because of human activities, the structural and functional variety of life forms at genetic, species, community, and ecosystem levels is being lost at the rate that exceeds natural processes (Mosquine *et al.* 1995). In efforts to conserve biodiversity in Canada, the World Wildlife Fund Canada (WWF) launched the Endangered Spaces Campaign. The main goal of the Campaign is to conserve Canada's biological diversity by protecting a representative sample of each of the country's natural regions by the year 2000 (Noss 1995). The first step in the Endangered Spaces' strategy is to locate gaps in the protection based on natural regions and their enduring features, and to fill these gaps by establishing new reserves. Enduring features, defined by topography, parent material, soil, and other physical factors, are relatively stable and are assumed to have a significant influence on the distribution of species and natural communities within natural regions. Therefore, it has been suggested that by representing all enduring features in the protected areas network a significant portion of the biological elements and evolutionary processes will be maintained. Others, however, pointed out that many rare species and communities are missed when only physical attributes are used (Kirkpatric and Brown 1994, Laurner and Murphy 1994, Noss 1995). Kirkpatric and Brown (1994) concluded that the optimal reserve selection approach might be one that combines physical and biological information in analysis

The Province of Alberta joined the international community in efforts to conserve biodiversity by initiating a program called Special Places 2000 (SP 2000). The main goal of the SP 2000 initiative is to protect a representative sample of the province's total natural diversity. The natural diversity includes non-biological landscape features (an abiotic matrix) and biological diversity. This program adopted the World Wildlife Fund's gap analysis approach for the completion of the protected areas network (Alberta Environmental Protection 1994, Noss 1995). Alberta has completed the gap analysis based on natural regions and enduring features. The gaps have been identified; protection targets set on percentage/area bases (Alberta Environmental Protection 1994), and process initiated to fill these gaps. But no unified approach exists to address the quality and quantity of biological diversity in Alberta or to evaluate how much biological diversity has already been represented in the existing protective areas (PA). Also, no standard approach exists for the selection of potential sites.

The purpose of this study was to evaluate how well the current protected areas system is able to represent Alberta's biological diversity, to examine various quantitative approaches to reserve selection, and to apply the best approach to complete biodiversity representation in the existing system of protected areas. The results of my research are presented in four chapters.

Chapter One discusses the genesis of protected areas. It explores changes in conservation efforts and in our perception of nature and its resources. In Chapter Two, I assess what information is available on the presence, specific locations, and distribution of wildlife species from six taxonomic groups in Alberta and evaluated to what extent these species are represented within the existing system of protected areas. I determined the percentage of Alberta's wildlife species that exist in one, two, three, or more of the existing protected areas, or are not included in the current system. In addition, I identified the protected areas that contribute the most to the goal of representation of biological diversity.

In Chapter Three, I explore strategies for locating sites (grid cells) for core areas of the protected areas system using heuristic algorithms. The goal was to represent 10% of all known species provincial ranges and Alberta's natural regions. First, various algorithms (random selection algorithm, species richness algorithm, species of special status algorithm, and species total rarity algorithm), including a set of rules for tie breaking among cells of equal conservation value, were evaluated with regards to efficiency and spatial configuration. Then, the best algorithms were applied to complimentary analysis aiming at completing the representation of natural features in the current protected areas system. The range representation of natural features was assessed and representation needs determined. Selected algorithm was used to identify grid cells currently in the system required for feature representation, and then additional grid cells were identified from the cells outside the current system that would complete the representation. All selected cells were then evaluated to eliminate any unnecessary duplication in feature representation. The results were assessed based on efficiency, spatial configuration (level of cell aggregation), overall natural feature representation, and other planning criteria, including land disturbance, land ownership, distance to the nearest site, and existing protection. The results are discussed in the context of major distribution patterns of species diversity and rarity in Alberta.

Chapter Four synthesizes all results and discusses importance of integrating wildlife into the process of selection and evaluation of protected areas in Alberta. It also discusses current and future benefits of using a systematic approach to site selection in building the protected areas network in Alberta.

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I. CONSERVATION IN PRACTICE - FROM RESERVES TO PROTECTED AREAS SYSTEMS.

1. The beginnings of protected areas

The practice of establishing reserves that encompass natural features has its beginnings in ancient Rome and Medieval Europe. Reserves were set aside for recreational needs of the ruling class. Occasionally aristocrats would designate areas to protect species valuable for hunting. In doing so, they were, in some cases unconsciously preparing the beginnings of subsequent natural reserves (Dixon and Sherman 1990). In North America, the situation was different. Pioneers "entered the new land" equipped with powerful technology. They were faced by the endless availability of natural resources, just waiting to be utilized. But they also recognized the beauty of some natural areas and potential economic return from their use as a tourism destination. There were enough natural resources to satisfy both the industrial resource development activities and recreational use. Even the first national parks, one of the oldest forms of conservation in Canada, were viewed as place for recreation rather than conservation.

Kevin McNamee (1993) offered a comprehensive review on the history of Canada's national parks and the evolution of biological conservation in Canada. The beginnings of Canada's national parks system, according to McNamee, could be traced to Alberta and the establishment of the 26km^2 reservation around Banff Hot Springs in 1885. In 1887, the boundaries of the hot springs were extended to 673 km^2 and a public park, later called Banff National Park, was established. This first public park was to be "*a pleasure ground for the benefit, advantage and enjoyment of the people of Canada*". But the government also reserved the right to make rules for the "*preservation and the protection of game and fish or of wild birds*" including the control over timber cutting and other resource exploitation (see McNamee, 1993 for references). For the first time, the need to conserve natural resources was acknowledged; however, because there were plenty of natural resources to exploit, timber cutting, mineral development, and grazing were allowed in the park. Over the next 15 years, inspired by profit, more national parks were established, including Alberta's Waterton Lakes and Jasper.

Though the national park is the most widely known form of protected areas, other categories were also applied, depending on objectives. In 1893, the Ontario government established Canada's first provincial park. In Alberta, early provincial parks were established after 1929 as small recreation areas (Mitchell and Pachal 1996).

In the following years, the perception that natural areas were vast and not in any danger and natural resources were there to be used as needed, began to change. This had an impact on conservation efforts, resulting in the passing of the Parks Act in 1911 that marked a dramatic shift in national parks policy, reducing the level of development allowed in the parks. Also, with high political and public support for the concept of national parks and wilderness, the Parliament passed the National Parks Act in 1930 that clearly stated that mineral development and exploration were prohibited in national parks and only limited use of timber was allowed.

The 1960's brought dramatic growth in public concern over the environment. Pollution and threats to wilderness became strong issues. The public and political attention shifted from the recreational value to the ecological value of parks. The preservation of significant features in national parks was viewed as the most important obligation of the 1964 parks policy. Also, Alberta's first designation of wilderness lands, outside the national parks, came in 1959 with the establishment of Willmore Wilderness Park (Mitchell and Pachal 1996). After a long public debate in 1971, the Wilderness Areas Act was formulated to protect samples of natural ecosystems as benchmarks against which to measure environmental change. In other words, Wilderness Areas were protected from industrial development by legislation (Mitchell and Pachal 1996).

In 1971, Parks Canada adopted a natural region system to guide the development of the national parks system. By considering this approach, Parks Canada moved from making *ad hoc* decisions, to a more systematic approach to site selection. The goal was to represent the characteristic physical, biological, and geographic features of each of the 39 Canadian natural regions within the national parks system. Over the next twenty years, more national parks were established across Canada. The urgency to complete the parks' network was high because of threats to the integrity of the existing parks due to the inappropriate land use around the parks, causing degradation of ecological quality within them and loss of wilderness across the country.

2. National efforts in conservation

In June 1992, Canada signed the Convention on Biological Diversity at the Earth Summit. The Convention inspired the global community to assess the adequacy of current conservation efforts and to develop strategies to prevent further deterioration of biodiversity (Ministry of Supply and Services Canada 1995). In response to the Convention, the World Wildlife Fund Canada (WWF) launched the Endangered Spaces Campaign. WWF Canada believes that, in order to maintain biological diversity, we must establish a network of carefully selected protected areas that collectively represent Canada's natural regions and develop sound stewardship over the remaining landscape.

The first step in the Endangered Spaces' strategy to reach its goal was to locate gaps in the protection based on natural regions and their enduring features, and to fill these gaps by establishing new reserves. Enduring features, defined by topography, parent material, soil, and other physical factors, are relatively stable and are assumed to have a significant influence on the distribution of species and natural communities within a natural region. Therefore, it has been suggested that, by representing all enduring features in the protected areas network, a significant portion of the biological elements and evolutionary processes will be maintained. Although, it was also stated, the reserve system alone will not be able to prevent further deterioration of biodiversity and that appropriate landscape management outside the reserve system will have to be implemented to assure the continuation of natural processes.

3. Alberta's contribution to national efforts in conservation

The province of Alberta joined the international community in efforts to conserve biodiversity by initiating a program called Special Places 2000 (SP 2000). The main goal of the SP 2000 initiative is to protect a representative sample of the province's total natural diversity. The natural diversity includes non-biological landscape features (an abiotic matrix) and biological diversity. This program adopted gap analysis approach promoted by the WWF and recommended by the Canadian Council on Ecological Areas (Peterson and Peterson 1991) for the completion of the protected areas network (Alberta Environmental Protection 1994, Noss 1995). Alberta has completed the gap analysis based on natural regions and enduring features. The gaps have been identified; protection targets have been set on percentage/area bases (Alberta Environmental Protection 1994), and process has been initiated to fill these gaps.

The process is based on nomination strategy. According to the Alberta Environmental Protection news release on Tuesday, March 28, 1995, *"Potential new Special Places may be nominated by an Albertan, industry, municipality, land authority or conservation group"*. A Provincial Coordinating Committee, comprising stakeholders groups would then review submitted nominations. The Committee would evaluate nominations based on: Special Places policy and principles, scientific criteria, and existing gaps in the system of protected areas". The scientific base would be provided by the natural region and sub-region land classification. *"Special Places will balance the preservation of Alberta's natural heritage with.... outdoor recreation, heritage appreciation and tourism/economic development"*. As to the activities within the nominated sites, the government states that " *While certain levels of use will be allowed in some Special Places, certain sensitive sites will not include any development*". Although the process is supposed to be systematic, the selection still allows for *ad hoc* site selection, where the action is guided rather by what is possible under the present political or social conditions than by what has been suggested by scientific studies or conservation biology.

Currently, there are five types of legally protected areas (PA): National Parks, Ecological Reserves, Wilderness Areas, Natural Areas, and Provincial Parks (Michell and Pachal 1996). All of the 241 PA vary greatly in size. Four PA, including Wood Buffalo National Park (NP), Banff NP, Jasper NP, and Willmore Wilderness Park exceed 1,000km^2 each. Another twelve, among them Upper Elbow-Sheep, Kakwa, Peter Lougheed, Waterton Lakes NP, White Goat, Siffleur, Cypress Hills, Elk Island NP, Ghost River, Lakeland, Suffield, and One-Four Agriculture Research Station (One-Four Station) range from 100km^2 to 1,000km^2. In addition, 47 PA are 10-100km^2, 121 PA are 1-10km^2, and the remaining 57 PA are less than 1km^2. All of the PA encompass almost 10% of province but the majority of the PA are small, dispersed, and isolated (Chapter 2, this study).

The 10% seem to be getting us closer to the 12% suggested by the 1987 Brundtland Commission to secure the survival of existing wild species and ecosystems, but many species of Alberta's wildlife are still underrepresented, experiencing population declines, and some are not represented in the current system (Chapter 2, this study). Some considered represented are in trouble, suggesting that representation does not constitute protection. This confirms what ecologists today agree upon, that the 12% preservation is insufficient (Mosquin *et al.* 1995). Part of the problem could be that protected areas, even if established, do not protect the natural features they contain due to their size, location, industrial developments, and other activities allowed within protected areas, and incompatible land management outside their boundaries.

We may never know how much land we must set aside to conserve biodiversity, but we will find out indirectly that we were successful in our conservation efforts if the number of species considered "in trouble" declines over time. Alberta's Wildlife Status document complied and published by the Alberta Government (1996) and its future revised editions could help by monitoring the trends. What may lead to success is a large-scale strategy based on a truly systematic approach to site selection for the Protected Areas Network in Alberta: strategy that would go beyond the natural regions and percent goals set by the course filter gap analysis conducted in Alberta. It has already been suggested that the natural region approach will not guarantee the representation of rare species (Noss 1995, Kirkpatric and Brown 1994, Laumer and Murphy 1994), and, as it was indicated earlier, the representation of species and landscapes will not guarantee their protection. The alternative strategy would allow for the expansion of site selection process to include wildlife species of known distribution, measure the contribution each area makes to achieving the goal of representation and conservation, explore alternative selections, and evaluate consequences of such decisions. It would also include spatial relationships among protected areas in the selection process and take under consideration existing land use and designations to select sites that have the best chance of maintaining their integrity. All of this would be evaluated on a large, provincial scale.

4. Alternative reserve selection strategies – a review

Scientists in Australia, Kirkpatric and Hardwood, first recommended alternative strategies to site selection that take under consideration a large spatial scale, conservation biology principles, and efficiency, in 1983. They developed an analytical tool that selected sites based on specific criteria. It was not a set of recommendations, suggestions, or ideas open for interpretations, but a practical approach that could give specific results. Since then, other scientists became involved in improving the scientifically based systematic approach to reserve selection, and their method has been recognized and applied internationally (see Pressey *et al.* 1997 for full references). The systematic process starts by identifying criteria to value potential sites before the selection process is initiated. Since a wide range of criteria has been used to evaluate and identify protected areas by different jurisdictions, Smith and Theberge (1986) conducted a comprehensive review. They concluded that the most frequently criteria used were rarity, uniqueness, naturalness, productivity, fragility, representativeness, and importance to wildlife. The most prevailing, however, were diversity and rarity (Margules and Usher 1981, Margules 1986, Usher 1986). The size of the area and the level of threat were among the most frequently recognized planning criteria. Additional criteria in this category involved shape, consideration for buffers, accessibility, location, and level of significance.

Once the decision has been made on the selection criteria for the evaluation of potential sites, various mathematical algorithms could be applied to explore efficient alternatives for establishing a reserve system. The most popular systematic approaches for identifying sites include iterative methods and linear programming methods. Usually, the objective is to select a minimum number of sites, or the smallest area to represent a certain portion of species or landscape distribution ranges (Nicholls and Margules 1994, Pressey *et al.* 1997, and this study), or to represent each species or landscape in one or more reserves (Pressey and Nicholls 1989, Rebello and Sigfried 1992, Nicholls and Margules 1993, Kershaw *et al.* 1994, 1995, Lombard *et al.* 1995, Willis *et al.* 1996, Freitag *et al.* 1996, Csuti *et al.* 1997).

The iterative approach to site selection (Pressey and Nicholls1989, Bedward *et al.*1991, Williams *et al.* 1996) was first proposed and applied by Kirkpatric and Hardwood (1983) to the conservation of wetland plants in Tasmania (Pressey and Nicholls 1989) and later, widely used in Australia, South Africa, United States, Norway, Great Britain, and other countries (see Pressey *et al.* 1997 for full references). These methods rely on heuristic algorithms and allow for the selection of objects based on their conservation value. The conservation values are calculated prior to the analysis based on quantified ecological criteria (richness, rarity, level of existing protection, etc.) describing natural features (species and/or landscapes). The algorithm selects the site that has the most of the required natural features and proceeds stepwise, adding at each step sites that contain the most of additional features not yet represented (Nicholls and Margules 1993, Csuti *et al.* 1997, Chapter 3 in this study).

This approach greatly reduces the number of sites needed to represent features. As a result, the iterative methods produce site priority lists. Some argue, however, that the stepwise method based on heuristic algorithms might not find the optimal solution to site selection because once sites were selected in the earlier iteration, the algorithm would not allow them to be dropped from a priority set. Therefore, many site combinations remained (Underhill 1994).

To find the optimal set of sites some applied optimality algorithms (Church *et al.* 1996). This method is based on exploring all possible combinations of sites that, overall, may have, for example, the highest species richness in the smallest number of sites. The result is a list of sites with no means of setting priorities among them, nor the ability to assess how many natural features could be represented in fewer sites. When dealing with large data sets or complicated analysis, the optimising algorithm required more processing time than heuristic algorithms (Csuti *et al.* 1997) and often failed to find a solution (Pressey *et al.* 1996, 1997). Also, comparative analysis revealed that optimality algorithms were only 5-10% more efficient (Lombard *et al.* 1995, Pressey *et al.* 1997) or in some cases as efficient as heuristic (Seaterdal *et al.* 1993, Willis *et al.* 1996, Stokland 1997). Therefore, in practice, heuristic seem to be a more appropriate method to assist in reserve selection at the present. In addition, the iterative approach provides conservation planners with a tool that enables them to explore alternatives in site selection quickly and easily within reasonable limits of optimality (Nicholls and Margules 1993).

5. Why should we implement a systematic site selection strategy based on heuristic algorithms in Alberta?

The current selection strategy, based on the nomination process, is still an extension of a "chance process" and could produce a network of reserve, that is insufficient in terms of preserving a diversity of ecosystems (Chapters 2 and 3, this study). The use of analytical tools in conjunction with GIS technology, would allow for the selection of efficient combination of sites based on selected criteria reducing potential costs of land acquisition and/or management. It would monitor our progress in meeting conservation objectives and examine options in future land designations/use/management negotiations. Each decision would be evaluated in the provincial context without biases. The sophisticated tools would also help us to take advantage of the increasing amounts of geographic and ecological data becoming available.

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II. BIOLOGICAL DIVERSITY IN ALBERTA AND ITS REPRESENTATION WITHIN THE EXISTING SYSTEM OF PROTECTED AREAS.

1. INTRODUCTION:

The decline of biodiversity is one of the most serious global environmental threats. Because of human activities, structural and functional variety of life forms at genetic, species and community and ecosystem levels, is being lost at the rate that exceeds natural processes (Mosquin *et al.* 1995). To conserve biodiversity, the Province of Alberta initiated a program, called Special Places 2000 (SP 2000). The main goal of the SP 2000 initiative is to protect a representative sample of the province's total natural diversity. The natural diversity includes non-biological landscape features (an abiotic matrix) and biological diversity. This program adopted the World Wildlife Fund's gap analysis approach for completion of the protected areas network (Alberta Environmental Protection 1994, Noss 1995). Alberta has completed the gap analysis based on enduring features but the second component of Alberta's diversity, namely biological diversity, has not been adequately addressed. Moreover, no unified approach exists to address biological diversity in Alberta or to evaluate its representation in the existing protected areas.

Purpose and Objectives

The purpose of this study is to assess what information is available on the presence, specific locations, and distribution of wildlife species in Alberta and to assess to what extent these species are represented within the existing system of protected areas. The two main objectives are:

1. Evaluate what information is available on the presence, locations, and distribution of species from various taxonomic groups in Alberta.
2. Identify gaps in representation of taxonomic groups in the existing system of protected areas for which sufficient information exists.
   - determine what percentage of Alberta's wildlife species is already represented in the existing protected areas,
   - identify species that exist in only one, two, or three of the protected areas,
   - find gaps in the species representation by identifying species that exist only outside the current system,
   - identify existing areas that contribute most to the goal of protecting a representative sample of Alberta's biological diversity

2. METHODS:

Data on the presence, locations, and distribution of birds, mammals, amphibians, reptiles, fishes, and butterflies in Alberta were obtained from the Alberta Provincial Museum database, various Provincial Government databases, Federation of Alberta Naturalist database, from sources published as atlases (Federation of Alberta Naturalists 1992, Nelson and Paetz 1992, Russell and Bauer 1993, Smith 1993, Bird *et al.* 1995), from scientific publications (Stelfox 1995, Takats 1995, Fukumoto 1997) and obtained through personal communication with various researchers (see reference section). All the data were registered to the ten degree Transverse Mercator (TTM) projection and referenced to a common 10 km x 10 km grid. Spatial data layers for species distribution were created using Geographic Information Systems (GIS) technology (ARC/View).

2.1 Confirmed species locations - sources and data retrieval.

Mammals and fishes:

- species locations in the Provincial Museum database were described by longitude and latitude coordinates.
- species locations, not found in the Provincial Museum database, were digitized from a 1:5,000,000 provincial base map of township and ranges (Nelson and Paetz 1992, Smith 1993). Each point within a township indicates that at least one specimen of that species has been collected in that township.
- data published in scientific reports (Stelfox 1995) and obtained through personal communication (T. Skorupka).

Butterflies:

- confirmed species locations were digitized from a 1:5,000,000 provincial base map of township and ranges (G. Hilchie pers. comm.). These locations were also verified with Bird et al. (1995).

Birds:

- The Federation of Alberta Naturalists' Breeding Birds Database, published in *The Atlas of Breeding Birds of Alberta* (Federation of Alberta Naturalists 1992), was the main source of information. Data from other sources were used if they supplemented already surveyed areas or came from studies that sampled large enough areas (Stelfox 1995, and S. Hannon, D. Scobie pers. comm.). The atlas data were collected between 1978-1991 in a systematic manner using the Universal Transverse Mercator (Military) grid system. The grid consists of 6000 10km by 10km squares. Approximately 37% of the province was surveyed. The surveyed squares were identified as "priority squares". In southern Alberta the priority squares were chosen from a block of four squares (20km by 20km) based on greatest habitat diversity. In northern Alberta, because of difficult access and low atlasser population, a minimum of one square for each block of 100 squares (100km by 100km) was assigned priority but usually more than one were surveyed (Federation of Alberta Naturalists 1992). Some surveys accounted only for one to 25 species within the assigned priority squares. The atlassers suggested that these areas were under-surveyed. Other areas, with more than 25 species, were considered well or very well surveyed. In addition to survey data the atlas also used information solicited from private individuals and published in scientific literature (Federation of Alberta Naturalists 1992).
- species locations in the Provincial Museum database described by longitude and latitude coordinates.

- locations obtained through personal communication with various researchers (S. Hannon , D. Scobie pers. comm.).

Amphibians and Reptiles:

- species locations in the Provincial Museum database described by longitude and latitude coordinates.
- locations from the Provincial Biodiversity/Species Observation Databases.
- additional data points digitized from a 1:5,000,000 provincial base map of township and ranges based on Russell and Bauer (1993).
- published information (Albert Forestry Lands and Wildlife 1990, Government of Alberta 1996).
- locations obtained through personal communication (K. Graham).

2.2 Species distribution - sources and data retrieval

Data from the confirmed species locations, information on species distribution published in atlases (Nelson and Paetz 1992, Smith 1993, Bird *et al.* 1995), and expert's knowledge (G. Hilchie pers. comm.) were used to delineate distribution boundaries of mammals, fishes, and butterflies in Alberta. The data were digitized from a 1:5,000,000 provincial township and ranges maps. These boundaries represent an extrapolation from the existing confirmed species locations data; therefore, they are the potential distributions of species in Alberta. They imply that species might be expected to occur within the extrapolated area if suitable habitat exits. In other words, the distribution of species might not be continuous throughout these ranges.

The distribution ranges for butterflies were delineated with the help from Mr. G. Hilchie from the Entomology Department at the University of Alberta and later compared with the information published in Bird *et al.* (1995). There was no suitable information published on the species ranges of birds. Therefore, the birds occurance data from the previously defined "priority squares" were extrapolated to represent larger (40km by 40km in southern Alberta or 100km by 100km in northern Alberta) blocks of land (Federation of Alberta Naturalists 1992). As a result, 91% of Alberta was included in the study.

2.3 How recent were the data?

An attempt was made to use data collected only in the past 27 years. Therefore, where possible, records older than 27 years were excluded (the Provincial Museum database and various published sources). In other cases, however, it was very difficult to separate the data collected in the past 27 years from those collected at an earlier time. The information sources cited in the atlases give some indication of how current the data were. For example, 75% of the cited documents in Nelson and Paetz (1992) and 66% of documents cited in Smith (1993) were published in the past 27 years. The birds survey was conducted 6-19 years ago. It should be noted, however, that the information was compiled, interpreted, and published in the past five years (Nelson and Paetz 1992, Smith 1993, Bird *et al.* 1995). Other sources of information used in this study, obtained through personal communication and published in scientific journals and reports, provided very recent data.

2.4 Species included in the analysis

Smith (1993) included 91 species of mammals in his book. However, as he pointed out, four of them: Gray Squirrel, Black Rat, Norway Rat, House Mouse were introduced by man. The Gray Fox is outside its range in Alberta and the Black-footed Ferret is extirpated. Therefore, a total of 84 species were considered in this study (Appendix 1). The *Alberta Butterflies* (Bird *et al.* 1995) accounted for 198 species and subspecies of butterflies. Only 161 were used in the analysis after four occasional migrants, one introduced species, and 17 species without sufficient evidence of their presence and distribution were excluded. In 15 cases, subspecies were combined, for example: *Lycaena dorcas dorcas* and *Lycaena dorcas florus* were included as one species, *Lycaena dorca* (Appendix 1).

Nelson and Paetz (1992) identified 59 fish species in Alberta, including 51 native species and eight introduced. Overall, 49 native species and two introduced (Brook Trout and Brown Trout) were included in the analysis (Appendix 1). Two native species (Arctic Lamprey and Round Whitefish) were excluded because of insufficient data. A total of 297 bird species were considered in the study (Appendix 1). This includes 251 breeding birds and nine species whose status in Alberta is currently undetermined, although eight of them are known to breed in our province, and 37 non-breeding migrants. The remaining 55 species are considered vagrants, accidental, or extirpated and were excluded from the analysis. All ten species of amphibians and eight of reptiles identified in *The Status of Alberta Wildlife* (Alberta Government 1996) were included in the analysis (Appendix 1).

2.5 Taxonomy

The scientific names and common names of the fishes follow Nelson and Paetz (1992). For mammals, I adopted the names as they were used by Smith (1993). The butterflies were classified according to Bird *et al.* (1995) and suggestions from Mr. G. Hilchie (pers. comm). The name of birds, amphibians and reptiles correspond with the taxonomic list of vertebrates published in *The Status of Alberta Wildlife* (Alberta Government 1996).

2.6 Species status

The Species of Special Status (SST) in this study were selected based on *The Status of Alberta Wildlife* (Alberta Government 1996). In this document, species are classified depending on the risk of extirpation in our province and assigned to separate species lists. Therefore, based on this classification, the SST are defined as the ones that, *are at risk* (red list), *may be at risk* (blue list), or *are not currently at risk, but may require special management to address concerns related to naturally low populations, limited provincial distribution, or demographic/life history feature that make them vulnerable to human-related changes to the environment* (yellow lists A and B) (Alberta

Government 1996). The SST group also includes species of Status Undetermined for which we do not have information to decide their status at the time. Overall, 88 species of birds and 33 species of mammals from the provincial red, blue, yellow A, yellow B, and Status Undetermined lists were considered in the analysis. Status of fishes was based on COSEWIC listing (1996). Information on the status of butterflies was not available.

2.7 Protected areas (PA) in Alberta

A total of 241PA were used in this analysis including National Parks, Provincial Parks, Wilderness Areas, Ecological Reserves, and Natural Areas protected through a legislation. Information on the spatial representation and the status of PA was obtained from the Provincial Government. All the PA were in TTM projections and were referenced to the same grid as the confirmed species locations and distribution data.

2.8 Criteria for PA evaluation

The *representativeness*, defined as the potential presence of species in PA, was used to evaluate the level of representation of species in PA and to evaluate contributions of individual PA to the goal of representation. This *species richness* is the number of species expected to occur in a PA.

2.9 Analytical approach - Gap analysis

The analytical approach involved iterative methods to achieve maximum efficiency in PA selection over large geographic areas to represent as many species as possible. Representation of species was achieved by selecting the minimum number of PA that represents each species of mammals, birds, fishes, and butterflies at least once, twice, or three times. First, the PA with the highest species richness (or greatest number of SST) is selected. If two or more PA have the same number of species (or number of SST), the largest area will be selected. Next, an area that contributes most of the species not previously selected will be chosen and so on, until all possible species are represented. Separate analyses were done for each taxonomic group, for SST of different taxonomic groups (where information was available), and for all species of mammals, birds, fishes, and butterflies combined. Representation of reptiles and amphibians was assessed based on information from *Alberta's Watchable Wildlife Checklist Series* (Government of Alberta 1996) and available confirmed species locations. This approach allowed determination of minimum representation of amphibians and reptiles in Alberta. It did not suggest the maximum representation because many PA have not been surveyed.

3. RESULTS

3.1 Information on confirmed species locations in Alberta

The status of Alberta's biodiversity and information on the confirmed species locations for six taxonomic groups are summarized in Table 2-1. Alberta, covering only 7% of Canada, is a major contributor to Canada's overall biodiversity. Seventy percent of Canadian birds and 43% of Canadian mammals could be found in our province. Other groups are also well represented. Despite of the importance of Alberta's biodiversity, information on species locations is scarce (Table 2-1 and Figure 2-1). This is especially evident in northern Alberta (Figure 2-1). Even the best bird survey data covers only 37% of the province (Table 2-1).

Table 2-1. Census of Alberta's taxonomic diversity and summary of data used in gap analysis.

Taxonomic groups	Estimated total no. of species described in Canada	Total no. of species used in the analysis and % of total in Canada [3]	Total no. of confirmed, individual species locations in Alberta [4]	Total area and % of Alberta with confirmed data on species presence [5]
Birds	426 [1]	297 (70%)	86,634	2,531 (37%)
Mammals	194 [1]	84 (43%)	2,128	914 (13%)
Fishes	204 freshwater [1]	51 (25%)	3,015	1,316 (19%)
Butterflies and Skippers	272 [2]	161 (59%)	10,244	1,493 (22%)
Amphibians	42 [1]	10 (24%)	1,189	854 (12%)
Reptiles	42 [1]	8 (19%)	345	259 (4%)

[1] Source: (Mosquin *et al.* 1995)
[2] Source: G. Hilchie pers. comm.
[3] The total number does not include vagrants, accidentals, extirpated species and most of migrants and introduced species.
[4] Total number of point locations collected for species used in the analysis. The number includes only a single record of each species per grid cell.
[5] The total area is the number of 10km x 10km grid cells with at least one confirmed species occurrence. The percent of total area has been calculated based on the total of 6838 grid cells in the province. The total number of grid cells in the province includes all grid cells that intersect or are contained within Alberta boundaries.

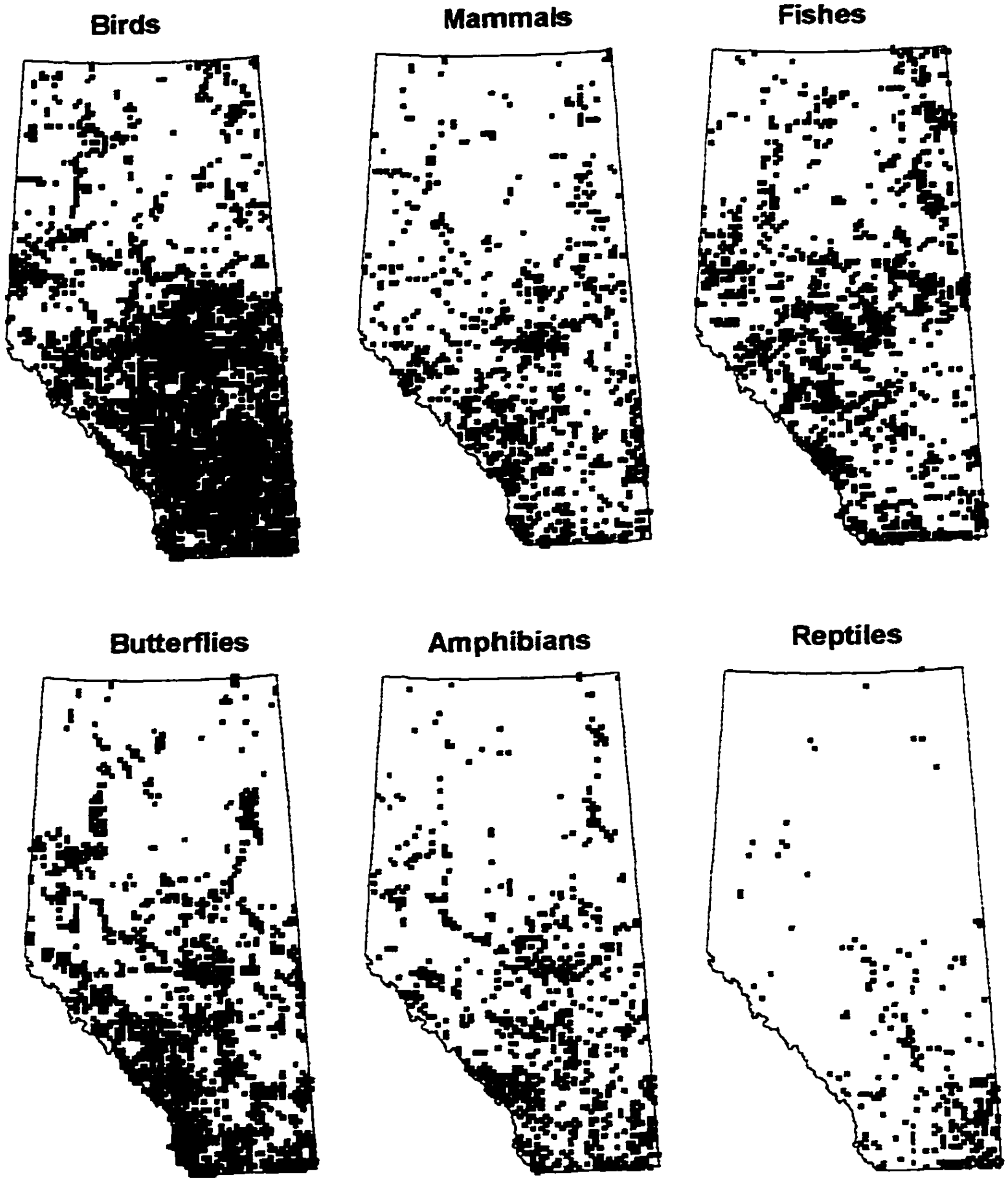

Figure 2-1. Distribution of known species locations in Alberta.

3.2 Representation of Alberta's biological diversity in the existing system of Protected Areas.

The 241 PA evaluated in this study vary greatly in size. Four PA, including Wood Buffalo National Park (NP), Banff NP, Jasper NP, and Willmore Wilderness Park exceed 1,000km^2 each. Another twelve, among them Upper Elbow-Sheep, Kakwa, Peter Lougheed, Waterton Lakes NP, White Goat, Siffleur, Cypress Hills, Elk Island NP, Ghost River, Lakeland, Suffield, and One-Four Agriculture Research Station (One-Four Station) range from 100km^2 to 1,000km^2. In addition, 47 PA are 10-100km^2, 121 PA are 1-10km^2, and the remaining 57 PA are less than 1km^2 (Figure 2-2).

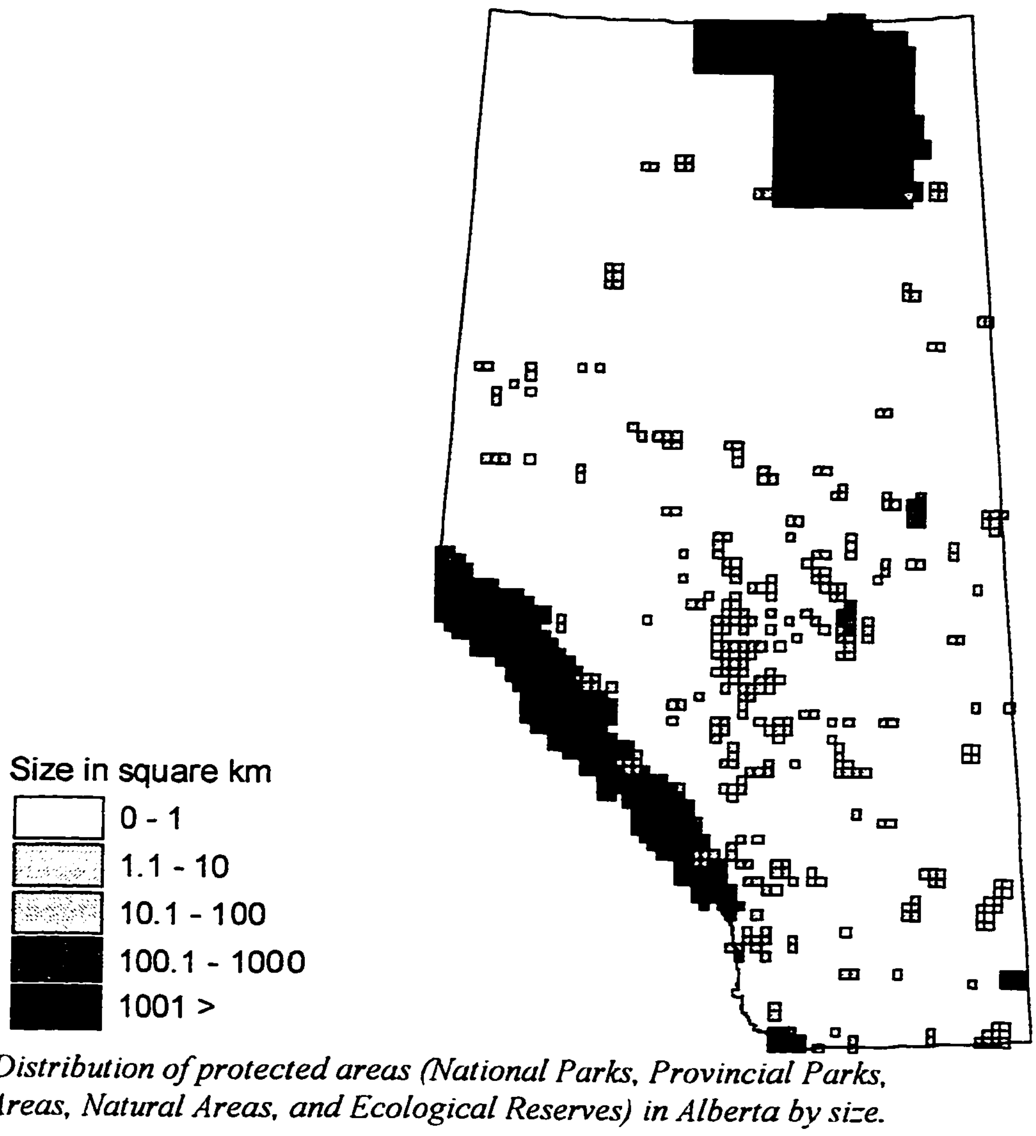

Figure 2-2.Distribution of protected areas (National Parks, Provincial Parks, Wilderness Areas, Natural Areas, and Ecological Reserves) in Alberta by size.

Species representation

A total of 84-95% of birds, mammals, fishes, and butterflies may be represented in more than three PA in the existing system (Table 2-2). The remaining three percent of birds (10 species), six percent of mammals (5 species), eight percent of butterflies (12 species), and sixteen percent of fishes (8 species) have their representation limited to a maximum of three PA. Among those species are rare breeders (Nashville Warbler, Pacific Loon, Cassin's Finch, Willow Ptarmigan), migrants (Smith's Longspur, Thayer's Gull, Glaucous Gull and Whimbrel), and one introduced species with two established populations in the province (Wild Turkey) (Table 2-3) (Alberta Government 1996, Federation of Alberta Naturalists 1992). Other species are on the periphery of their distribution (Clodius Parnassian, Sooty Gossamer Wing, Lorquin's Admiral, Blue Cooper, Rhesus Skipper, Oreas Anglewing, Napaea Fritillary, Palaeno Sulphur, Hobomok Skipper, Pigmy Whitefish), uncommon with unknown status (Red Bat), highly localized (Red-tailed Chipmunk and Ord's Kangaroo Rat, Magdalena Alpine), or rare (Checkered White, Small Checkered Skipper, Shorthead Sculpin, Logperch, Brassy Minnow, Stonecat, Northern Squawfish) (Nelson and Paetz 1992, Smith 1993, Bird *et al.* 1995, Alberta Government 1996). Some species are not only rare but have endangered or threatened status in Canada (Swift Fox, Mountain Plover, Shortjaw Cisco, Deepwater Sculpin (Table 2-3) (Alberta Government 1996, COSEWIC 1996). For five out of the 35 species recorded in three or less PA the representation equals their total provincial distribution. Therefore, they should be considered represented.

The representation of amphibians and reptiles is more difficult to assess because of lack of information on species distribution. However, based on published sources (Alberta Government 1996, Government of Alberta 1996) and collected confirmed species locations, it was possible to determine their minimum representation in PA. All species of reptiles and at least eight species of amphibians could be found in more than three PA. The Great Plains Toad and Plains Spadefoot were recorded in two and three PA respectively (Table 2-2).

Among those species not represented in the existing system, are six species of birds, two species of mammals and seven species of butterflies (Table 2-2 and 2-3). The Sabine's Gull is a rare migrant in Alberta arriving in Alberta in September and June (Federation of Alberta Naturalists 1992). Sage Thrasher, Clark's Grebe and White-faced Ibis are uncommon breeders with the latter two being also highly localized (Federation of Alberta Naturalists 1992, Alberta Government 1996). The American Black Duck is an uncommon nester in Alberta (Federation of Alberta Naturalists 1992). Common Poorwill is a peripheral species with unknown breeding status (Federation of Alberta Naturalists 1992, Alberta Government 1996). Wandering Shrew is rare, highly localized, and peripheral species (Smith 1993, Alberta Government 1996). Arctic Fox is uncommon in our province and its status is currently unknown (Alberta Government 1996). All of the butterfly species not represented are either peripheral species or highly localized (Bird *et al.* 1995).

A total of 88 species (30%) of birds, 33 species (39%) of mammals, and all of amphibians and reptiles are considered here as SST (Alberta Government 1996). In addition, two species (4%) of fishes are also called SST because of their threatened status in Canada (COSEWIC 1996). Overall, 83 species (94%) of birds and 28 species (85%) of mammals are potentially represented in more than three PA (Table 2-2). The SST not represented are mentioned before: Clark's Grebe, White-faced Ibis, Saga Thrasher, and Wandering Shrew (Table 2-3).

Table 2-2. Summary of representation of Alberta's biodiversity in the existing system of Protected Areas (PA).

Taxonomic Group	Total number of species	No. and % of species not in PA	No. of species represented [2] in PA				Total no. of SST[1]	No. of SST [1] not in PA	No. of SST[1] represented [2] in PA			
			1 time	2 times	3 times	>3 times			1 time	2 times	3 times	>3 times
Birds	297	6 (2%)	5	2	3	281 (95%)	88	3 (3%)	1	0	1	83 (94%)
Mammals	84	2 (2%)	3	2	0	77 (92%)	33	1 (3%)	3	1	0	28 (85%)
Fishes	51	0 (0%)	4	2	2	43 (84%)	2	0	2	0	0	0 (0%)
Butterflies	161	7 (4%)	4	5	3	142 (88%)	-	-	-	-	-	-
Amphibians	10	0	0	1	1	min.8 (80%)	10	0	0	1	1	min.8 (80%)
Reptiles	8	0	0	0	0	8 (100%)	8	0	0	0	0	8 (100%)

[1] SST: Species of Special Status

[2] Representation of birds, mammals, butterflies, and fishes was based on confirmed species location and species distribution data. Representation of amphibians and reptiles was based on confirmed species locations in the province and information on species presence published for selected PA (8,3). However, the confirmed species locations for amphibians and reptiles were used only if the PA that was supposed to represent the species was greater than $100 km^2$ (the size of a single grid cell).

Table 2-3. Species not represented or with limited representation in protected areas (PA) in Alberta.

Birds	Mammals	Fishes	Butterflies
	Species not represented[1] in the PA		
American Black Duck Clark's Grebe[2] Common Poorwill Sabine's Gull Sage Thrasher[2] White-faced Ibis[2]	Arctic Fox Wandering Shrew[2]	None	Eyed Brown Grizzled Skipper Least Skipper Moss' Elfin Ochreous Ringlet Question Mark Purple Azure
	Species represented[1] in one PA		
Mountain Plover[2] Nashville Warbler Smith's Longspur Thayer's Gull Wild Turkey	Ord's Kangaroo Rat[2] Red-tailed Chipmunk[2] Swift Fox[2]	Deepwater Sculpin[2] Logperch Shorthead Sculpin Shortjaw Cisco[2]	Checkered White Clodius Parnassian Small Checkered Skipper Sooty Gorsammer Wing
	Species represented[1] in two PA		
Pacific Loon Willow Ptarmigan	Brown Lemming[2] Red Bat	Brassy Minnow Pigmy Whitefish	Blue Copper Hobomok Skipper Liorquin"s Admiral Oreas Anglewing Rhesus Skipper
	Species represented[1] in three PA		
Cassin's Finch[2] Glaucous Gull Whimbrel		Stonecat Northern Squawfish	Magdalena Alpine Napaea Fritillary Palaeno Sulphur

[1] Representation of birds, mammals, butterflies, and fishes was based on confirmed species location and species distribution data.
[2] Species of Special Status

3.3 Evaluation of protected areas

• Species richness:

Many of our PA are rich in wildlife, but species richness varies among PA and taxonomic groups. The highest number of birds could be found in Beaverhill (231 species - 78%), Elk Island NP (223 species - 75%), and Moonshine Lake (205 species - 73%). Other areas have between 1- 203 species. Among them 15 PA have less than 25 species recorded and should be considered inadequately surveyed. Jasper NP has the highest number of mammals (58 species - 69%), followed by Waterton Lakes NP (57 species -

68%), Banff NP (57 species - 68%), and Willmore Wilderness Park (56 species - 67%). The species richness of mammals in the remaining areas ranged from 28-55. Fishes are present in greatest numbers in Wood Buffalo NP (29 species - 57%), Strathcona Science (27 species 53%) and Victoria Settlement (26 species - 51%) and 10-25 species could be found in other PA. The highest numbers of butterflies were identified in Waterton Lakes NP (113 species - 70%), Upper Elbow- Sheep (105 species - 65%), and Banff NP (104 species - 65%). In other areas the richness varied between 46-102 species. If all of the birds, mammals, fishes, and butterflies are combined, Waterton Lakes NP has the potential highest species richness - 384 (65% of species).

- Protected areas required for species representation.

The process of site selection identified the smallest number of PA required to represent each species at least once, twice, or three times. Results showed that the minimum number of PA to represent species once is: 13 PA for birds, six PA for mammals, eight PA for fishes, and nine for butterflies (Table 2-4). However, it will take 20 PA to represent all off the species once (Table 2-4). To represent each species twice, an additional 13 PA are required for birds, five PA for mammals, seven PA for fishes, and eight PA for butterflies, but 20 to represent them all (Table 2-5). Also, eight PA still have to be added for birds, three PA for mammals, three PA for fishes, five for butterflies, and 10 PA for all of them together to represent each species at least three times (Table 2-6).

The birds and mammals of SST, if considered alone, will require five PA to represent birds once, an additional six PA to represent them twice and still another five PA to represent these species three times. For mammals of SST, seven PA are needed to represent the species once, an additional three PA to capture them twice, and another two PA to represent them three times. Beaverhill Lake and Banff NP are the major contributors of the SST. Table 7 contains the names of sites required to achieve representation, listed in order as they were selected, and shows number of SST contributed by each area.

Table 2-4. Protected areas required to represent species once listed in order as they were selected.

Birds	Mammals	Fishes	Butterflies	All species
Beaverhill Lake	Jasper NP	Wood Buffalo NP	Waterton Lake NP	Waterton Lakes NP
Waterton Lakes NP	Writing-on-Stone	Waterton Lakes NP	Jasper NP	Beaverhill Lake
Jasper NP	Elk Island NP	Whitney Lake	One-Four Station	Jasper NP
One-Four Station	Waterton Lakes NP	Milk River	Wood Buffalo NP	One-Four Station
Cold Lake	Suffiled	Cold Lake	Banff NP	Cold Lake
Cypress Hills	Fish Creek	Silver Valley	Notikiwin	Strathcona Science
Elk Island NP		Writing-on-Stone	Cold Lake	Fish Creek
Dinosaur		Gregoir Lake	Milk River	Wood Buffalo NP
Miquelon Lake			Fish Creek	Silver Valley
Whitecourt Mountain				Banff NP
Chedderville				Suffield
Sherwood Park				Cypress Hills
Wood Lake				Milk River
				Writing -on -Stone
				Miquelon Lake
				Gregoir Lake
				Whitecourt Mountain
				Chedderville
				Sherwood Park
				Wood Lake

Table 2-5. Additional protected areas required to represent species two times listed in order as they were selected.

Birds	Mammals	Fishes	Butterflies	all species
Banff NP	Willmore Wilderness Park	Bellis North	Peter Lougheed	Beauvais Lake
Gregoir Lake	One-Four Station	Jasper NP	Cypress Hills	Willmore Wilderness Park
Queen Elizabeth	Strathcona Park	Fourth Creek	Willmore Wilderness Park	Elk Island NP
Lakeland	Banff NP	Kennedy Coulee	Beauvais Lake	Whitney Lake
Dilberry Lake	Ross Lake	Lakeland	Kennedy Coulee	Caribou River
Sasakatoon Mountain		Crow Lake	Caribou River	Notikewin
Kinbrook Island		Beauvais Lake	Sand Lake	Kinbrook Island
Strathcona Science			Whitney Lake	Upper Elbow-Sheep
Wood Buffalo				White Goat
Milk River				Lakeland
Beauvais lake				Dinosaur
Clearwater Ricinus				Ross Lake
Nevis				Fourth Creek
				Kennedy Coulee
				Saskatoon Island
				Crow Lake
				Wabamun Lake
				Clear Water Ricinus
				Nevis
				Wood Buffalo NP

Table 2-6. Additional protected areas required to represent species three times listed in order as they were selected.

Birds	**Mammals**	**Fishes**	**Butterflies**	**all species**
Fish Creek	Lakeland	Strathcona Science	Kakwa	Kakwa
Suffield	Cypress Hills	Dunvegan	Upper Elbow-Sheep	Bragg Creek
White Goat	Wainwright	Butcher Creek	Beehive	Beehive
Moonshine Lake			Silver Valley	Bellis North
LA Saline			Child Lake Meadows	Moonshine Lake
Wabamun Lake				LA Saline
Bragg Creek				Child Lake Meadows
Medicine Lodge Hills				Queen Elizabeth
				Medicine Lodge Hills
				Dunvegan

Table 2-7. Protected areas (PA) required to represent Species of Special Status (SST) once, twice, or three times listed in order as they were selected.

Birds			**Mammals**		
PA name	SST richness	No.of SST contributed	PA name	SST richness	No.of SST contributed
PA selected to represent[1] SST one time					
Beaverhill	62	62	Banff NP	16	16
Waterton NP	50	15	Suffield	14	9
One-Four Station	32	4	Elk Island NP	12	3
Cold Lake	49	3	Jasper NP	15	1
Jasper NP	35	1	Waterton Lakes NP	15	1
			One-Four Station	15	1
			Fish Creek	9	1
additional PA selected to represent[1] SST two times					
Elk Island NP	54	19	Cypress Hills	15	6
Banff NP	36	8	Willmore Wilderness Park	14	4
Gadsby Lake	44	7	Whitney Lake	7	2
Milk River	20	3			
Lakeland	37	2			
Beauvais Lake	26	2			
additional PA selected to represent[1] SST three times					
Cypress Hills	34	2	Miquelon Lake	9	2
Chedderville	20	2	Milk River	15	1
White Goat	36	1			
Fish Creek	20	1			
Bragg Creek	25	1			

[1] Representation based on confirmed species location and species distribution data.

4. DISCUSSION:

The conservation of Alberta's biodiversity should be based on an understanding of the state of biodiversity and assessment of qualitative and quantitative trends in biodiversity (Mosquin *et al.* 1995). This study has identified gaps in our knowledge on Alberta's biodiversity. For some high priority species information on species presence, confirmed locations, and distribution exists because of their consumptive value (birds, mammals, fishes), commercial value (plants, mammals, fishes), or non-consumptive public value (birds, butterflies). Other groups, amphibians and reptiles, have only recently gained recognition. The confirmed species locations are unevenly distributed throughout our province. In southern Alberta we have many records of species presence, but as we move northwards to central and northern Alberta, the gaps in information are very wide.

Current efforts by the Alberta Government, including the design of the Biodiversity/Species Observation Databases, publishing *The Status of Alberta Wildlife* (Alberta Government 1996), and other initiatives, may help with planning of strategies to improve our knowledge. Considering the high costs of wildlife surveys, future activities should involve prioritization of survey efforts. Areas not surveyed, especially in northern Alberta, should be recognized as high priority mainly because of ongoing industrial activities related to oil, gas, and timber resources. Also, to eliminate the duplication of efforts in data collection and to reduce costs, individuals or organizations engaged in various research activities involving data collection should be obligated to submit information on species presence and locations in their study area to a designated government agency. This should be a requirement to obtain research or collection permits from the province.

Although Alberta has many protected areas, some wildlife species are still not represented in the system or have limited representation because they occur in three or less of the PA. Some of them are rare, others are highly localized. For many species, Alberta is a fringe of their distribution. These marginal species survive in Alberta at the extreme limits of their geographical range and are likely to have unique adaptation properties essential for survival (Mosquin *et al.* 1995). Such properties may have a particular significance in time of global warming because marginal populations could be a source of highly adaptive genes for the rehabilitation of other lost populations (Lesica and Allendorf 1995, Mosquin *et al.* 1995). Therefore, the need for their representation in PA should be carefully evaluated.

Almost ten percent of our province is allocated in some form of protection, but many protected areas have similar species composition. Beaverhill Lake and Elk Island National Park, each has 78 and 80 percent of bird species respectively, but a minimum of 32 additional PA are required to represent each bird species at least three times in the PA system. Similar results were obtained for other taxonomic groups. Also, all five of our National Parks were selected to represent all the species together at least three times but an additional 48 were added to complete the representation. This suggests that there is a considerable overlap in species composition among our National Parks.

The 241 PA we have in AB provide multirepresentation for between 80-100 percent of birds, mammals, fishes, butterflies, amphibians and reptiles. Among them are species considered Species of Special Status (SST). Some of those represented SST, such as the Burrowing Owl, Sprague's Pipit, Lesser Yellowlegs, Richardson's Ground Squirrel, and others, are still experiencing population declines (Alberta Government 1996). This suggests that sufficient representation does not mean protection. If the 241 PA covering ten percent of our province are not providing the expected protection for biodiversity, we should look further for solutions. Most of our PA are very small and isolated, making the populations within them susceptible to disturbances such as disease, fire, climate change, and human activities (Mosquin *et al.* 1995). Therefore, reducing the level of isolation and practising appropriate land use in the surrounding areas should improve the chances of survival for these populations and others, that might show similar trends in the future.

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Dry Island Buffalo Jump Provincial Park to Tolman Bridge.
Lesser Slave Lake Provincial Park and Vicinity.
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Red Rock Coulee Natural Area
Sir Winston Churchill Provincial Park.
Therien Lakes
Vermilion Provincial Park.
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Wagner Natural Area
Whitney Lakes Provincial Park.
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III. RESERVE SELECTION STRATEGIES FOR PROTECTED AREAS NETWORK IN ALBERTA.

1. INTRODUCTION

Conserving a representative sample of natural features in the system of protected areas has become a widely accepted approach towards maintaining long-term existence of biological diversity and its functions (Margules *et al.* 1988, Noss 1995 and others). Reserve selection is "*...one of the key strategies...*" for biodiversity conservation (Noss 1995) and an "*essential prerequisite for conservation evaluation*" (Margules *et al.* 1988). Although many agree that the reserve system alone will not be able to prevent further deterioration of biodiversity and that appropriate landscape management outside the reserve system will have to be implemented to assure the continuation of natural processes. In Alberta, almost 10% of the province is under some form of protection (Alberta Environmental Protection 1994, Pawlina 1997). But many of the protected areas were established for reasons other than conservation, and some elements of diversity are not represented in the current PA system (Pawlina 1997). Moreover, Alberta is quickly approaching the year 2000 deadline to complete the site selection process, putting pressure on landscape managers and scientists to identify suitable sites.

A wide range of criteria has been used to identify areas for conservation (Smith and Theberge 1986). The most prevailing among them are diversity and rarity (Margules and Usher 1981, Margules 1986, Usher 1986). Many have looked at the distribution patterns of species diversity and rarity to determine if they coincide with each other. If they do, then reserves high in rare species would also contain high numbers of more common species and vice versa, making the selection process efficient. Thomas and Mallorie (1985) found that restricted-range butterfly species in Morocco tended to occur in the most species rich communities, so conservation of restricted-range species would, in fact, coincidentally protect most other species. Similar observations have been reported for birds and beetles (Stokland 1997), for endangered and vascular plants (Jarvinen 1982), for rare and all plants species (Rebelo and Siegfried (1992), and 368 species of terrestrial Mammalia, Plusiinae, *Lasioglossum*, and Papilionidae (Kerr 1997, see also Siegfried and Brown 1992). But others have reported that species-rich areas frequently do not coincide for different taxa and many rare species do not occur in the most-species rich areas (Emberson 85, Ryti and Gilpin 1987, Pagel *et al.* 1991, Pendegarst *et al.* 1993, Saeterdale *et al.* 1993, Gaston 1994, Lawton *et al.* 1994, Williamson *et al.* 1996, Kerr 1997). This suggests that examining distribution patterns of species richness and rarity is an important prerequisite to reserve selection.

The WWF (World Wildlife Fund) recommended using natural regions and their enduring features to identify areas for protection. The enduring features, defined by topography, parent material, soil, and other physical factors, are assumed to have a significant influence on the distribution of species and natural communities within a natural region. They are also perceived to be more stable in their distribution than vegetation and other biotic elements (Noss 1995). Kirkpatric and Brown (1994), however, compared reserve selection priorities based on physical attributes of the environment versus biological data in Tasmania. They noted that many rare species and communities were missed when only physical attributes were used. Laurner and Murphy (1994) made similar observations. They reported that the distribution of checkerspot butterflies was influenced more by the distance from a single core population than by physical characteristics of the site. Therefore, the reserve selection strategy should involve biological and landscape features (Noss 1995, Kirkpatrick and Brown 1994).

After the decision has been made on the selection criteria for evaluation of potential sites, various mathematical algorithms can be applied to explore alternatives for establishing a reserve system. The most popular systematic approaches for identifying sites to be included in the reserve system fall into three categories: multiple scoring procedures, iterative methods, and linear programming methods. The objective usually is to select a minimum number of sites or the smallest area to represent a certain portion of species or landscape distribution ranges (Nicholls and Margules 1994, Pressey *et al.* 1997 and this study) or to represent each species or landscape in one or more reserves (Pressey and Nicholls 1989, Rebello and Sigfried 1992, Nicholls and Margules 1993, Kershaw *et al.* 1994, 1995, Lombard *et al.* 1995, Willis *et al.* 1996, Freitag *et al.* 1996, Csuti *et al.* 1997).

The scoring procedures rank sites according to a combined score from a variety of criteria such as diversity, rarity, size etc. (Margules and Usher 1981, Smith and Theberg 1986, Usher 1986). The result is a list of sites in order of conservation value. The major limitation of this method is that, if sites are conserved in order of their position on the list, very large numbers and areas may be required to represent samples of all natural environments or species (Pressey and Nicholls 1989). Scoring procedures do not sample biodiversity efficiently because any set with highest scores duplicates some attributes many times and may miss others.

An alternative and more efficient approach to site selection, termed iterative (Pressey and Nicholls1989, Bedward *et al.*1991, Williams *et al.* 1996), was first proposed and applied by Kirkpatric and Hardwood (1983) to the conservation of wetland plants in Tasmania and later, widely used to identify the minimum or near minimum number of areas or sites to represent required natural features in Australia, South Africa, United States, Norway, Great Britain, and other parts of the World (see Pressey *et al.* 1997 for full references). These methods rely on heuristic algorithms and allow selection of objects (sites, grid cells, remnant vegetation patches or other geographically referenced areas) based on their conservation value. The conservation values are calculated prior to the analysis based on quantified criteria (richness, rarity, level of existing protection etc.) describing natural features (species and/or landscapes).

First, the algorithm selects the site that has the most of required natural features and proceeds stepwise, adding at each step sites that contain the most additional features not yet represented (Nicholls and Margules 1993, Csuti *et al.* 1997 and others). The main strategies applied to achieve the required representation of features involve the use of richness algorithms and rarity algorithms. A richness algorithm (eg. Kirkpatrick 1983, Pawlina 1997) starts with the site having the greatest number of features and then add sites containing most of the under-represented features. Similarly, rarity algorithms start with sites containing rare, unique features and progressively add sites that contain the most underrepresented, unique, rare features. This approach greatly reduces the number of sites needed to represent features. As a result, the iterative methods produce site priority lists and allow evaluate site contribution at each step. But some argue that the stepwise method utilizing heuristic algorithms may not find the optimal solution to site selection because every new step depends on the result of the previous one. Once sites were selected in the earlier iteration the algorithm would not allow them to be dropped from a priority set. Therefore, many site combinations remained unexamined. Moreover, it is impossible to say how far from optimality the solutions are (Underhill 1994).

To find the optimal set of sites some turn to so called optimality algorithms (Church *et al.* 1996). This method is based on exploring all possible combinations of sites that, overall, may have, for example, the highest species richness. The result is a list of the minimum number of sites required to meet the goal of representation but with no means of setting priorities among them, nor the ability to assess how many species could be covered in fewer sites. When dealing with large data sets or complicated analysis, the optimising algorithm requires more processing time than heuristic algorithms (Csuti *et al.* 97) and often fails to a find solution (Pressey *et al.* 1996, 1997). Also, when the efficiency of the heuristic and optimality algorithms was compared, the results ranged from heuristic being 5-10% less efficient than optimality (Lombard *et al.* 1995, Pressey *et al.* 1997) to equally efficient (Seaterdal *et al.* 1993, Willis *et al.* 1996, Stokland 1997).

Overall, optimality is a very attractive concept and would provide a benchmark for comparing different solutions, but a heuristic approach seems to be a more appropriate method to assist in reserve selection at the present time because we are usually dealing with large data sets and complex analysis. Merrill *et al.* (1995) stated that we do not have sufficient knowledge to define the minimum land area required to maintain a viable population. Therefore, no matter which technique we use, we may improve optimality, but none of the options will produce a truly optimal solution and the objective to protect the greatest number of species with a minimum amount of land may not be desirable. On the other hand, the iterative approach provides conservation planners with a tool that enables them to explore alternatives in site selection quickly and easily within reasonable limits of optimality. It is explicit, because of the specific rules. It is also relatively efficient, because it greatly narrows down site selection, and flexible, because the rules can be easily adjusted (Nicholls and Margules 1993).

In this study, I explored various strategies for locating the best sites (grid cells) for the protected areas system in Alberta. The assumption is, that over a long time, most species will become threatened, so the best approach to conservation is to set aside areas that will represent as wide range of biotic diversity as possible (Kershaw *et al.* 1995). The designation of priority areas was based on biological criteria to ensure species representation, and on planning criteria in support of the continuation of biological processes. Iterative methods using the heuristic algorithms were applied in conjunction with various sets of rules if more selected areas were of equal conservation value. First, the most efficient approach to site selection was identified based on biological criteria (species richness, number of Species of Special Status, and total species rarity) and used to explore various scenarios of site selection based on planning criteria (land disturbance, land ownership, distance to the nearest site, existing protection). Next, the tradeoffs associated with those scenarios were compared in terms of efficiency, spatial configuration of potential protected areas system (number and size of clusters formed), and overall species and landscape representation. The most promising strategies were then applied to complement the existing PA system to meet the goal of biodiversity representation. To my knowledge, this is the only study in Alberta evaluating standardized approaches to reserve selection and range representation of species and landscapes in the current reserve system. It is also one of few studies that addresses the issue of area representation of species and landscapes in reserve system using heuristic algorithms. The results are discussed in the context of major distribution patterns of species diversity and rarity in Alberta.

Goal for evaluation of site selection strategies

The goal is to find a minimum number of sites (grid cells) that together will represent at least 10% of species ranges in Alberta and at least 10% of each of Alberta's natural regions (NR) in the protected areas system. The 10% of species range is an arbitrary number used only as a criterion to evaluate analytical methods. It does not suggest the 10% of species ranges would maintain their viable populations.

Study objectives

1. Determine the effect of different computational approaches, including random selection, and alternative rules for prioritizing on the efficiency and spatial configuration of reserve system.

2. Discuss the results based on the distribution patterns of species richness and rarity of target taxonomic groups in Alberta.

3. Evaluate the current range representation of species and natural regions in the existing system of protected areas in Alberta.

4. Using the best approach, identify areas that could efficiently supplement the existing protected areas system to complete the representation.

2. METHODS:

2.1 Surrogates of Alberta's biodiversity

For the purpose of the evaluation, the distribution of birds, mammals, fishes, and butterflies in Alberta, together with Alberta's natural regions (Achuff 1994) classified based on environments abiotic features and vegetation patterns, are assumed to be the surrogates of genetic, taxonomic, and ecosystem variations in Alberta and the physical environment. In addition, the total number of cells selected to represent the biodiversity is considered as surrogate of costs and/or conservation effort.

2.2 Criteria for determining conservation values of grid cells

Two criteria, species richness and species, were used to determine the conservation value of each grid cell before the site selection began. In addition, a Species of Special Status (SST) criterion was applied in the site selection process for birds and mammals. Information on SST for other taxonomic groups was not available. The criteria are defined as follow:

Species richness is the total number of species in a grid cell (Margules and Usher 1981, Usher 1986).

Species total rarity: is expressed as the sum of each species inverse number of grid-cell records (Williams *et al.* 1996).

Species of Special Status average richness: is the total number of species of special status (SST) divided by the cell's species richness. The SST are defined as the ones that *are at risk* (provincial red list), *may be at risk* (provincial blue list), or *are not currently at risk, but may require special management to address concerns related to naturally low populations, limited provincial distribution, or demographic/life history feature that make them vulnerable to human-related changes to the environment* (provincial yellow lists A and B) (Alberta Government 1996). The SST group also includes Species of Status Undetermined for which we do not have information to decide on their status at this time. Overall, 88 species of birds and 33 species of mammals from the provincial red, blue, yellow A, yellow B, and Status Undetermined lists were considered in the analysis. Similar provincial classification was not available for butterflies and fishes (Appendix 1).

2.3 Distribution patterns of rarity and richness.

The relationship between the distribution of species richness and rarity was examined using Spearmans rank correlation method (Procedure PROC CORR, SAS Institute Inc. 1975). The hypothesis was that the taxa considered in this study exhibit similar diversity and rarity patterns in Alberta. The conservation values for grid cells were ranked before correlation analysis were conducted (Procedure PROC RANK, SAS Institute Inc. 1975) because of non-normal distribution of data (Procedure PROC Univariate, SAS Institute Inc. 1975). A total of 5523 out of 6619 grid cells were included in the correlation analyses after cells with no bird survey data or with a species count of less than 25 for bird species were eliminated. Results were considered non-significant if the p value exceeded 0.05. Species distribution ranges were plotted separately for each taxonomic group and for all groups together.

2.4 Criteria for tie breaking in site selection process

Once the ecological criteria were selected and the cells' conservation values determined, a set of rules was identified to resolve conflicts if two or more cells had the same conservation value. The main criteria were: level of disturbance, existing protection, connectivity with other areas and proximity of other areas, and, in case of birds and mammals, a total or average number of SST. All the indices were constant values calculated for each cell in the beginning of the selection process.

Level of disturbance: represents the threat to population viability and site integrity and was expressed as the cumulative index of disturbances related to oil and gas industries, forest industry activities, human population, and presence of major roads. Only major sources of threat for which digital information was available were considered in this study. Each disturbance was first individually scored based on its magnitude (Table 3-1). The magnitude values were grouped based on their frequency distribution creating "natural" breaks. Then the scores were totalled for each cell and the level of disturbance was assigned. The disturbance was low if the total score was between one and four; moderate, if the total score was five to nine; and high, if the score was above ten. Areas with the disturbance score equal zero were considered undisturbed. The grid cell GIS coverage of the province was overlaid with the land disturbance GIS coverages and population census coverage. Cells were assigned to various disturbances based on the spatial relationship between the center of the cell and relevant disturbance polygon of the coverage.

Existing protection: cells are assumed to have existing protection if they intersect with, or are enclosed in the existing protected area, or contain a protected area.

Connectivity and proximity to other sites relates to the degree of clustering of selected cells and their proximity to other clusters.

Species of Special Status : total number of SST in a cell.

Average SST: total number of SST in a grid cell divided by total species richness of the cell.

Table 3-1. Classification of selected land disturbances in Alberta.

Disturbance Type	Disturbance magnitude per grid cell	Disturbance score
Population Census	0	0
(no. of people)	34 - 6,014	1
	6,015 - 60,975	2
	60,975 - 710,795	3
Pipelines	0	0
(km per grid cell)	0.17 - 101.12	1
	101.12 - 269.49	2
	269.49 - 970.23	3
Wells	0	0
(no. per grid cell)	1 – 5	1
	6 – 17	2
	18 - 49	3
Road present	No	0
	Yes	1
Forestry Cutover	0	0
(ha)	0.1 – 756.8	1
	756.8 – 2,412.3	2
	2,412.3 – 5,878.3	3

2.5 Spatial Data in support of site selection process

All the data were registered to the ten degree Transverse Mercator (TTM) projection and referenced to a common 10 km x 10 km grid.

Species distribution. Spatial data layers for species distributions were created using Geographic Information Systems (GIS) technology (ARC/View). The distribution boundaries of birds, mammals, fishes, and butterflies in Alberta represent an extrapolation from the existing confirmed species locations data; therefore, they are the potential distributions of species in Alberta. They imply that a species might be expected to occur within the extrapolated area if suitable habitat exists. The species was considered present in a grid cell if the cell intersected or was contained within the species distribution boundaries. For discussion on data sources and retrieval to delineate the species distribution boundaries, see Chapter 1.

Population Census. The 1991 population census data for CSDs (census subdivisions) was obtained from Statistics Canada in Edmonton in the ARC/INFO format. The CSD refers to municipalities as determined by provincial legislation (such as city, town, village, or its equivalent (e.g. Indian reserve, Indian settlement and unorganized territory) (Appendix 2, Figure 1).

Pipelines and oil and gas wells. The 1996 geographic data was obtained from Ensight Information Services Ltd. in Calgary in AUTOCAD format and later converted to the ARC/INFO format. The pipelines are expressed as the total length per grid cell (Appendix 2, Figure 2). Wells are expressed as the total number wells per grid cell (Appendix 2, Figures 3).

Forestry cutover data set refers to total harvested area per Township in the Alberta Township System (ATS) over the past 30 years. The ATS format was converted to the ARC/INFO format (Appendix 2, Figure 4).

Roads data was retrieved from a 1:1,000 000 provincial base map obtained from Alberta Environmental Protection. The data set contains grid cells that intersect with major highways in Alberta (Appendix 2, Figure 5).

Protected areas data set contains all grid cells that intersect with the existing PA boundaries. The source data of the PA boundaries was obtained from the AEP Natural Resource Services, Recreation and Protected Areas in ARC/INFO format (Appendix 2, Figure 6).

Land ownership refers to the Crown land and includes all land owned by the province, federal land inside national parks, and land along major rivers. The Crown land does not include Indian Reserves, Department of National Defense land, Metis Settlements, privately owned land, land covered by water, or land of mixed and of unclassified ownership. The land ownership 1997 data in ATS format was obtained from the Department of Environmental Protection. A grid cell was classified as Crown land if its center overlapped with an area designated as Crown based on the above definition (Appendix 2, Figure 7).

The Grid system of Alberta was developed especially for this study. The system is in TTM projection and consists of 6619 10km by 10km grid cells that have their centers in Alberta. Three cells were added manually because some PA, located close to the Alberta border, were excluded from the grid system selected, based on the center point approach.

2.6 Computational techniques for reserve selection

Three different types of heuristic algorithms were evaluated to determine which is more efficient in selecting grid cells to represent species and landscapes. The algorithms selected sites based on their conservation value calculated using biological criteria: species richness (R), Species of Special Status (SST), and species total rarity (TR) algorithms. In addition, a random selection algorithm was applied to provide basis for comparison. The heuristic algorithms and selection rules are summarized in Table 3-2.

Each heuristic algorithm started by selecting the cell with the highest conservation value. Then, the next cell with the highest score was selected. If a species reached the goal of 10% range representation, the scores for all remaining sites were recalculated. This means that the represented species was excluded from the data set and did not contribute to the remaining cells' conservation values. If two or more cells had the same conservation values, various rules to break the tie were applied. For example, the rule might have been selecting the cell with the lower level of disturbance if the cells are otherwise of equal conservation value. If there is still a tie, select the first one encountered. Overall, the rules for resolving the ties included: level of disturbance, existing protection, closest cell within a certain area buffer and/or species buffer, total unadjusted number of SST or total and unadjusted number of SST divided by total unadjusted species richness (Table 3-2). The iterative process was continued until all species were represented. Then, the results were evaluated based on efficiency and spatial configuration. The efficiency was measured by the total number of cells selected, spatial configuration, and by the size of the total number of clusters formed.

The pool of cells available to select from varied among taxonomic groups depending on availability of distribution data. The total number of cells available in the province was 6619. For mammals and butterflies, the pool of cells equaled the provincial total. For fishes, the pool was 6304 cells because of lack of aquatic habitat in some areas. The birds had a pool that included 6041 cells, 91% of the province, because of limited data. This included some grid cells that could be considered inadequately surveyed because of a low bird count. The uneven sizes of cell pools did not have an impact on the compression among algorithms within taxonomic groups. However, when all groups were combined together two approaches were considered to address the issue. The first one relied on the distribution data for mammals, butterflies, and fishes, with or without natural regions. This was followed by assessment of representation of birds in this particular set of cells. In the second approach, all taxonomic groups were involved but only the cells that were common among all taxonomic groups were considered (6041 grid cells). Both approaches allowed comparison of efficiency among algorithms but the information from the first approach, and its ability to represent bird species, could be useful when the results of the evaluations are applied in the complimentary analysis aiming at locating sites needed to complete the species and landscape representation in the existing system of protected areas.

In the random selection, each cell had randomly assigned hypothetical conservation value. The cell with the highest hypothetical value was selected first. Every time a species reached its representation target the remaining cells in a pool received a new randomly selected conservation value. The selection process continued until all species reached their representation target.

Table 3-2. Summary of iterative algorithms and rules to guide selection process.

Algorithm	Rule no. 1	Rule no. 2	Tie 1	Tie 2
		Approach 1 - Total Richness		
R1	Richest	next richest with underrepresented features	already in PA	first encountered
R2	Richest	next richest with underrepresented features	low disturbance	first encountered
R3	Richest	next richest with underrepresented features	highest in SST unadjusted	first encountered
R4	Richest	next richest with underrepresented features	highest in SST/Richness unadjusted	first encountered
R5	Richest	next richest with underrepresented features	nearest : within 6 cell buffer	first encountered
R6	Richest	next richest with underrepresented features	nearest: within 10 cell buffer	first encountered
R7	Richest	next richest ±6 species buffer	nearest: within 6 cell buffer	first encountered
R8	Richest	next richest ±6 species buffer	nearest: within 10 cell buffer	first encountered
R9	Richest	next richest ±30 species buffer	nearest: within 6 cell buffer	first encountered
R10	Richest	next richest ±30 species buffer	nearest: within 10 cell buffer	first encountered
		Approach 2 - Species of Special Status Average Score		
ST 1	Highest AV_SST score	next highest score AV_SST score	already in PA	first encountered
ST 2	Highest AV_SST score	next highest score AV_SST score	low disturbance	first encountered
		Approach 4 - Total rarity		
TR	Rarest	next rarest	highest richness	first encountered
		Approach 5 – Random selection		
RA	Highest hypothetical value	Next highest hypothetical value	First encountered	

2.7 Application of selected algorithms to complete the representation of natural features in the existing system of protected areas.

The most efficient algorithms were used to identify sites that would complement the existing PA system. First, sites were selected from cells already in the current PA system and representation of natural features was examined to determine which species and landscapes are not adequately represented and how much more representation they required. Then, additional sites were identified from the remaining cells, located outside the current PA system, to complete the representation of features. In the third and final step, the selected sites were added to those already selected from the current PA system and the selection process was repeated from the new pool of cells to eliminate any duplications. After the analyses were completed, the overall range representation was calculated. The overall range representation refers to coincidental additional range representation or "sweeping". The program conducted a total recount of species presence in all the selected grid cells. The results were evaluated based on efficiency (total number of cells selected), configuration (spatial arrangement of cells), "sweeping", grid cell overlay among algorithms, level of land disturbance, and land ownership within the selected sites. The process was repeated to identify cells that would complement the representation of species currently captured only in PA greater than 100km^2. In addition, two data sets, one with all the natural features and one without birds were used to determine the effect of data set on the selection process.

3. RESULTS

3.1 Distribution patterns of species richness and rarity in Alberta.

The correlation analysis showed a weak association of species richness among taxonomic groups, suggesting that areas of high species richness in these groups do not coincide with each other (Table 3- 3, Appendix 3, Figures 1,3,5,7,9). The overall association was positive, but low among birds, fishes, and mammals. The species richness of butterflies was negatively correlated with the distribution of species richness of fishes ($r = -0.26$, $p=0.0001$) and birds ($r=-0.24$, $p=0.0001$), and was not significant with species richness of mammals ($p=0.26$). Therefore, selecting sites based on species richness of one of the taxonomic groups would result in insufficient representation of species from other groups. If, however, the site could be selected without area limitation based on species richness of all species combined, the butterflies, for example, would not be found in great numbers in reserves with overall high species richness ($r= -0.06$, $p=0.0001$), but would be sufficiently represented (Appendix 3, Figures 7,10). Birds, on the other hand, because they contribute 50% of the species considered in this analysis, should be found in great numbers in areas of high overall species richness ($r=0.96$ $p=0.0001$) (Appendix 3, Figures 1, 10).

Table 3-3. Relationship among centers of species richness in Alberta *.

	Birds	Butterflies	Fishes	Mammals	All species
Birds	r=1 p=0.0000				
Butterflies	r= -0.23 p=0.0001	r=1 p=0.000			
Fishes	r=0.24 p=0.0001	r= -0.26 p=0.0001	r=1 p=0.0000		
Mammals	r=0.23 p=0.0001	r= -0.02 p=0.2530	r=0.26 p=0.0001	r=1 p=0.0000	
All species[2]	r=0.96 p=0.0001	r= -0.06 p=0.0001	r=0.28 p=0.0001	r=0.38 p=0.0001	r=1 p=0.0000

[1] Spearman rank correlation coefficients (r) among values of species richness.
[2] All species refer to all species of birds, butterflies, mammals, and fishes together.

The distribution patterns of total species rarity values between taxa showed an improved spatial relationship. The correlation was positive and significant, and ranging from low between fishes and other groups, to moderate among the remaining groups (Tables 3-4, Appendix 3, Figures 2,4,6,8,10). Selecting sites based on restricted range of any one of the taxonomic groups, however, would still result in insufficient representation of some species from other groups.

Table 3-4. Relationship among total rarity scores of wildlife species in Alberta *.

	Birds	Butterflies	Fishes	Mammals	All species
Birds	r=1 p=0.0000				
Butterflies	r=0.11 p=0.0001	r=1 p=0.000			
Fishes	r=0.16 p=0.0001	r=0.14 p=0.0001	r=1 p=0.0000		
Mammals	r=0.17 p=0.0001	r=0.64 p=0.0001	r=0.26 p=0.0001	r=1 p=0.0000	
All species[2]	r=0.81 p=0.0001	r=0.50 p=0.0001	r=0.42 p=0.0001	r=0.55 p=0.0001	r=1 p=0.0000

[1] Spearman rank correlation coefficients (r) among total rarity scores.
[2] All species refers to all species of birds, butterflies, mammals, and fishes together.

When the relationships between species richness and species rarity for all the taxa combined were examined, species total rarity showed moderate relationship with the total species richness (r=0.60, p=0.0001) (Table 3-5). Therefore, selecting sites based on species richness has the potential to efficiently capture species of restricted ranges and vice versa.

Table 3-5. Relationship among distribution of centers of species richness and centers of species total rarity for different taxonomic groups in Alberta.

Taxonomic group	Correlation coefficient[1]
Birds	r=0.79, p=0.0001
Butterflies	r=0.96, p=0.0001
Fishes	r=0.60, p=0.0001
Mammals	r=0.28, p=0.0001
All species [2]	r=0.60, p=0.0001

[1] Spearman rank correlation coefficients (r) among values of species richness and total rarity scores.
[2] All species refers to all species of birds, butterflies, mammals, and fishes together.

3.2 Effect of selection algorithms on efficiency

The algorithms for site selection in Alberta evaluated here: the species richness algorithm, total species rarity algorithm, average SST algorithm, and random selection algorithm, differed in efficiency (Table 3-6). The richness and total rarity algorithm were more efficient in selecting grid cells, whether for all natural features or individual taxonomic groups. The total rarity algorithm selected the rarest features early in the process, whereas the richness algorithm did not select some of these sites until later on. The efficiency of the selection process, however, was not affected because of the spatial correlation between the patterns of richness and the total rarity scores. A subset of cells selected by each algorithm appeared to be common among them, suggesting that some cells could be essential for the reserve network (Table 3-7).

The SST algorithm was less efficient. The conservation values in this approach were calculated based on the richness of species, not necessarily of limited provincial distribution, but of concern to wildlife managers because of their population declines or some other threat. It is probable that these species do not necessarily occur in areas of high species richness or high species rarity. The random selection algorithm was overall the least efficient method for site selection. Therefore, considering the low efficiency of these two approaches, and that the evaluation based on SST was available only for birds and mammals and did not provide a suitable surrogate for other groups, both algorithms was excluded from further analysis.

3.3 The effect of ties on efficiency

Making different choices when ties are reached within an algorithm's iterative procedure may have an impact on the efficiency of site selection and may result in a different set of cells being selected. Selecting cells using richness algorithms that have the lower disturbance score, are already in the existing PA system, or are within a 10 cell buffer if cells are otherwise of equal conservation value, resulted in similar efficiency when all features were concerned (Table 3-6). Increasing the species buffer decreased the efficiency which could be expected because relaxing the richness criteria would allow for selecting sites with lower conservation score and contributing less species. In the cases of some individual taxonomic groups there was no difference in efficiency among rules if they spatially overlapped. Five percent of cells in the current PA system are in the area with lowest land disturbance level and 86% in areas within areas of moderate disturbance (Table 3-7). The unadjusted SST, compared to the average SST rule did not effect the efficiency for either birds or mammals because once all SST were sufficiently represented, the algorithm selected cells in order as they were encountered, and not based on their conservation value. Although the ties did not always influence the efficiency, they had an impact on the set of cells selected.

Table 3-6. Efficiency of site selection algorithms in representing natural features among 10km by 10km grid cells in Alberta.

	Birds	Mammals	Butterflies	Fishes	All species	All species and Natural Regions
Total grid cells available[1]						
	6041	6619	6619	6304	6041	6041
Richness Algorithms						
R1	557	683	744	630	763	773
R2	557	683	747	630	774	775
R3	557	694	NA	NA	NA	NA
R4	557	693	NA	NA	NA	NA
R5	NA[2]	NA	NA	NA	NA	776
R6	NA	NA	NA	NA	NA	772
R7	NA	NA	NA	NA	NA	795
R8	NA	NA	NA	NA	NA	781
R9	NA	NA	NA	NA	NA	934
R10	NA	NA	NA	NA	NA	918
Total Rarity Algorithm						
TR	558	723	702	630	692	771
Species of Special Status Algorithm						
SST1	1293	1033	NA	NA	NA	NA
SST2	1331	964	NA	NA	NA	NA
Random Selection Algorithm (best and average result after 30 simulations)						
RA						1404 (1591)

[1] The total number of grid cells in Alberta is 6619. The fishes are present in 6304 cells because other cells did not contained adequate water bodies. For birds, the cell pool was limited to 6041 cells because of lack of data. Therefore, the 6041 pool cell was also used for all species combined and natural regions.

[2] N/A means that no relevant data was available or a specific rule was not considered for this particular type of selection.

Table 3-7. Frequency of grid cells based on level of disturbance and current protection

Disturbance level[1]	Cells in PA system	Cells outside PA system	Total cells
low	52 (5%)	1022 (18%)	1074 (16%)
moderate	910 (86%)	3865 (70%)	4775 (72%)
high	99 (9%)	671 (12%)	770 (12%)
Total cells	1061 (100%)	5558 (100%)	6619 (100%)

[1]See Methods section for explanation.

3.4 The effect of algorithms and ties on reserve system configuration.

The R6 richness algorithm that gave priority to cells within a 10 cell buffer was efficient and had less dispersed grid cell configurations than other sets selected by the remaining algorithms (Table 3-8). The total rarity approach was as efficient but selected more single cell reserves. Even though some computational methods selected a similar number of cells and in a similar configuration, they did not necessarily select the same grid cells. All the richness based algorithms selected a common pool of 532 cells. This suggests that other factors related to the quality of selected sites (land ownership, distance to the nearest protected areas, etc.) should be included while considering computational approaches to site selection.

Table 3-8. Cell aggregation to represent 10% of range of all features resulted from various reserve selection approaches.

		Cluster size					
Approach	Algorithm	1 cell	2 cells	3 cells	3> cells	Total clusters	Total cells
Richness	R1	35	15	9	38	97	773
	R2	27	12	5	35	79	775
	R5	27	12	10	35	84	776
	R6	**23**	**15**	**7**	**32**	**77**	**772**
	R7	21	14	6	34	74	795
	R8	24	14	6	41	83	781
	R9	25	9	3	38	75	934
	R10	32	14	7	29	82	918
Total rarity	**TR**	**35**	**8**	**8**	**35**	**86**	**771**

3.5 Complementary analysis - selecting sites to complete species representation in the existing system of protected areas.

The current protected areas system does not meet the goal of 10% range representation of 135 species and four landscape features (Appendix 4, Table 1). Among them are 15 species whose total distribution in Alberta ranged from 1 to 20 grid cells and which were not represented at all in the current system. This was determined by selecting grid cells from the pool of cells that are within, or are parts of the current PA system using both, the R6 and TR algorithms. To identify cells that should complement the existing system, additional cells were selected from outside the current system using the above algorithms. Overall, the R6 algorithm selected 768 cells including 635 cells already in the PA system (Table 3-9, Figure 3-1). The TR algorithm selected 763 cells with 663 already in the PA system (Table 3-9, Figure 3-2). There was no difference in the cell configuration. Overall, the TR selected five cells less than R6, with more cells already in PA system.. Because of the lack of data for bird species for nine percent of the province and an additional eight percent that were inadequately surveyed, the resulting reserve selection should be interpreted with caution. Any under- surveyed grid cell will carry an underestimated conservation value that will effect its chances of being selected.

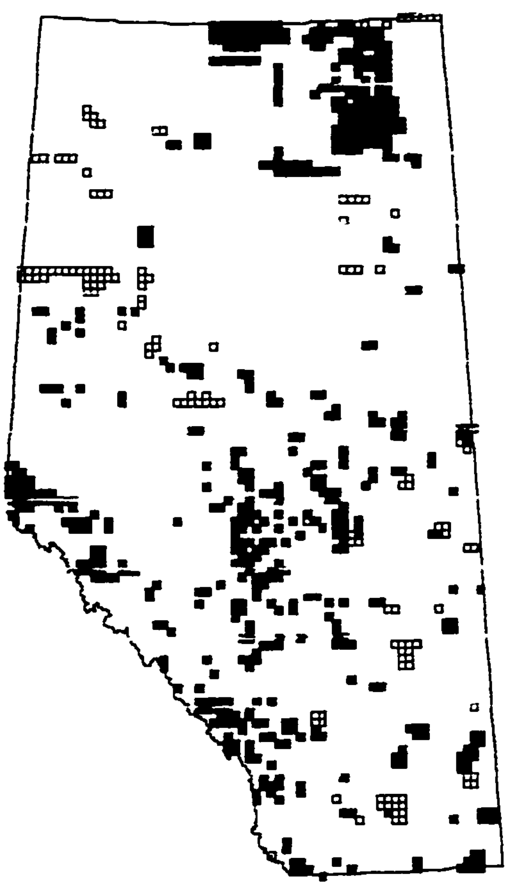
To show the effect of data set on site selection a subset of data consisting of mammals, butterflies, fishes, and natural regions for which extrapolated distribution data was available for the whole province, were used to identify grid cells to complement the existing PA system. Initially, the R6 algorithm was applied to select grid cells from the provincial pool of 6619 cells to determine how well the set of cells selected based on the three taxonomic group would represent bird species. The analysis showed, that potentially 44 (15%) of birds species would have less than 10% of their provincial ranges represented in such reserve system.

Next, the same subset of data was used in the complementary analysis for the existing PA system. First, the R6 algorithm selected 830 cells from the pool of 1061 grid cells that are a part of the existing system. A total of 51 natural features were not adequately represented; therefore, additional 110 grid cells were selected using R6 from a pool of cells outside the current system. In the final, third step to remove duplicates, 796 cells were selected to represent a minimum of 10% of mammals, fishes, butterflies, and natural regions (Figure 3-3). However, when the representation of birds was assessed, 80 (27%) of the bird species did not meet their representation goal.

Because some of the PA are very small in size, perhaps their contribution to species range representation and their current protection could be overestimated, so yet another approach was used in complementary analysis. The selection process started with selecting cells that are a part of a PA that is a minimum of $100km^2$ in size. This first step selected 749 grid cells from a pool of 749 cells available, resulting in 118 species of mammals, butterflies, fishes, and natural regions not being adequately represented. This indicates the importance of smaller PA in representing natural features in the existing system. An additional 295 cells were selected from the remaining pool of cells, including those containing PA smaller than $100km^2$ to complete the representation. The final set of cells, after the elimination of duplicates, consisted of 863 cells, but did not adequately represent 118 species of birds, 67 more than in the previous approach (Figure 3-4).

Also, analyses were conducted to recognize the potential importance of the set of cells that was consistently selected by various algorithms. It was assumed here that the common set of cells is the core of the potential reserve system. In the first step, the representation of all natural features in that common set of 528 cells was assessed. The evaluation showed that 192 natural features were not adequately represented. Then, a set of 302 cells was selected from an additional pool of cells already in the current PA system. This improved the representation; however, Clark's Grebe, whose provincial range equals eight grid cells, was still underrepresented. Therefore, one cell was selected from the remaining pool of available cells to meet its representation goal. The final selection was from the combined pool of 831 to remove any redundancy. A total of 798 cells were selected to represent all features (Figure 3-5).

The summaries of tradeoffs related to the four types of complementary analyses are presented in Table 3-9. Overall, higher efficiency of rarity algorithm could require accepting more computational time. On the other hand, setting priorities based on rarities would allow addressing the needs of most vulnerable species in the beginning of the process. Also, the computational time might not be a problem in the near future with the dynamic changes in computer technology. Improving configurations could decrease the species representation of some taxonomic groups as it was shown with birds. The common pool of cell approach did not benefit the process. It decreased the efficiency and would require more management effort because only 48% of selected cells were already in the current PA system and 28% of them were on private land. Both algorithms were effective in eliminating duplication of cells needed to meet the goal of representation, confirming the capability of heuristic algorithms to effectively eliminate redundancy in site selection and feature representation.



10km by 10km grid cells in the current PA system

additional grid cells selected to complete the representation

Figure 3-1. A total of 768 grid cells selected by the richness algorithm (R6) based on the distribution of birds, mammals, butterflies, fishes, and natural regions in Alberta.

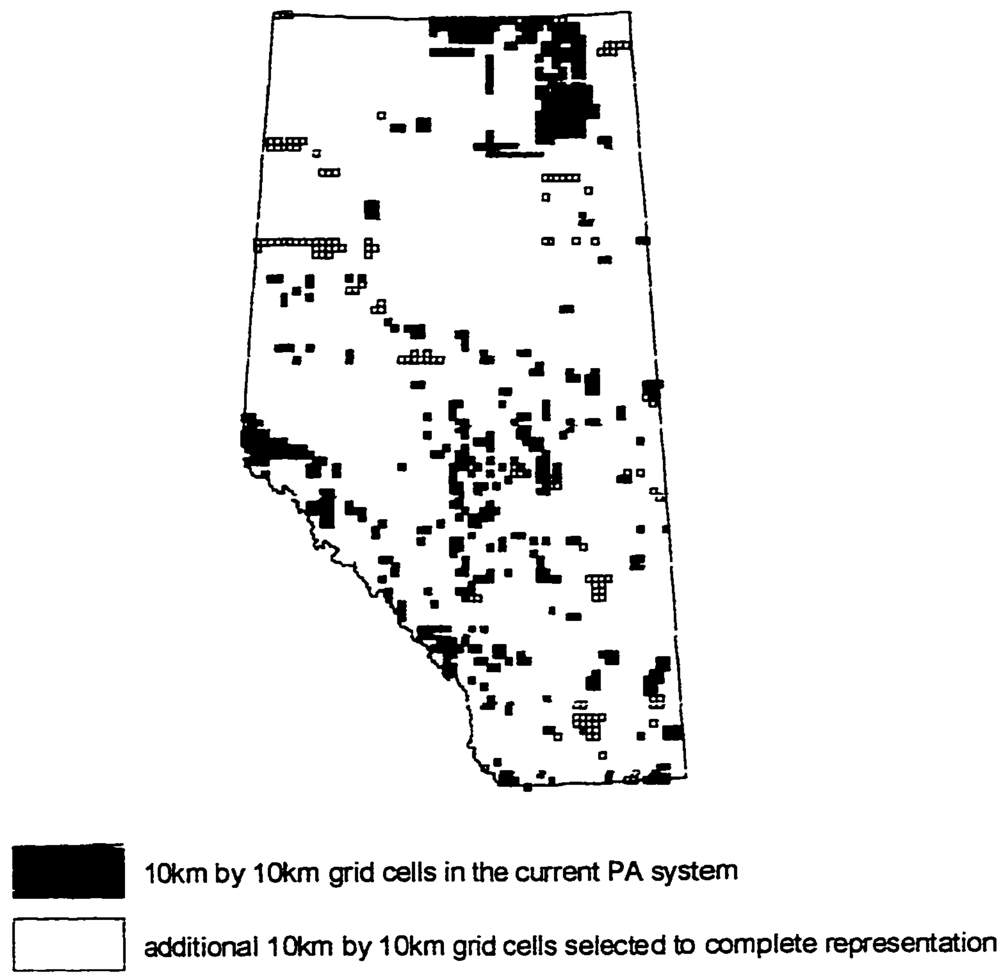


Figure 3-2. A total of 763 grid cells selected by the rarity algorithm (TR) based on the distribution of birds, mammals, butterflies, fishes, and natural regions in Alberta.

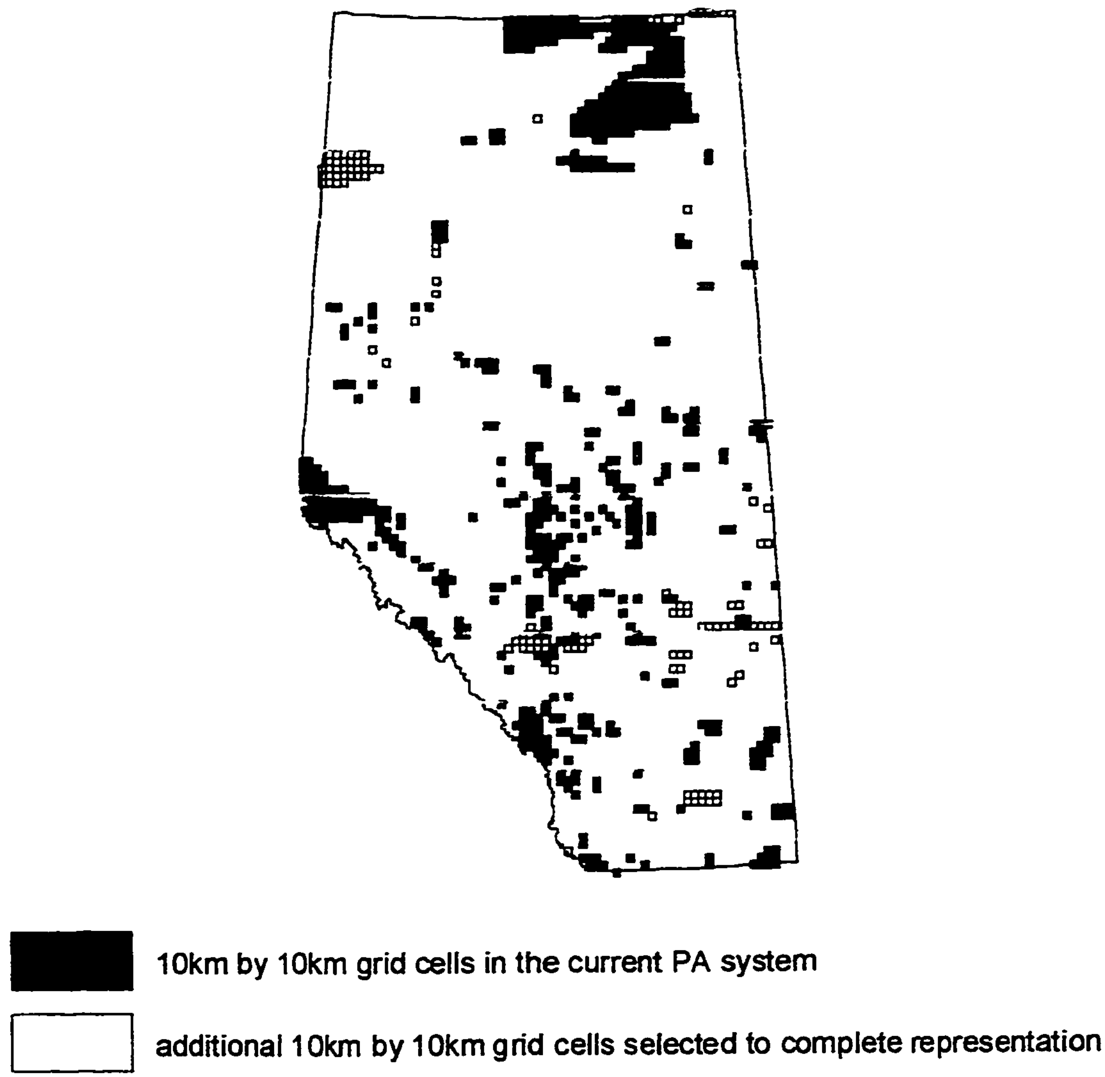


Figure 3-3. A total of 796 grid cells selected by the richness algorithm (R6) based on the distribution of mammals, butterflies, fishes, and natural regions in Alberta.

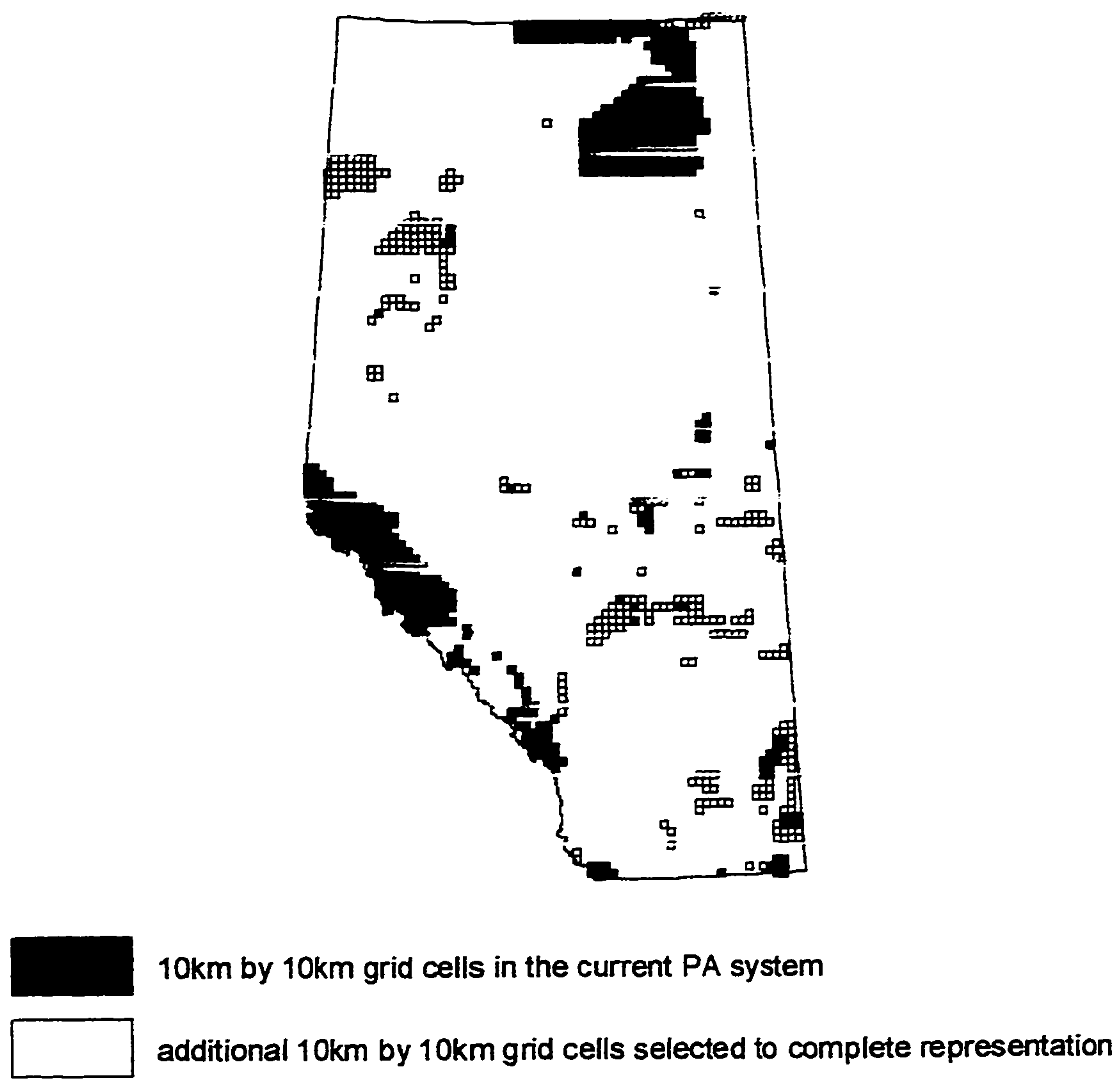
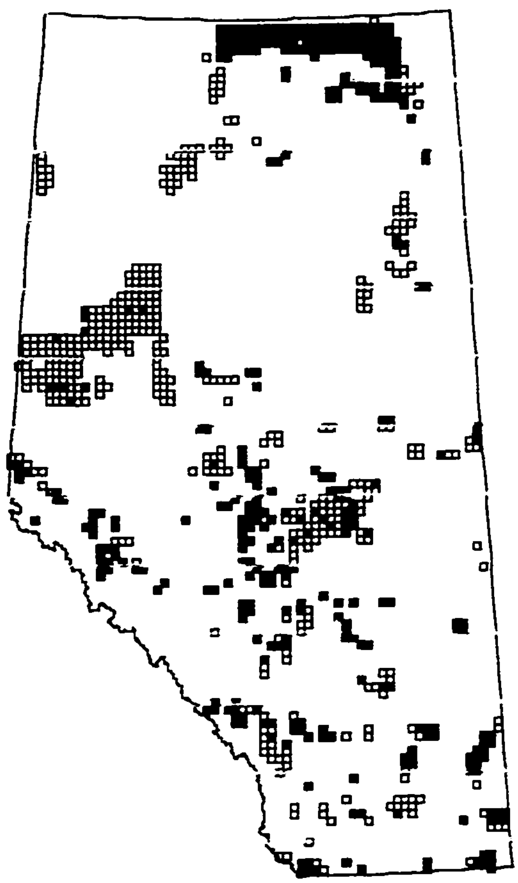


Figure 3-4. A total of 863 grid cells selected by richness algorithm (R6) based on the distribution of mammals, butterflies, fishes, and natural regions in Alberta.



10km by 10km grid cells in the current PA system

additional 10km by 10km grid cells selected to complete representation

Figure 3-5. A total of 798 grid cells selected by richness algorithm (R6) based on the distribution of birds, mammals, butterflies, fishes, and natural regions in Alberta with special preference to cells consistently selected by all algorithms.

Table 3-9. Results of complementary analyses using different data set and selected algorithms.

Data set and algorithm	Data set without birds (R6)	Data set without birds (R6)	All natural features (R6)	All natural features (TR)	All natural features (R6)
Procedure:	-Select from cells in PA -Select from remaining cells - Re-select	-Select from cells in PA 100km^2 or greater -Select from remaining cells -Re-select	-Select from cells in PA -Select from remaining cells -Re-select	-Select from cells in PA -Select from remaining cells -Re-select	-Select from common cells -Select from additional cells in PA -Select from remaining cells -Re-select
Efficiency:	796 cells	863 cells	768 cells	763 cells	798 cells
Configuration:	no. of cells	no. of cells	no. of cells	no. of cells	no. of cells
1 cell reserves	46	13	45	47	29
2 cell reserves	27	5	26	25	16
3 cell reserves	17	2	16	21	11
>3 cell reserves	34	25	49	41	36
Total clusters	124 cells	47	136	134	92
Representation	80 birds underrepresented	118 birds underrepresented	All represented	All represented	All represented
Provincial range representation: no. of features out of 302 and percent of total			no. out of 599 features and percent of total		
10%	12 (4%)	8 (3%)	16 (3%)	22 (4%)	9 (2%)
10%-20%	194 (64%)	192 (64%)	439 (73%)	435 (73%)	406 (68%)
20%-30%	56 (19%)	38 (13%)	85 (14%)	83 (14%)	103 (17%)
30%-40%	14 (5%)	16 (5%)	24 (4%)	20 (3%)	43 (7%)
40%-50%	7 (2%)	15 (5%)	14 (2%)	17 (3%)	15 (3%)
50%-60%	6 (6%)	14 (5%)	10 (2%)	9 (2%)	8 (1%)
60%-70%	3 (1%)	5 (2%)	1 (0.2%)	3 (1%)	5 (1%)
70%-80%	1 (0.3%)	3 (1%)	1 (0.2%)	1 (0.2%)	1 (0.2%)
80%-90%	0 (0%)	3 (1%)	0 (0%)	0 (0%)	1 (0.2%)
90%-100%	9 (3%)	8 (3%)	9 (2%)	9 (2%)	8 (1%)
Existing protection					
Cells in PA system	683 cells (86%)	591 cells (68%)	635 (83%)	663 (87%)	384 cells (48%)
Cells outside PA	110 cells (14%)	272 cells (32%)	133 (17%)	100 (13%)	414 cells (52%)
Land Ownership					
Cells on private land	132 cells (17%)	108 cells (13%)	137 (18%)	130 (17%)	220 (28%)
Cells on crown land	664 cells (83%)	755 cells (87%)	631 (82%)	633 (83%)	578 (72%)
Land disturbance					
Low	44 cells (6%)	80 cells (9%)	62 (8%)	62 (8%)	64 cells (8%)
Moderate	639 cells (80%)	728 cells (84%)	600 (78%)	596 (78%)	567 cells (71%)

4. DISCUSSION

4.1 Diversity and rarity - distribution patterns

The lack of spatial relationships in species richness between taxonomic groups is not surprising because different taxonomic groups have different habitat requirements that do not have to overlap (Grehan 1996). The consequence of this could be that the reserve selection based on one umbrella species (Noss *et al.* 1996) would result in the incomplete representation of other taxa (Kerr 1996, Williams *et al.* 1996 and this study). Why the spatial relationship between the measures of species total rarity of taxonomic groups was stronger than between species richness might be explained by land disturbances and habitat fragmentation. Species, although they may have different habitat requirements, could be sensitive to the same threats.

The correlation between measures of species richness and total species rarity within selected taxonomic groups in Alberta suggests that distributions of rare species are nested within the distribution of more-widespread species. This relationship varied between individual groups but was overall moderate among all groups combined. These observed patterns could be unique to a specific geographic location. Some suggested that the coincidence of areas high in species richness and rarity might improve at a smaller scale (Prendergast *et al.* 1983, Curnut *et al.* 1994). If the spatial relationship is scale dependent, then the scale used for landscape planning should be sensitive enough to detect such changes. Although direct evidence on the scale sensitivity for Alberta is not available, Williams *et al.* (1996) reported low correlation between rarity and richness of British birds, as opposed to this study, in 10km by 10km grid cells, suggesting that this particular scale does not guarantee correlation. Also, data from this study were used to compare the species composition of birds and mammals determined, based on this extrapolated data to that published by the Alberta Environmental Protection agency for a number of reserves in Alberta. The extrapolated data were able to correctly determine the species composition within a 10% error range (Pawlina 1996, unpublished data). Although the sources of data were not completely independent, they provided some approximation of reliability of the data of various resolutions applied to different spatial scales.

4.2 Site selection methods

Standardized methods based on heuristic algorithms are useful for selecting new reserves, evaluating current reserves, or looking for reserves to complement the existing system to complete the representation, and, most of all, for considering alternative options and assessing tradeoffs associated with each approach. They effectively reduce redundant selections of sites, reduce our personal biases, and provide justification for site selection decisions. They allow for control over specific rules to guide the selection process and for the evaluation of results in terms of area requirements, level of representation of target features, spatial configuration of reserves, and levels of various threats within the system. The heuristic algorithm, in conjunction with the GIS technology, is a very powerful tool because each selection could be visually examined. The results from this study provide base line information that should be used in developing other algorithms for indicative analysis in conservation evaluation and planning in Alberta. Both richness and rarity algorithms efficiently selected reserves in Alberta. However, others have reported that, in more divers environments with great numbers of endemic species, the rarity algorithms would probably provide the most efficient solution to the reserve selection problem (Kershaw *et al.* 1996). The comparable performance of the two algorithms in this study may have been caused by a relatively low species richness and a low number of narrowly distributed species in Alberta, located in a temperate region, and the observed spatial correlation between scores of species richness and total rarity between taxonomic groups.

4.2 Spatial configuration

The efficiency of the selection process is only one aspect of that process. The other is the spatial arrangement of selected sites. Conservationists agree that the spatial configuration of the reserve system is important and that less isolated sites could improve their chances of maintaining the integrity of the system and, therefore, the chances of long term survival of its elements. The less dispersed configuration of the core areas would allow to save time and money when the issues of corridors and buffers will have to be addressed to reduce isolation due to habitat fragmentation within the reserve system, (Wilcox and Murphy 1985). Williams *et al.* (1996) suggested that, ideally, reserves should be close enough so that the connections are functional, allowing populations to interchange.

The incorporation of area buffers in the selection algorithms could improve the spatial configuration of the reserve system. In Alberta, the species rich cells tend to congregate; therefore, selecting grid cells that are within a 10-cell buffer if cells are equally rich in species, improved spatial configurations without sacrificing efficiency. The values of buffers, however, are probably unique to specific geographic regions and would need to be calibrated if applied outside our province or on a different scale. This approach could be most useful in situations where planners are only beginning the process of site selection. In Alberta, such a process is in an advanced stage and according to Alberta's government, should be completed by the year 2000 or earlier. Therefore, the results from the algorithm evaluation could be applied to identify currently existing reserves that are essential for the natural features' representation, additional sites needed to complete the features' representation, and, as diagnostic/monitoring tool for future system evaluations.

4.3 Complementary analysis

In this study, both the richness algorithm (R6) and rarity algorithm (TR) were applied to complementary analyses aiming at exploring various options and tradeoffs associated with them in completing the representation of natural features in the PA system in Alberta. This involved selecting first the sites from the existing PA system (step one), then locating the most suitable cells to complement the feature representation outside the current system (step two) and finally re-selecting from the combined set of cells from step one and two. Kershaw *et al.* (1996) reported that selecting sites from subsets of data showed different efficiency, with the rarity algorithms outperforming the richness algorithm. The main advantage of the rarity approach has been that the rarest elements were selected early on in the selection process, eliminating accidental species overrepresentation if they were to be selected later. In this study, the restricted species approach improved the efficiency of the selection process by less than one percent (five grid cells) in compare to the richness algorithm. In Alberta, perhaps the number of restricted species is to small to have a significant impact on the selection process. The configuration also did not seem to be affected because of the initial selection of cells from already dispersed pool of cell in the current PA system. However, the rarity algorithm selected more cells already in the PA system suggesting less effort and cost if more land needs to be acquired to complete the representation. This was accomplished at a price of 75% more of computational time needed to provide solution, which if balanced against cost of acquiring and managing more area, might not be a problem.

The use of different subsets of distribution data (with or without the bird species) affected the efficiency, configuration, natural features' representation, and quality of selected cells evaluated based on land ownership, land disturbance within cells, and existing protection. Most importantly, not all bird species were represented. Therefore, increasing the number of taxonomic groups included in the analysis would improve other species representation. Overall, the mammals, butterflies, and fishes were only moderate surrogate for bird species. The question still remains how good surrogates of the selected taxonomic groups would be for other groups not considered in this study. This points out the importance of improving our knowledge on the distribution of natural features in Alberta as an important prerequisite to site selection.

The configuration of these cells was dispersed but improved when the complementary analyses started with PA larger than $100km^2$ and giving the priority to sites within a 10 cell buffer. However, conserving large, continuous chunks of land may not be feasible in the fragmented Alberta's landscape, and this approach decreased the representation of birds. Starting the selection process from the pool of common cells did not provide a better option for completing the representation of features in the PA system. This suggest that either the common cells should not be considered the core of the system or that many of the current PA are not the best choice for the PA system according to criteria used in the study.

4.4 Recommendations

The analyses presented here are only an initial step towards the development of analytical tools for landscape planning and PA system evaluation. The method is scale independent but depends on data. In areas such as the Forestry Management Areas, where the information on the distribution of natural features is available from heterogeneous habitats, that are missed at a smaller scale, such tools could be applied in conjunction with other aspect of landscape management, harvest, establishing corridors for wildlife, or putting aside areas for conservation. On a smaller, provincial scale, it could be used for designing the PA network and monitoring current conservation efforts. Eventually, the results from larger and finer scale analyses should be cross-referenced to examine its limitations resulting from the resolution and quality of the data.

More information on the distribution of natural features, other than those included in this study, would not necessarily affect the efficiency but would affect the content of the selected set of cells. More data would allow refining the selection process. Some data, such as the Alberta's subregions, are already available in digital format. Other, especially regarding species of conflicting habitat requirements, should be collected and incorporated into the selection process.

The most important benefit of using mathematical algorithms is its flexibility. It allows for incorporating various rules or set of rules to guide the selection process, evaluation of tradeoffs, and visual examination of results. With the increasing amount of data being collected and available for landscape managers, it is becoming more and more difficult to take advantage of their existence without tools that summarize the information in a meaningful way. As to the choice of richness versus rarity approach, it would depend on specific application and reduction in computational time of the rarity algorithm.

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IV. CONCLUSIONS

Establishing a system of protected areas (PA), in practice, is no easy task. With time, the opportunities for creating new reserves are decreasing, triggering the urgency to act now, often without adequate information. The challenge is to utilize all possible sources of relevant scientific data, harness available scientific knowledge, and, with the assistance of new technology, meet the goal of establishing a PA network to conserve biodiversity.

Alberta's approach to reserve selection, based on natural regions and gaps in their representation, provides a good framework for the intended process. However, the targets set by planners were, at best, just educated guesses, and the nomination process that was supposed to guide the process of filling gaps in natural regions representation, is still subject to decisions based on what is possible, and not necessarily what is required. Although many suggest that such a process is not adequate, and that it is only the first step in a long process, it is actually possible to assess the effectiveness of current efforts in meeting the conservation goals, mainly the goal of representation, using available information on the distribution and status of wildlife species in Alberta. The compilation of available species presence and distribution data and assessment of species representation were the first two main objectives of this study.

Recent publications regarding the presence of fishes, butterflies, mammals, birds, amphibians, and reptiles in Alberta, together with data retrieved from various government agencies and individual researchers, led to the preparation of maps which show where information on species presence is missing. The areas that are the least surveyed are mainly located in the northern part of the province. These are also areas that contain timber and/or oil and gas resources. Wherever such commercially valuable resources are present there is a possibility of loss of biodiversity. Also, our knowledge on wildlife provincial distributions is limited to only a few taxonomic groups. Considering that different taxonomic groups have different habitat requirements, it would make sense, from a biodiversity point of view, to expand our efforts to collect information on the distribution of other taxonomic groups. Although it is easy to recommend doing just that, the high costs of surveys would most likely limit options. An alternative approach would be to coordinate efforts for data sharing. A data sharing clause on the research and collection permits issued by the province to individuals involved in various ecological researches in Alberta would save money and improve our knowledge.

The available species distribution data were used to assess wildlife representation in the current reserves. These potential species distribution assume continuous species distribution throughout their ranges. Considering that it is most likely not the case for majority of species, the representation of species in PA was overestimated. Nevertheless, 80% or more of all Alberta's birds, mammals, butterflies, fishes, amphibians, and reptiles could potentially be found in more than three PA. The redundancy is considered very valuable because it could enhance species persistence (Gotelli 1991) if local extinctions occurred (Vane-Wright et al. 1991) due to natural or manmade disturbances (Frankel and Soule 1981). This qualitative planning criterion has to be approached with caution because it does not take under consideration the size and isolation of PA, the availability of suitable habitat within them, and the general lack information on metapopulations dynamics. The question is, if, hypothetically, three PA, each less than 10km^2 in size, happen to be located within a distribution range of a large carnivore whose home range requirements are rather extensive (Weaver et al. 1996), would those small, dispersed PA provide adequate protection for this species? Should we be satisfied with such a measure of representation?

Many of Alberta's species, considered well represented, are experiencing population declines while others have their status not determined (Alberta Government 1996); therefor, this qualitative analysis suggests that representation does not constitute protection. The gap analysis also identified species not represented at all, or species that could be found in less than three PA. Five out of the 35 that were underrepresented had the current representation corresponding with their total known distribution in the province; therefore, could actually be considered represented. The remaining were rare breeders, migrants, highly localized species, species endangered or threatened in Canada, or peripheral species. Although some believe that peripheral species should not be included in the conservation efforts, others suggest that marginal species survive at the extreme limits of their geographical range and are likely to have unique adaptation properties essential for survival. Such properties may have a particular significance in time of global warming because marginal populations could be a source of highly adaptive genes for the rehabilitation of other lost populations (Lesica and Allendorf 1995, Masquin et al. 1995). Most importantly, unless we understand what their functions are in ecosystems, it would be unwise to dismiss them from consideration.

Another way to measure the representation is to determine percent representation of species provincial ranges. Although we do not know what the required percent range representation to maintain viable populations would be, this provides us with additional, quantitative measures of natural features representation. We may try to use this approach to represent species based on their body size and area requirements. This could be accomplished by setting our goals on, for example, 80% range representation for large carnivores, 40% for animals of medium body size, and 10% for animals of small body size. This is still based on hypothetical numbers but acknowledges that different species have different spatial requirements.

The site selection process in Alberta has not been completed yet, but there is a possibility that the current strategy would result in inefficient and incomplete representation of natural features in the PA network in the year 2000. Two hundred and forty one PA, covering almost 10% of the province, were considered in this study. Most of them are small, dispersed, and isolated while others have their integrity threatened. Twenty four percent are less than 1km^2. Moreover, recent controversies regarding industrial activities within the PA and in the surrounding areas add a new dimension to the planning process. Selecting sites using the nomination process to complete the representation of natural regions should be extended to selecting sites with consideration given to size, distance to the nearest PA, and level of disturbance within and outside the potential site to insure reserves' integrity (Noss1995). It should also be extended to wildlife species since their needs have not been met by the natural regions' representation approach.

The availability of relevant spatial data provided unique opportunities to examine different approaches to site selection in Alberta that could improve the selection process and later be used as a monitoring tool. The evaluation of various systematic methods to site selection and their potential use for completing the current PA system was the third major objective of this study.

The species distribution data allowed for the evaluation of spatial relationships in species richness and rarity between taxonomic groups. The lack of spatial relationships in species richness between taxonomic groups observed in this study might have an impact on the reserve design recommended by some scientists based on "umbrella species" (Noss et al. 1996). Umbrella species are usually large carnivores whose habitat requirements encompass habitats of many other species. The assumption is that areas large enough to support populations of large carnivores are likely to include many other species and communities (Noss et al. 1996), but if there is no sufficient overlap, this approach would result in the incomplete representation of other species and taxa (Kerr 1996, Williams et al. 1996, and this study). On another hand, relatively good spatial relationships between centers of species richness and rarity, especially when all taxonomic groups were considered, suggested that we might be able to efficiently represent natural features in Alberta if we select sites based on species richness or rarity. In fact, both types of heuristic algorithms were applied to site selection in this study and efficiently selected reserves. However, because species rich cells in Alberta tend to congregate, selecting grid cells that were within a 10 cell buffer if cells were equally rich in species improved spatial configurations in this study without sacrificing efficiency.

The restricted species approach, when applied to complete the current PA network, improved the efficiency of the selection process by less than one percent (five grid cells) in comparison to the richness algorithm. The spatial configuration of reserves seemed to be similar because of the initial selection from the already dispersed pool of cells in the current PA system. However, the rarity algorithm selected 28 more cells already in the PA system than the richness algorithm, suggesting less effort and cost if more land needs to be acquired to complete the representation. It also required 33 cells less from outside the current system than the richness approach. This was accomplished at a price of 75% more computational time needed to provide a solution, which could be less of a problem if the costs of acquiring and managing land are considered. Also, because the rarity algorithm tends to select the rarest features early on in the process, areas containing the highest numbers of those vulnerable species would be on the top of the planners' priority list.

Removing one taxonomic group from the site selection process affected the efficiency, configuration, natural features' representation, and quality of selected cells evaluated based on land ownership, land disturbance within cells, and existing protection. Therefore, increasing the number of taxonomic groups included in the analysis would improve their role as biodiversity surrogates. It supports the previously suggested urgency to increase efforts in gathering species presence and distribution data for many different taxonomic groups so that we could examine biodiversity patterns. Recognizing those patterns is an important prerequisite to understanding biodiversity functions. The aim of this evaluation was to identify the most suitable method to select sites for completing our current PA system, not to recommend what the actual PA network should be, mainly because the 10% range representation was just a hypothetical number and did not reflect the species range representation needs.

With time, opportunities for creating new reserves will decrease. We will be left with what we selected and any changes will have to be re-negotiated. The proposed iterative method, if implemented, would not only assist in current site selection but also be an essential tool for future land "swapping" discussions and evaluation of options. It could provide a provincial perspective and justification for the future PA network refinement decisions. It could also assist in the establishment of corridors among PA to reduce their isolation.

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APPENDIX 1

Table 1 - List of Alberta mammals included in the analysis.

No.	Common Name	Species Name	Status[1]
1	Arctic Fox	Alopex lagopus	
2	Arctic Shrew	Sorex arcticus	
3	Badger	Taxidea taxus	YA
4	Beaver	Castor canadensis	
5	Big Brown Bat	Eptesicus fuscus	
6	Bighorn Sheep	Ovis canadensis	
7	Bison	Bison bison	R
8	Black Bear	Ursus americanus	
9	Bobcat	Lynx rufus	YB
10	Brown Lemming	Lemmus sibiricus	U
11	Bushy-tailed Woodrat	Neotoma cinerea	
12	Canada Lynx	Lynx canadensis	YB
13	Caribou	Rangifer tarandus	B
14	Columbian Ground Squirrel	Spermophilus columbianus	
15	Cougar	Felis concolor	YB
16	Coyote	Canis latrans	
17	Deer Mouse	Peromyscus maniculatus	
18	Dusky Shrew	Sorex monticolus	
19	Ermine	Mustela erminea	
20	Fisher	Martes pennanti	YB
21	Franklin's Ground Squirrel	Spermophilus franklinii	U
22	Golden-mantled Ground Squirrel	Spermophilus lateralis	
23	Gray Wolf	Canis lupus	
24	Grizzly Bear	Ursus arctos	B
25	Heather Vole	Phenacomys intermedius	
26	Hoary Bat	Lasiurus cinereus	U
27	Hoary Marmot	Marmota caligata	YB
28	Least Chipmunk	Tamias minimus	
29	Least Weasel	Mustela nivalis	
30	Little Brown Bat	Myotis lucifugus	
31	Long-tailed Weasel	Mustela frenata	YA
32	Long-eared Bat	Myotis evotis	U
33	Long-legged Bat	Myotis volans	U
34	Long-tailed Vole	Microtus longicaudus	
35	Marten	Martes americana	
36	Masked Shrew	Sorex cinereus	
37	Meadow Jumping Mouse	Zapus hudsonius	
38	Meadow Vole	Microtus pennsylvanicus	
39	Mink	Mustela vison	
40	Moose	Alces alces	
41	Mountain Goat	Oreamnos americanus	
42	Mule Deer	Odocoileus hemionus	

43	Muskrat	Ondatra zibethicus	
44	Northern Bog Lemming	Synaptomys borealis	
45	Northern Flying Squirrel	Glaucomys sabrinus	YB
46	Northern Grasshopper Mouse	Onychomys leucogaster	YB
47	Northern Long-eared Bat	Myotis septentrionalis	B
48	Northern Pocket Gopher	Thomomys talpoides	
49	Nuttall's Cottontail	Sylvilagus nuttallii	YB
50	Olive-backed Pocket Mouse	Perognathus fasciatus	YB
51	Ord's Kangaroo Rat	Dipodomys ordii	B
52	Pika	Ochotona princeps	
53	Porcupine	Erethizon dorsatum	
54	Prairie Vole	Microtus ochrogaster	U
55	Prairie shrew	Sorex haydeni	U
56	Pronghorn	Antilocapra americana	YB
57	Pygmy Shrew	Sorex hoyi	
58	Raccoon	Procyon lotor	
59	Red Bat	Lasiurus borealis	
60	Red Fox	Vulpes vulpes	
61	Red Squirrel	Tamiasciurus hudsonicus	
62	Red-tailed Chipmunk	Tamias ruficaudus	B
63	Richardson's Ground Squirrel	Spermophilus richardsonii	YA
64	River Otter	Lutra canadensis	
65	Sagebrush Vole	Lagurus curtatus	U
66	Silver-haired Bat	Lasionycteris noctivagans	
67	Snowshoe Hare	Lepus americanus	
68	Southern Red-backed Vole	Clethrionomys gapperi	
69	Striped Skunk	Memphitis memphitis	
70	Swift Fox	Vulpes velox	R
71	Thirteen-lined Ground Squirrel	Spermophilus tridecemlineatus	YA
72	Wandering Shrew	Sorex vagrans	YB
73	Wapiti	Cervus elaphus	
74	Water Shrew	Sorex palustris	
75	Water Vole	Microtus richardsoni	
76	Western Harvest Mouse	Rethrodontomys megalotis	YB
77	Western Jumping Mouse	Zapus princeps	
78	Western Small-footed Bat	Myotis ciliolabrum	YB
79	White-tailed Deer	Odocoileus virginianus	
80	White-tailed Jack Rabbit	Lepus townsendii	
81	Wolverine	Gulo gulo	B
82	Woodchuck	Marmota monax	
83	Yellow-bellied Marmot	Marmota flaviventris	
84	Yellow-pine Chipmunk	Tamias amoenus	

[1] R - Red List, B - Blue List, YA - Yellow A List, YB - Yellow B List, G - Green List (Alberta Government 1996; The status of Alberta wildlife, Pub. I/620p)

Table 2 - List of Alberta butterflies included in the analysis.

No.	Common Name	Species Name
1	Acadian Hairstreak	Satyrium acadicum
2	Acastus Checkerspot	Charidryas acastus
3	Acmon Blue	Plebejus acmon
4	Afranius Duskywing	Erynnis afranius
5	Alberta Fritillary	Boloria alberta
6	Alberta Arctic	Oeneis alberta
7	Alexandra Sulphur	Colias alexandra
8	Alfalfa Butterfly	Colias eurytheme
9	Anicia Checkerspot	Euphydryas anicia
10	Anise Swallowtail	Papilio zelicaon
11	Aphrodite Fritillary	Speyeria aphrodite
12	Arctic Skipper	Carterocephalus palaemon
13	Arrowhead Blue	Glaucopsyche piasus
14	Astrate Fritillary	Boloria astarte
15	Atlantis Fritillary	Speyeria atlantis
16	Blue Copper	Lycaena heteronea
17	Bog Fritillary	Boloria eunomia
18	Bronze Copper	Lycaena hyllus
19	Brown Elfin	Incisalia augustinus
20	Cabbage Butterfly	Pieris rapae
21	California Tortoise Shell	Nymphalis californica
22	California White	Pontia sisymbrii
23	Callippe Fritillary	Speyeria callippe
24	Canada Sulphur	Colias canadensis
25	Canadian Tiger Swallowtail	Papilio canadensis
26	Checker Skipper	Pyrgus communis
27	Checkered White	Pontia protodice
28	Christina Sulphur	Colias christina
29	Chryxus Arctic	Oeneis chryxus
30	Clodius Parnassian	Parnassius clodius
31	Clouded Sulphur	Colias philodice
32	Common Alpine	Erebia epipsodea
33	Common Branded Skipper (L.)	Hesperia assiniboia
34	Common Branded Skipper (S.)	Hesperia manitoba
35	Common Wood Nymph	Cercyonis pegala
36	Compton's Tortoise Shell	Nymphalis vaualbum
37	Coral Hairstreak	Harkenclenus titus
38	Cranberry Blue	Plebejus optilete
39	Dark Wood Nymph	Cercyonis oetus
40	Delaware Skipper	Atrytone logan
41	Dingy Arctic Fritillary	Boloria improba
42	Disa Alpine	Erebia disa

43	Dorcas Cooper	Lycaena dorcas
44	Dotted Blue	Euphilotes enoptes
45	Draco Skipper	Polites draco
46	Dreamy Duskywing	Erynnis icelus
47	Eastern Pine Elfin	Incisalia niphon
48	Edith's Checkerspot	Euphydryas editha
49	Edward's Fritillary	Speyeria edwardsii
50	European Skipper	Thymelicus lineola
51	Eyed Brown	Satyrodes euridice
52	Field Crescent	Phyciodes pulchella
53	Freija Fritillary	Boloria freija
54	Frigga Fritillary	Boloria frigga
55	Garita Skipper	Oarisma garita
56	Giant Sulphur	Colias gigantea
57	Gillett's Checkerspot	Euphydryas gillettii
58	Gorgone Checkerspot	Charidryas gorgone
59	Gray Comma	Polygonia progne
60	Gray Hairstreak	Strymon melinus
61	Great Gray Copper	Lycaena dione
62	Great Spangled Fritillary	Speyeria cybele
63	Green Comma	Polygonia faunus
64	Greenish Blue	Plebejus saepiolus
65	Grizzled Skipper (E.)	Pyrgus loki
66	Grizzled Skipper (W.)	Pyrgus freija
67	Hoary Comma	Polygonia gracilis
68	Hoary Elfin	Incisalia polia
69	Hobomok Skipper	Poanes hobomok
70	Hydaspe Fritillary	Speyeria hydaspe
71	Icarioides Blue	Plebejus icarioides
72	Inirnate Ringlet	Coenonympha inornata
73	Jutta Arctic	Oeneis jutta
74	Large Marble	Euchloe ausonides
75	Least Skipper	Ancyloxypha numitor
76	Little Copper	Lycaena phlaeas
77	Long Dash Skipper	Polites mystic
78	Lorquin's Admiral	Limenitis lorquini
79	Lustrous Copper	Lycaena cuprea
80	Magdalena Alpine	Erebia magdalena
81	Margined White	Pieris marginalis
82	Mariposa Copper	Lycaena mariposa
83	Maucoun's Arctic	Oeneis macounii
84	Mead's Sulphur	Colias meadii
85	Meadow Fritillary	Boloria bellona
86	Melissa Arctic	Oeneis melissa

87	Melissa Blue	Lycaeides melissa
88	Milbert's Tortoise Shell	Aglais milberti
89	Monarch	Danaus plexippus
90	Mormon Fritillary	Speyeria mormonia
91	Moss' Elfin	Incisalia mossii
92	Mourning Cloak	Nymphalis antiopa
93	Mustard White	Pieris oleracea
94	Napaea Fritillary	Boloria napaea
95	Nastes Sulphur	Colias nastes
96	Nevada Skipper	Hesperia nevada
97	Northern Blue	Lycaeides idas
98	Northern Checkerspot	Charidryas palla
99	Northern Cloudywing	Thorybes pylades
100	Northern Marble	Euchloe creusa
101	Northern Pearl Crescent	Phyciodes cocyta
102	Northwestern Fritillary	Speyeria electa
103	Ochreous Ringlet	Coenonympha ochracea
104	Old World & Anise Swallowtail	Papilio zelicaonXmac
105	Old World Swallowtails (C.)	Papilio hudsonianus
106	Old World Swallowtails (M.)	Papilio dodi
107	Old World Swallowtails (P.)	Papilio pikei
108	Olympia Marble	Euchloe olympia
109	Oreas Anglewing	Polygonia oreas
110	Oslar's Roadside Skipper	Amblyscirtes oslari
111	Palaeno Sulphur	Colias palaeno
112	Pale Swallowtail	Papilio eurymedon
113	Pearl Crescent	Phyciodes tharos
114	Peck's Skipper	Polites peckius
115	Pelidne Sulphur	Colias pelidne
116	Persius Duskywing	Erynnis persius
117	Pink-edged Sulphur	Colias interior
118	Polixenes Arctic	Oeneis polixenes
119	Purple Azur	Celastrina nigrescens
120	Purple Fritillary	Boloria chariclea
121	Purplish Cooper	Lycaena helloides
122	Question Mark	Polygonia interrogationis
123	Red Admiral	Venessa atlanta
124	Red-disked Alpine	Erebia discoidalis
125	Rhesus Skipper	Polites rhesus
126	Riding's Satyr	Neominois ridingsii
127	Roadside Skipper	Amblyscirtes vialis
128	Rockside Checkerspot	Charidryas damoetas
129	Ruddy Copper	Lycaena rubida
130	Rustic Blue	Plebejus rusticus

131	Sara Orange Tip	Anthocharis sara
132	Satyr Anglewing	Polygonia satyrus
133	Shasta Blue	Plebejus shasta
134	Sheridan's Hairstreak	Callophrys sheridanii
135	Silver-bordered Fritillary	Boloria selene
136	Silverspotted Skipper	Epargyreus clarus
137	Silvery Blue	Glaucopsyche lygdamus
138	Small Checkered Skipper	Pyrgus scriptura
139	Smintheus Parnassian	Parnassius smintheus
140	Sooty Gossamer Wing	Satyrium fuliginosum
141	Spring Azure	Celastrina lucia
142	Striped Hairstreak	Satyrium liparops
143	Tawny Crescen	Phyciodes batesii
144	Tawny-edged Skipper	Polites themistocles
145	Thicket Hairstreak	Mitoura spinetorum
146	Two-banded Checker Skipper	Pyrgus ruralis
147	Two-tailed Swallowtail	Papilio multicaudatus
148	Uhler's Arctic	Oeneis uhleri
149	Uncas Skipper	Hesperia uncas
150	Variegated Fritillary	Euptoieta claudia
151	Viceroy	Limenitis archippus
152	Weidemeyer's Admiral	Limenitis weidemeyerii
153	Western Meadow Fritillary	Boloria epithore
154	Western Pine Elfin	Incisalia eryphon
155	Western Tailed Blue	Everes amyntula
156	Western White	Pontia occidentalis
157	White Admiral	Limenitis arthemis
158	White-veined Arctic	Oeneis taygete
159	Woodland Skipper	Ochlodes sylvanoides
160	Zephyr	Polygonia zephyrus
161	Zerena Fritillary	Speyeria zerene

Table 3 - List of Alberta fishes included in the analysis.

No.	Common Name	Species Name	Status[1]
1	Arctic Grayling	Thymallus arcticus	N
2	Brassy Minnow	Hybognathus hankinsoni	N
3	Brook Stickleback	Culaea inconstans	N
4	Brook Trout	Salvelinus fontinalis	I
5	Brown Trout	Salmo trutta	I
6	Bull Trout	Salvelinus confluentus	N
7	Burbot	Lota lota	N
8	Cisco	Coregonus artedi	N
9	Cutthroat Trout	Oncorhynchus clarki	N
10	Deepwater Sculpin	Myoxocephalus thompsoni	N
11	Emerald Shiner	Notropis atherinoides	N
12	Fathead Minnow	Pimephales promelas	N
13	Finescale Dace	Phoxinus neogaeus	N
14	Flathead Chub	Platygobio gracilis	N
15	Goldeye	Hiodon alosoides	N
16	Iowa Darter	Etheostoma exile	N
17	Lake Chub	Couesius plumbeus	N
18	Lake Sturgeon	Acipenser fulvescens	N
19	Lake Trout	Salvelinus namaycush	N
20	Lake Whitefish	Coregonus clupeaformis	N
21	Largescale Sucker	Catostomus macrocheilus	N
22	Logperch	Percina caprodes	N
23	Longnose Dace	Rhinichthys cataractae	N
24	Longnose Sucker	Catostomus catostomus	N
25	Mooneye	Hiodon tergisus	N
26	Mountain Sucker	Catostomus platyrhynchus	N
27	Mountain Whitefish	Prosopium williamsoni	N
28	Ninespine Stickleback	Pungitius pungitius	N
29	Northern Pike	Esox lucius	N
30	Northern Redbelly Dace	Phoxinus eos	N
31	Northern Squawfish	Ptychocheilus oregonensis	N
32	Pearl Dace	Margariscus margarita	N
33	Pygmy Whitefish	Prosopium coulteri	N
34	Quillback	Carpiodes cyprinus	N
35	Rainbow Trout	Oncorhynchus mykiss	N
36	Redside Shiner	Richardsonius balteatus	N
37	River Shiner	Notropis blennius	N
38	Sauger	Stizostedion canadense	N
39	Shorthead Redhorse	Moxostoma macrolepidotum	N
40	Shorthead Sculpin	Cottus confusus	N
41	Shortjaw Cisco	Coregonus zenithicus	N

42	Silver Redhorse	Moxostoma anisurum	N
43	Slimy Sculpin	Cottus cognatus	N
44	Spoonhead Sculpin	Cottus ricei	N
45	Spottail shiner	Notropis hudsonius	N
46	Stonecat	Noturus flavus	N
47	Trout-perch	Percopsis omiscomaycus	N
48	Walleye	Stizostedion vitreum	N
49	Western Silvery Minnow	Hybognathus argyritis	N
50	White Sucker	Catostomus commersoni	N
51	Yellow Perch	Perca flavescense	N

[1] N - Native species, I - Introduced species
(Nelson, J. and M. Paetz 1992; The fishes of Alberta. The University of Alberta Press, University of Calgary Press).

Table 4 - List of Alberta birds included in the analysis.

No.	Common Name	Species Name	Status[1]
1	Alder Flycatcher	Empidonax alnorum	G
2	American Avocet	Recurvirostra americana	YB
3	American Bittern	Botaurus lentiginosus	YA
4	American Black Duck	Anas rubripes	G
5	American Coot	Fulica americana	G
6	American Crow	Corvus brachyrhynchos	G
7	American Dipper	Cincilus mexicanus	YB
8	American Goldfinch	Carduelis tristis	G
9	American Kestrel	Falco sparverius	G
10	American Redstart	Setophaga ruticilla	G
11	American Robin	Turdus migratorus	G
12	American Tree Sparrow	Spizella arborea	G
13	American White Pelican	Pelecanus erythrorhynchos	YB
14	American Wigeon	Anas americana	G
15	Baird's Sandpiper	Calidris bairdii	G
16	Baird's Sparrow	Ammodramus bairdii	YA
17	Bald Eagle	Haliaeetus leucocephalus	YB
18	Bank Swallow	Riparia riparia	G
19	Barn Swallow	Hirundo rustica	G
20	Barred Owl	Strix varia	YB
21	Barrow's Goldeneye	Bucephala islandica	G
22	Bay-breasted Warbler	Dendroica castanea	B
23	Belted Kingfisher	Megaceryle alcyon	G
24	Black Swift	Cypsoloides niger	YB
25	Black Tern	Chlidonias niger	YA
26	Black-and-white Warbler	Mniotilta varia	YB
27	Black-backed Woodpecker	Picoides arcticus	YB
28	Black-bellied Plover	Pluvialis squatarola	G
29	Black-billed Cuckoo	Coccyzus eruthropthalmus	G
30	Black-billed Magpie	Pica pica	G
31	Black-capped Chickadee	Parus atricapillus	G
32	Black-crowned Night-heron	Nyctiocorax nyctiocorax	YB
33	Black-headed Grosbeak	Pheuticus melanocephalus	G
34	Black-necked Stilt	Himantopus mexicanus	YB
35	Black-throated Green Warbler	Dendroica virens	B
36	Blackburnian Warbler	Dendroica fusca	G
37	Blackpoll Warbler	Dendroica striata	G
38	Blue Grouse	Dendragapus obscurus	G
39	Blue Jay	Cyanocitta cristata	G
40	Blue-winged Teal	Anas discors	G
41	Bobolink	Dolichonyx oryzivorus	YB
42	Bohemian Waxwing	Bombycilla garrulus	G

43	Bonaparte's Gull	Larus philadelphia	G
44	Boreal Chickadee	Parus hudsonicus	G
45	Boreal Owl	Aegolius funerus	YB
46	Brewer's Blackbird	Euphagus cyanocephalus	G
47	Brewer's Sparrow	Spizella breweri	YB
48	Broad-winged Hawk	Buteo platypterus	YB
49	Brown Creeper	Certhia americana	YB
50	Brown Thrasher	Toxostoma rufum	YA
51	Brown-headed Cowbird	Molothrus ater	G
52	Buff-breasted Sandpiper	Tryngites subroficolias	G
53	Bufflehead	Bucephala albeola	G
54	Burrowing Owl	Athena cunicularia	R
55	California Gull	Larus californicus	G
56	Calliope Hummingbird	Stellula calliope	G
57	Canada Goose	Branta canadensis	G
58	Canada Warbler	Wilsonia canadensis	YB
59	Canvasback	Aythya valisineria	G
60	Cape May Warbler	Dendroica tigrina	B
61	Caspian Tern	Sterna caspia	YB
62	Cassin's Finch	Carpodacus cassinii	U
63	Cedar Waxwing	Bombycilla cedrorum	G
64	Chestnut-collared Longspur	Calcarius ornatus	G
65	Chestnut-sided Warbler	Dendroica pensylvanica	YB
66	Chipping Sparrow	Spizella passerina	G
67	Cinnamon Teal	Anas cyanoptera	G
68	Clark's Grebe	Aechmophorus clarkii	YB
69	Clark's Nutcracker	Nucifraga columbiana	YB
70	Clay-colored Sparrow	Spizella pallida	YA
71	Cliff Swallow	Hirundo pyrrohonata	G
72	Common Goldeneye	Bucephala clangula	G
73	Common Grackle	Quiscalus quiscalus	G
74	Common Loon	Gavia immer	G
75	Common Merganser	Mergus merganser	G
76	Common Nighthawk	Chordelies minor	G
77	Common Poorwill	Phalaenoptilus nuttallii	G
78	Common Raven	Corvus corax	G
79	Common Snipe	Gallinago gallinago	G
80	Common Tern	Sterna hirundo	G
81	Common Yellowthroat	Geothypis trichas	G
82	Connecticut Warbler	Oporornis agilis	G
83	Cooper's Hawk	Accipiter cooperii	YB
84	Dark-eyed Junco	Junco hvemalis	G
85	Double-crested Cormorant	Phalacrocorax auritus	YB
86	Downy Woodpecker	Picoides pubescens	G

87	Dunlin	Calidris alpina	G
88	Dusky Flycatcher	Empidonax oberholseri	G
89	Eared Grebe	Podiceps nigricollis	G
90	Eastern Kingbird	Tyrannus tyrannus	G
91	Eastern Phoebe	Sayornis phoebe	G
92	Eurasian Wigeon	Anas penelope	G
93	European Starling	Sturnus vulgaris	G
94	Evening Grosbeak	Coccothraustes vespertinus	G
95	Ferruginous Hawk	Buteo regalis	B
96	Foster's Tern	Sterna forsteri	YB
97	Fox Sparrow	Pusserella iliaca	G
98	Franklin's Gull	Laeus pipixcan	G
99	Gadwall	Anas strepera	G
100	Glaucous Gull	Larus hyperboreus	G
101	Golden Eagle	Aquila chrysaetos	YB
102	Golden-crowned Kinglet	Regulus satrapa	G
103	Golden-crowned Sparrow	Zonotrichia atricapilla	YB
104	Grasshopper Sparrow	Ammodramus savannarum	YB
105	Gray Catbird	Dumetella carolinensis	G
106	Gray Jay	Perisoreus canadensis	G
107	Gray Partridge	Perdix perdix	G
108	Gray-cheeked Thrush	Catharus minimus	G
109	Great Blue Heron	Ardea herodias	YB
110	Great Gray Owl	Strix nebulosa	YB
111	Great Horned Owl	Bubo virginianus	G
112	Great-crested Flycatcher	Myiarchus crinitus	YB
113	Greater Scaup	Aythya marila	G
114	Greater White-fronted Goose	Anser albifrons	G
115	Greater Yellowlegs	Tringa melanoleuca	G
116	Green-winged Teal	Anas crecca	G
117	Gyrfalcon	Falco rusticolus	G
118	Hairy Woodpecker	Picoides villosus	G
119	Hammond's Flycatcher	Empidonax hammondii	G
120	Harlequin Duck	Histrionicus histrionicus	YA
121	Harris' Sparrow	Zonotrichia querula	G
122	Hermit Thrush	Catharus guttatus	G
123	Herring Gull	Larus argentatus	YB
124	Hooded Merganser	Lophodytes cucullatus	G
125	Horned Grebe	Podiceps auritus	YA
126	Horned Lark	Eremophila alpestris	G
127	House Sparrow	Passer domesticus	G
128	House Wren	Tryglodytes aedon	G
129	Killdeer	Charadirus vociferus	G
130	Lapland Longspur	Calcarius lapponicus	G

131	Lark Bunting	Calamospiza melanocorys	G
132	Lark Sparrow	Chondestes grammacus	YB
133	Lazuli Bunting	Passerina amoena	G
134	Le Conte's Sparrow	Ammodramus leconteii	G
135	Least Flycatcher	Empidonax minimus	G
136	Least Sandpiper	Calidris minutilla	G
137	Lesser Golden Plover	Pluvialis dominica	G
138	Lesser Scaup	Anthya affinis	G
139	Lesser Yellowlegs	Tringa flavipes	YA
140	Lincoln's Sparrow	Melospiza lincolnii	G
141	Loggerhead Shrike	Lanius ludovicianus	YA
142	Long-Billed Curlew	Numenius americanus	B
143	Long-billed Dowitcher	Limnodromus scolopaceus	G
144	Long-eared Owl	Asio otus	G
145	MacGillivray's Warbler	Oporornis tolmiei	G
146	Magnolia Warbler	Dendroica magnolia	G
147	Mallard	Anas platyrhynchos	G
148	Marbled Godwit	Limosa fedoa	G
149	Marsh Wren	Cistothorus palustris	YB
150	McCown's Longspur	Calcarius mccownii	G
151	Merlin	Falco columbarius	G
152	Mew Gull	Larus canus	G
153	Mountain Bluebird	Sialia currocoides	G
154	Mountain Chickadee	Parus gambeli	G
155	Mountain Plover	Charadirus montanus	YB
156	Mourning Dove	Zanaida macroura	G
157	Mourning Warbler	Oporornis philadelphia	YB
158	Nashville Warbler	Vermivora ruficapilla	G
159	Northern Flicker	Colaptes auratus	G
160	Northern Goshawk	Accipiter gentilis	YB
161	Northern Harrier	Circus cyaneus	YA
162	Northern Hawk-owl	Surnia ulula	G
163	Northern Mockingbird	Mimus polyglottos	G
164	Northern Oriole	Icterus galbula	G
165	Northern Pintail	Anas acuta	G
166	Northern Pygmy-owl	Glaucidium gnoma	U
167	Northern Rough-winged Swallow	Stelgidopteryx serripennis	G
168	Northern Saw-whet Owl	Aegolius acadicus	G
169	Northern Shoveler	Anas clypeata	G
170	Northern Shrike	Lanius excubitor	G
171	Northern Waterthrush	Seiurus novoboracensis	G
172	Oldsquaw	Clangula hyemalis	G
173	Olive-sided Flycatcher	Contopus borealis	G
174	Orange-crowned Warbler	Vermivora celata	G

175	Osprey	Pandion haliaetus	YB
176	Ovenbird	Seiurus aurocapillus	G
177	Pacific Loon	Gavia pacifica	G
178	Palm Warbler	Dendroica palmarum	G
179	Pectoral Sandpiper	Calidris melanotos	
180	Peregrine Falcon	Falcon peregrinus	R
181	Philadelphia Vireo	Vireo philadelphicus	G
182	Pied-billed Grebe	Podilymbus podiceps	YA
183	Pileated Woodpecker	Dryocopus pileatus	YB
184	Pine Grosbeak	Pinicola enucleator	G
185	Pine Siskin	Carduelis pinus	G
186	Piping Plover	Charadrius melodus	R
187	Prairie Falcon	Falcon mexicanus	YA
188	Purple Finch	Carpodacus purpureus	G
189	Purple Martin	Progne subis	G
190	Red Crossbill	Loxia curvirosta	G
191	Red Knot	Calidris canutus	G
192	Red-breasted Merganser	Mergus serrator	G
193	Red-breasted Nuthatch	Sitta canadensis	G
194	Red-eyed Vireo	Vireo olivaceus	G
195	Red-naped Sapsucker	Sphyrapicus nuchalis	G
196	Red-necked Grebe	Podiceps grisegena	YA
197	Red-necked Phalarope	Phalaropus lobatus	G
198	Red-tailed Hawk	Buteo jamaicensis	G
199	Red-throated Loon	Gavia stellata	G
200	Red-winged Blackbird	Agelaius phoeniceus	G
201	Redhead	Aythya americana	G
202	Ring-billed Gull	Larus delawarensis	G
203	Ring-necked Duck	Aythya collaris	G
204	Ring-necked Pheasant	Phasianus colchicus	YB
205	Rock Dove	Columba livia	G
206	Rock Wren	Salpincteus obsoletus	YB
207	Rose-breasted Grosbeak	Pheucticus ludovicianus	G
208	Ross's Goose	Chen rossii	G
209	Rosy Finch	Leucosticte arctoa	G
210	Rough-legged Hawk	Buteo logopus	G
211	Ruby-crowned Kinglet	Regulus calendula	G
212	Ruby-throated Hummingbird	Archilochus colubris	G
213	Ruddy Duck	Oxyura jamaicensis	G
214	Ruddy Turnstone	Arenaria interpres	G
215	Ruffed Grouse	Bonasa umbellus	G
216	Rufous Hummingbird	Selasphorus rufus	G
217	Rufous-sided Towhee	Pipilo erythrophthalamus	G
218	Rusty Blackbird	Euphagus carolineus	G

219	Sabine's Gull	Xema sabini	G
220	Sage Grouse	Centrocercus urophasianus	B
221	Sage Thrasher	Oreoscoptes montanus	U
222	Sanderling	Calidris alba	G
223	Sandhill Crane	Grus canadensis	YB
224	Savannah Sparrow	Passerculus sandwichensis	G
225	Say's Phoebe	Savornis saya	G
226	Sedge Wren	Cistothorus platensis	YB
227	Semipalmated Plover	Charadrius semipalmatus	G
228	Semipalmated Sandpiper	Calidris pusilla	G
229	Sharp-shinned Hawk	Accipiter striatus	G
230	Sharp-tailed Grouse	Tympanochus phasianellus	YA
231	Sharp-tailed Sparrow	Ammodramus caudacusta	G
232	Short-billed Dowitcher	Limnodromus griseus	G
233	Short-eared Owl	Asio flammeus	B
234	Smith's Longspur	Calcarius pictus	G
235	Snow Goose	Chen caerulescens	G
236	Solitary Sandpiper	Tringa solitaria	G
237	Solitary Vireo	Vireo solitarius	G
238	Song Sparrow	Melospiza melodia	G
239	Sora	Porzana caeolina	G
240	Spotted Sandpiper	Actitis macularia	G
241	Sprague's Pipit	Anthus spragueii	B
242	Spruce Grouse	Dendragapus canadensis	G
243	Steller's Jay	Cyanocitta stellari	YB
244	Stilt Sandpiper	Calidris hymantopus	G
245	Surf Scoter	Melanitta percipicillata	G
246	Swainson's Hawk	Buteo swainsoni	YA
247	Swainson's Thrush	Catharus ustulatus	G
248	Swamp Sparrow	Melospiza georgiana	G
249	Tennessee Warbler	Vermivora peregrina	G
250	Thayer's Gull	Larus thayeri	G
251	Three-toed Woodpecker	Piscoides tridactylus	G
252	Townsend's Solitaire	Myadesces towsendii	G
253	Townsend's Warbler	Dendroica towsendi	YB
254	Tree Swallow	Tachycineta bicolor	G
255	Trumpeter Swan	Cygnus buccinator	B
256	Tundra Swan	Cygnus columbianus	G
257	Turkey	Meleagris gallopavo	G
258	Turkey Vulture	Cathartes aura	YB
259	Upland Sandpiper	Bartramia longicaudata	YA
260	Varied Thrush	Ixoreus naevius	G
261	Veery	Catharus fuscescens	G
262	Vesper Sparrow	Pooecetus gramineus	G

263	Violet-green Swallow	Tachycineta thallassina	G
264	Virginia Rail	Rollus limicola	U
265	Warbling Vireo	Vireo gilvus	G
266	Water Pipit	Anthus rubescns	G
267	Western Flycatcher	Empidonax difficilis	YB
268	Western Grebe	Aechmophorus occidentalis	YB
269	Western Kingbird	Tyrannus verticalis	G
270	Western Meadowlark	Sturnalla neglecta	YA
271	Western Sandpiper	Calidris mauri	G
272	Western Tanager	Piranga ludoviciana	YB
273	Western Wood-pewee	Contopus sordidulus	G
274	Whimbrel	Numenius phaeopus	G
275	White-breasted Nuthatch	Sitta corolinensis	G
276	White-crowned Sparrow	Zonotrichia leucophrys	G
277	White-faced Ibis	Plegadis chihi	YB
278	White-rumped Sandpiper	Calidris fusciocollis	G
279	White-tailed Ptarmigan	Lagopus leucurus	G
280	White-throated Sparrow	Zonotrichia albicollis	G
281	White-winged Crossbill	Loxia leucoptera	G
282	White-winged Scoter	Melanita fusca	G
283	Whooping Crane	Grus americana	R
284	Willet	Catoptrophorus incanus	YB
285	Willow Flycatcher	Empidonax traillii	U
286	Willow Ptarmigan	Lagopus lagopus	G
287	Wilson's Phalarope	Wphalaropus tricolor	G
288	Wilson's Warbler	Wilsonia pusilla	G
289	Winter Wren	Troglodytes troglodytes	G
290	Wood Duck	Aix sponsa	G
291	Yellow Rail	Cotornicopus novoboracensi	U
292	Yellow Warbler	Dendroica petechia	G
293	Yellow-bellied Flycatcher	Empidonax flaviventris	U
294	Yellow-bellied Sapsucker	Sphyrapicus varius	G
295	Yellow-breasted Chat	Icteria virens	YB
296	Yellow-headed Blackbird	Xanthocephalus xanthocephalus	G
297	Yellow-rumped Warbler	Dendroica coronata	G

[1] R - Red List, B - Blue List, YA - Yellow A List, YB - Yellow B List, G - Green List (Alberta Government 1996; The Status of Alberta Wildlife, Pub. I/620p)

Table 5 - List of Alberta Amphibians included in the analysis.

No.	Common Name	Species Name
1	Boreal chorus frog	Pseudacris triseriata
2	Boreal frog	Bufo boreas
3	Canadian toad	Bufo hemiophrys
4	Great plains toad	Bufo cognatus
5	Long-toed salamander	Ambystoma macrodactylum
6	Northern leopard frog	Rana pipiens
7	Plains spadefoot	Spea bombifrons
8	Spotted frog	Rana pretiosa
9	Tiger Salamander	Ambystoma tigrinum
10	Wood Frog	Rana sylvatica

Table 6 - List of Alberta reptiles included in the analysis.

No.	Common Name	Species Name
1	Bullsnake	Pituophis melanoleucus
2	Eastern short-horned lizard	Phrynosoma douglassi
3	Plain hognose snake	Heterodon nasicus
4	Prairie rattlesnake	Crotalus viridis
5	Red-sided garter snake	Thamnophis sirtalis
6	Wandering garter snake	Thamnophis elegans
7	Western painted turtle	Chrysemys picta
8	Western plains garter snake	Thamnophis radix

APPENDIX 2

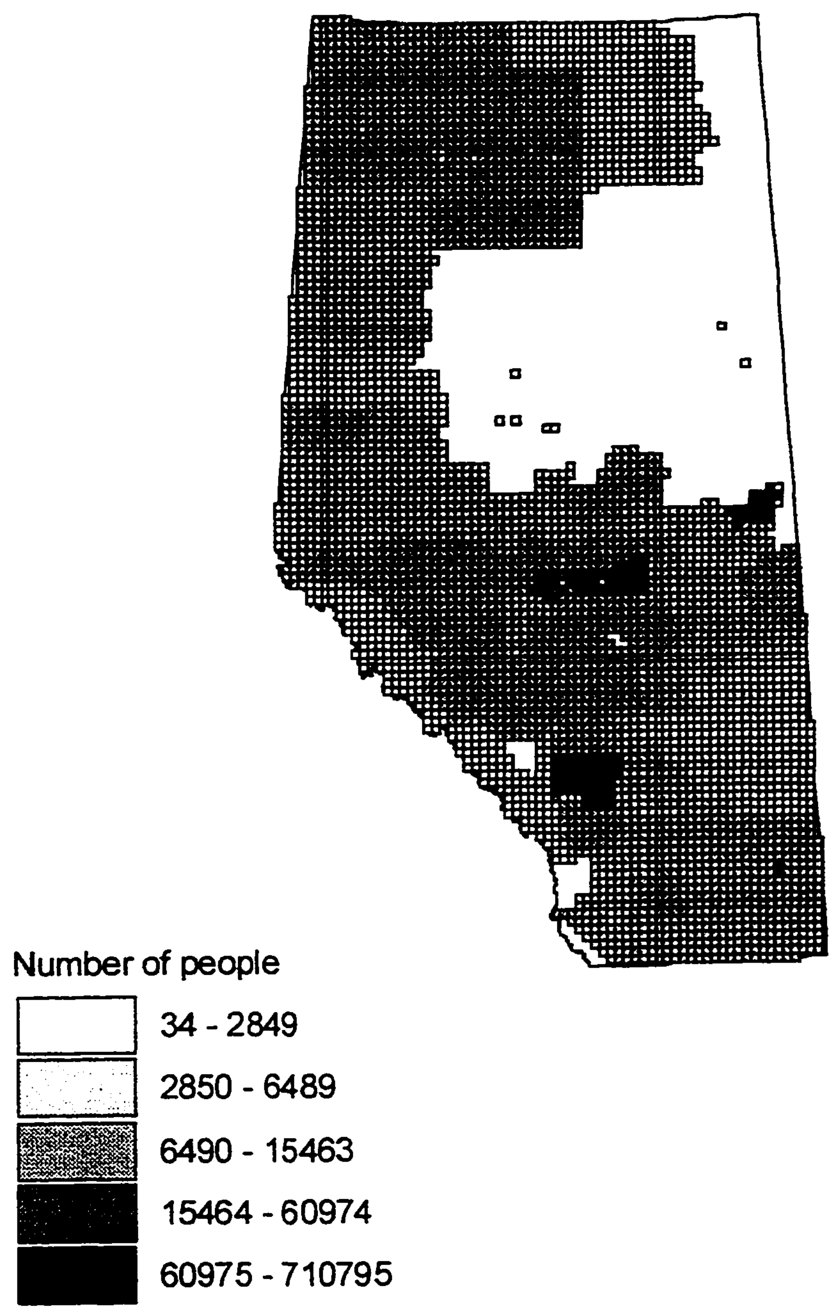


Figure 1. Number of people per 100km² grid cell based on 1991 population census.

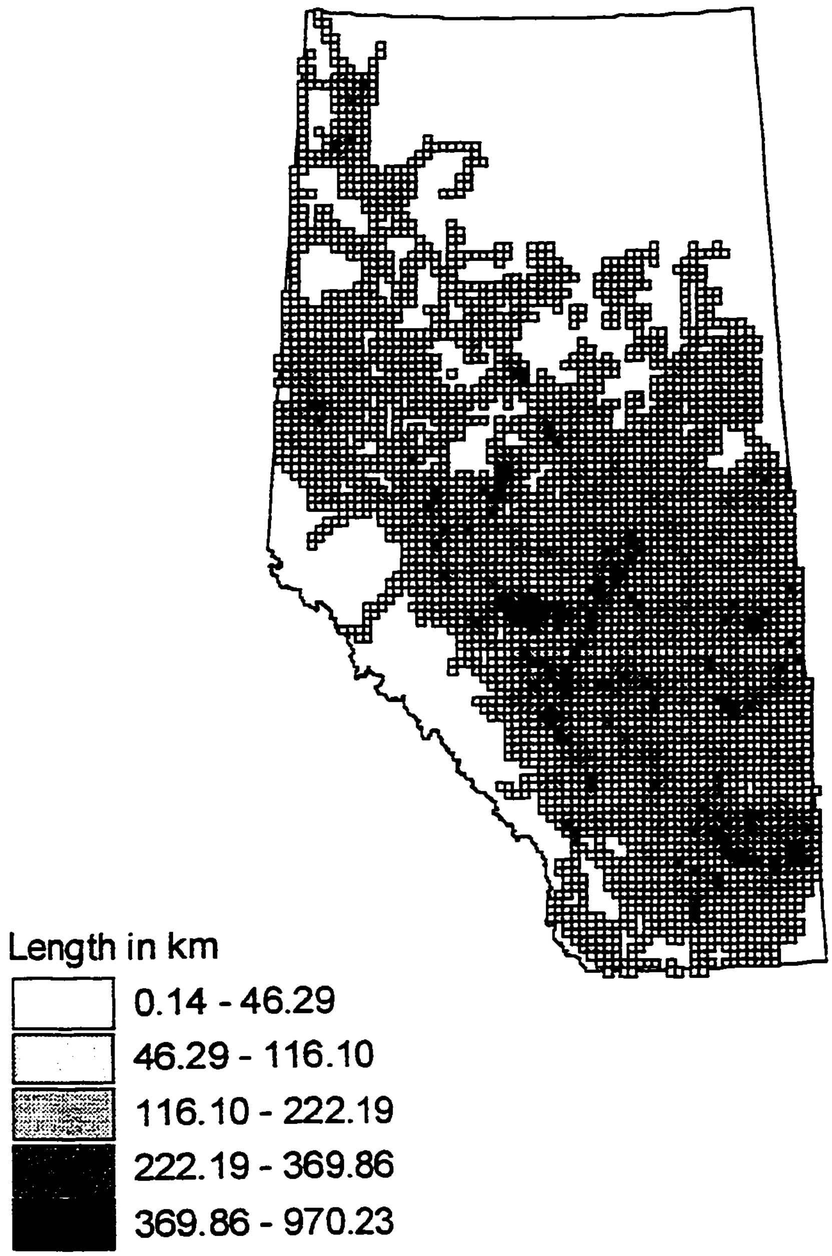


Figure 2. Provincial pipelines per 100km² grid cell (January 28, 1997).

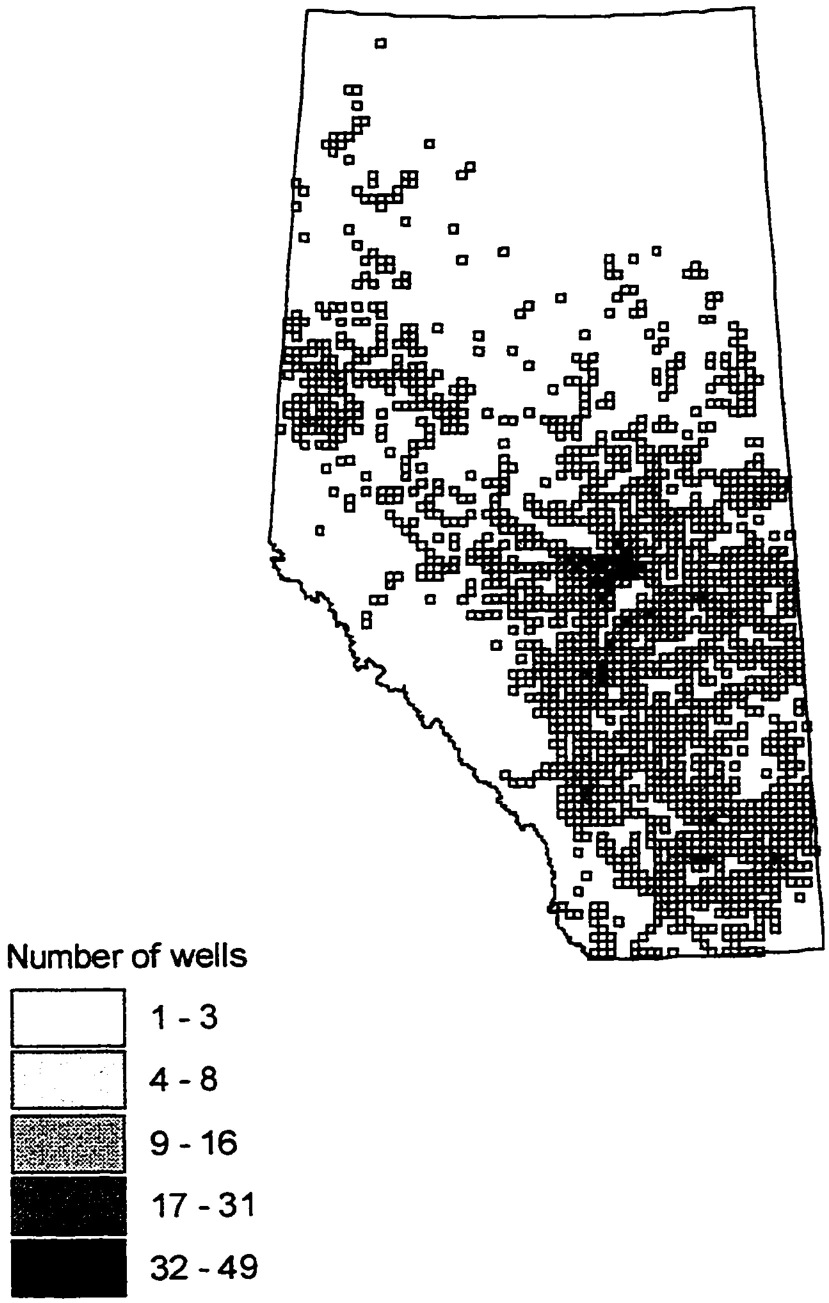


Figure 3. Provincial gas wells per 100km² grid cell (January 28, 1997)

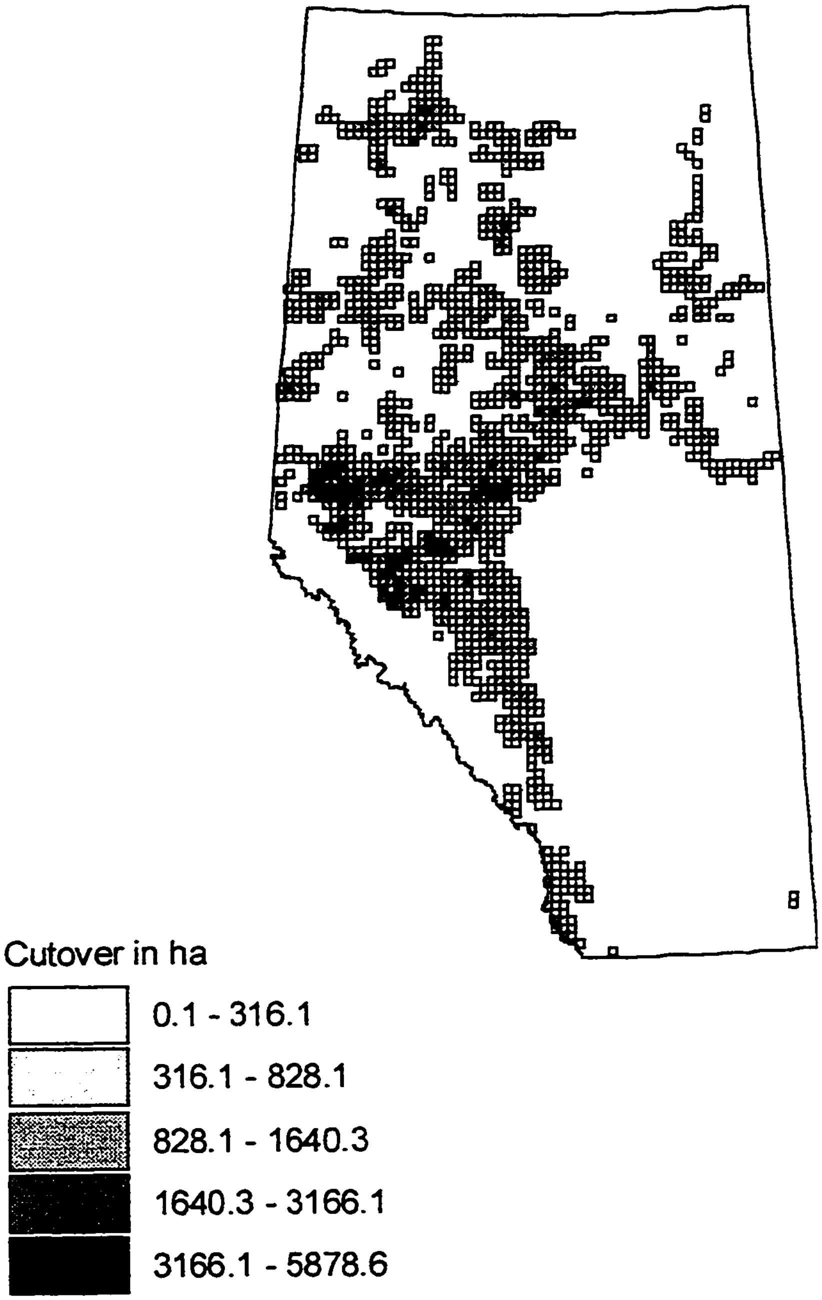


Figure 4. Forestry cutover in 1997 in Alberta per 100km² grid cell.

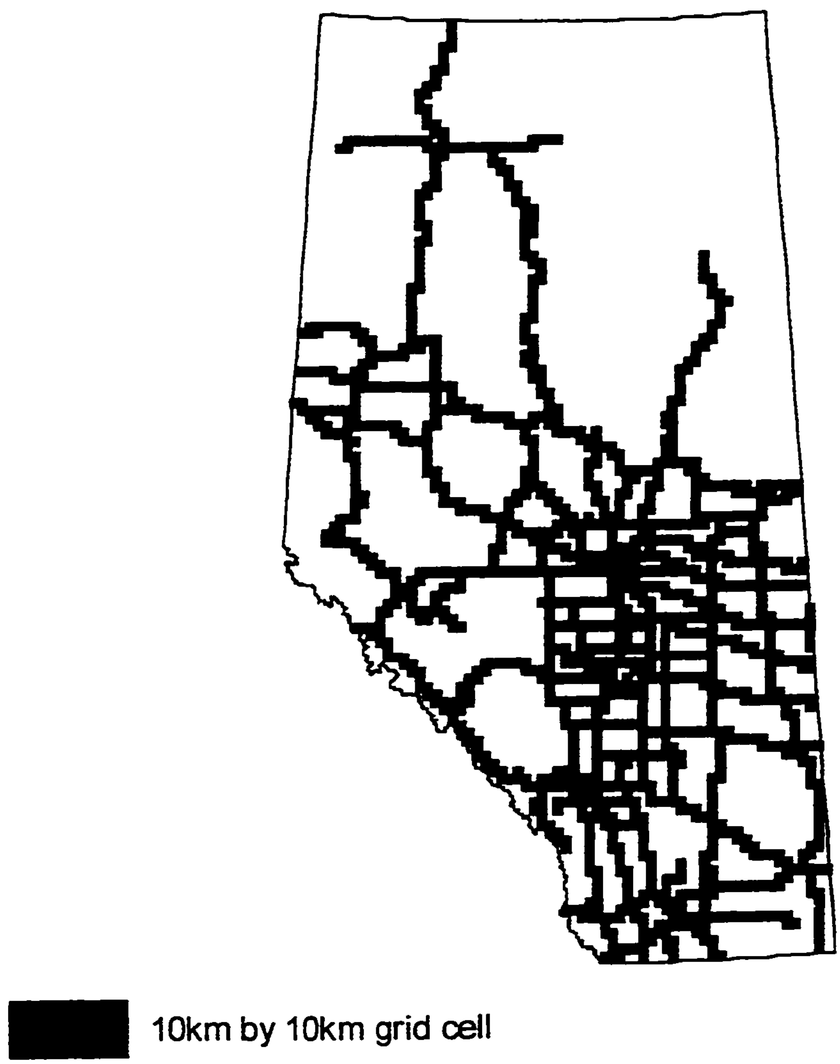


Figure 5. Grid cells that intersect with major Alberta's highways (1997).

Figure 6 . Land ownership in Alberta in 1997 per 100km² grid cell

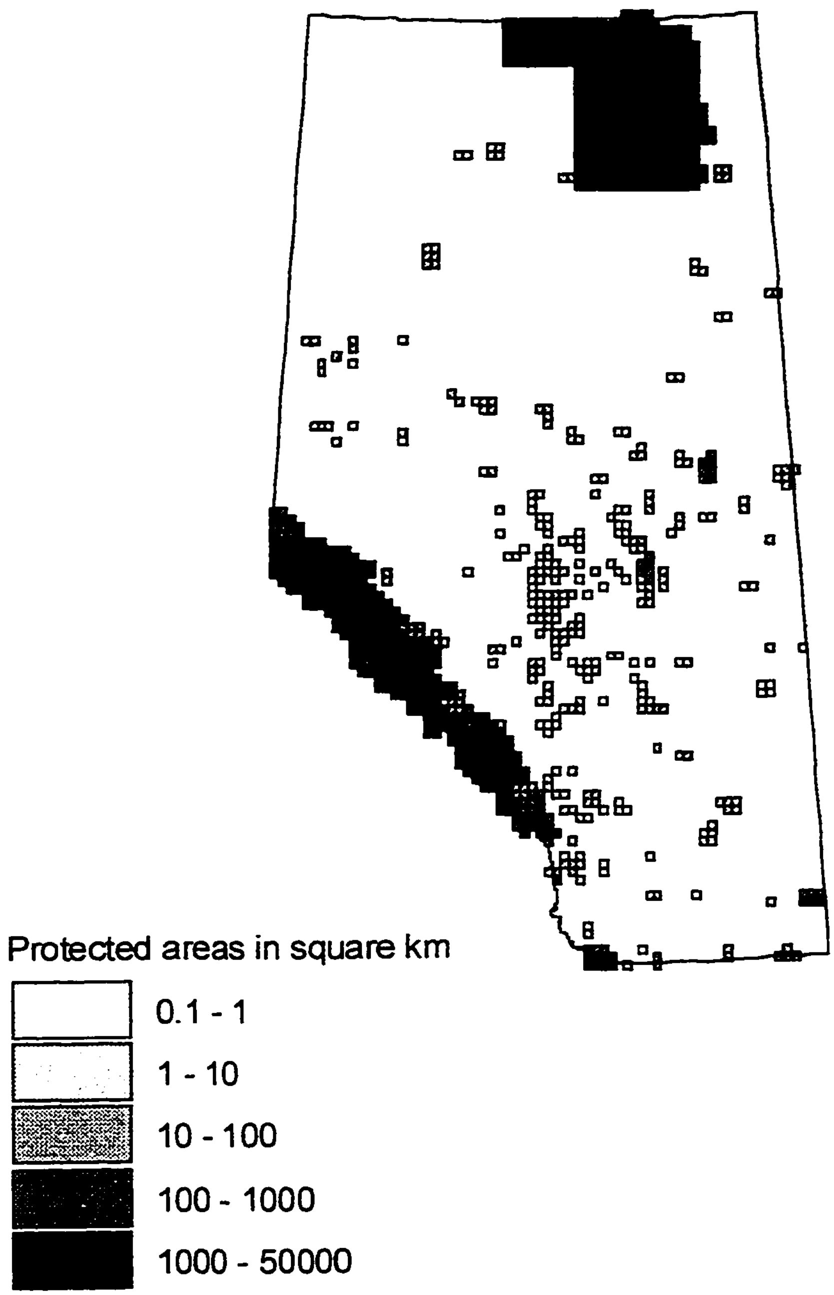


Figure 7. Protected areas in Alberta based on $100km^2$ grid.

APPENDIX 3

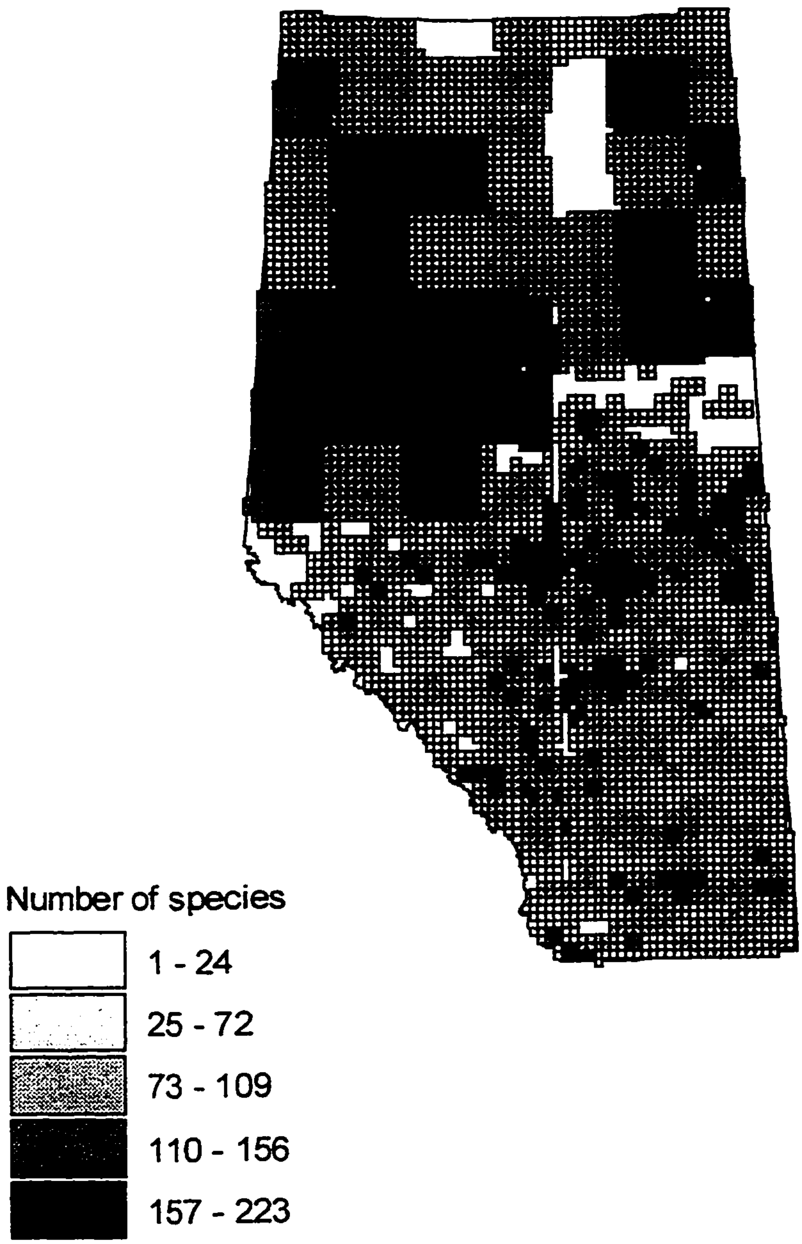


Figure 1. Distribution of birds species richness in Alberta per 100km² grid cell.

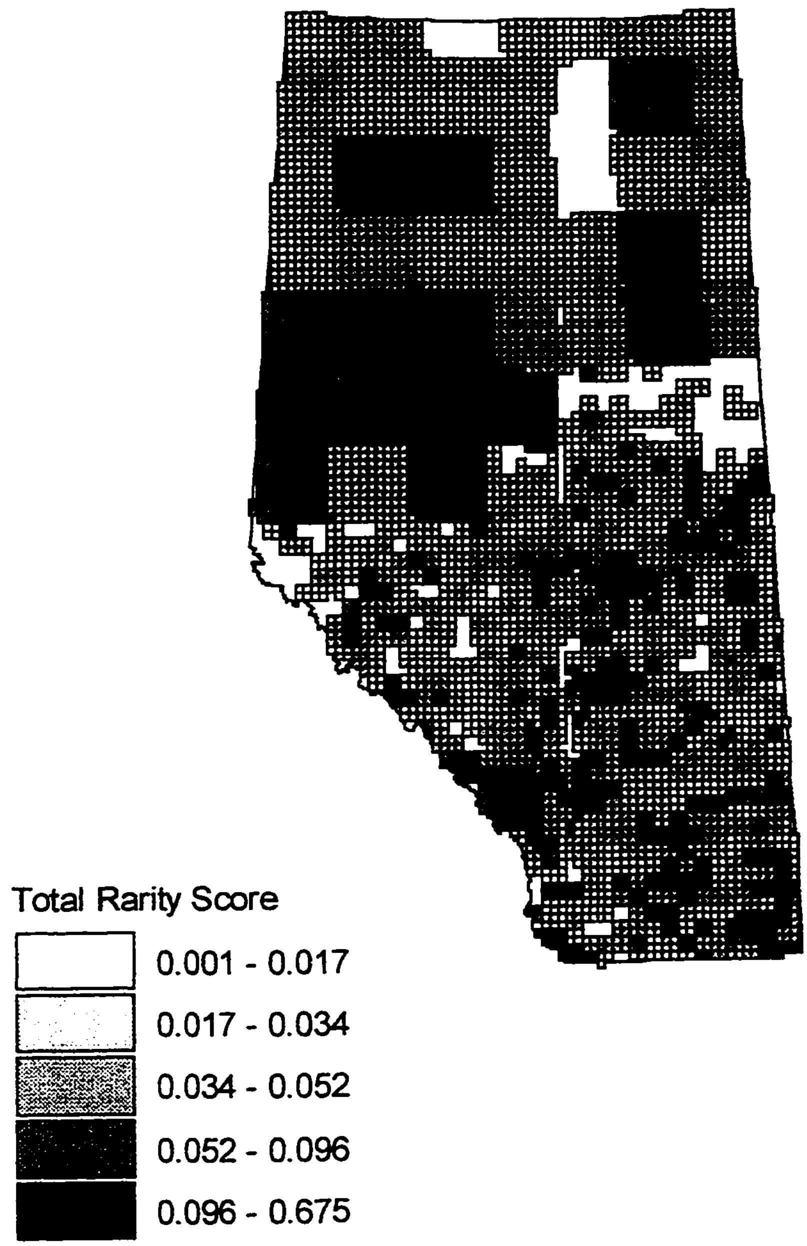


Figure 2. Distribution of total rarity score of birds in Alberta per 100km² grid cell.

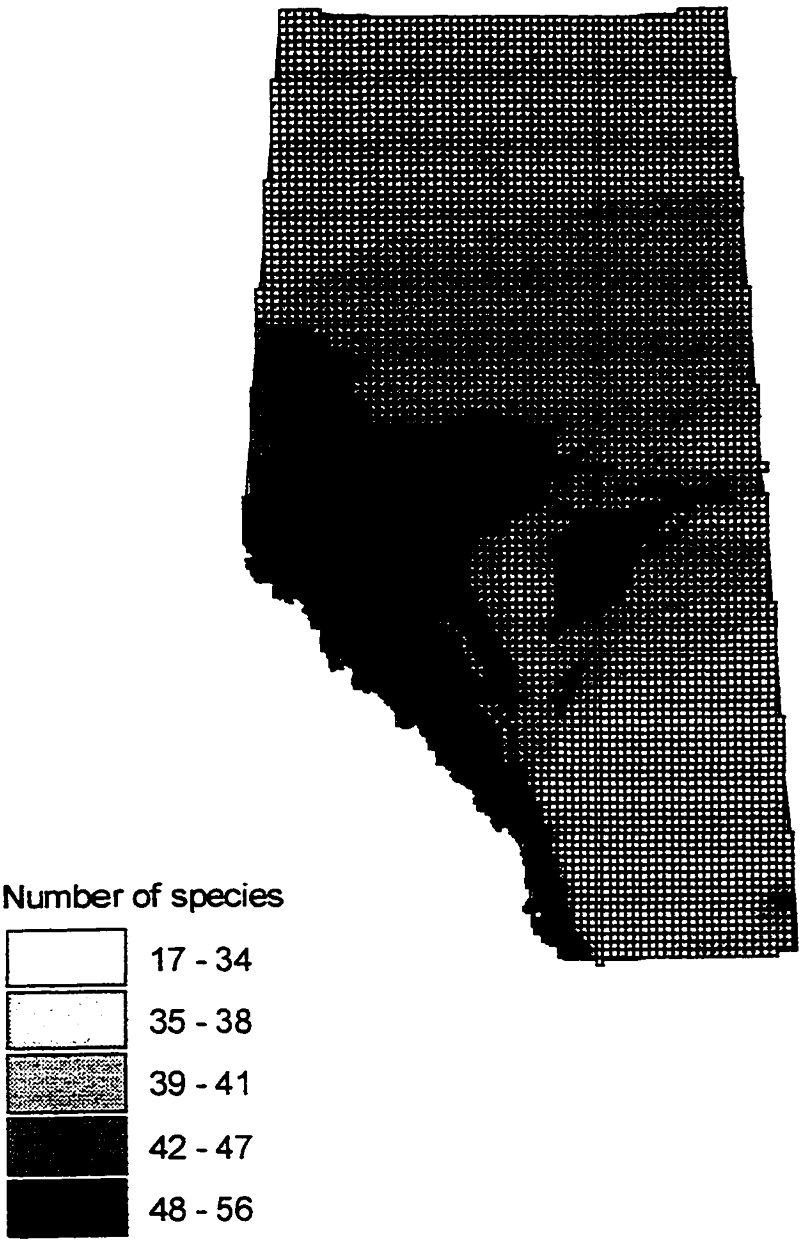


Figure 3. Distribution of mammals species richness in Alberta per 100km^2 grid cell.

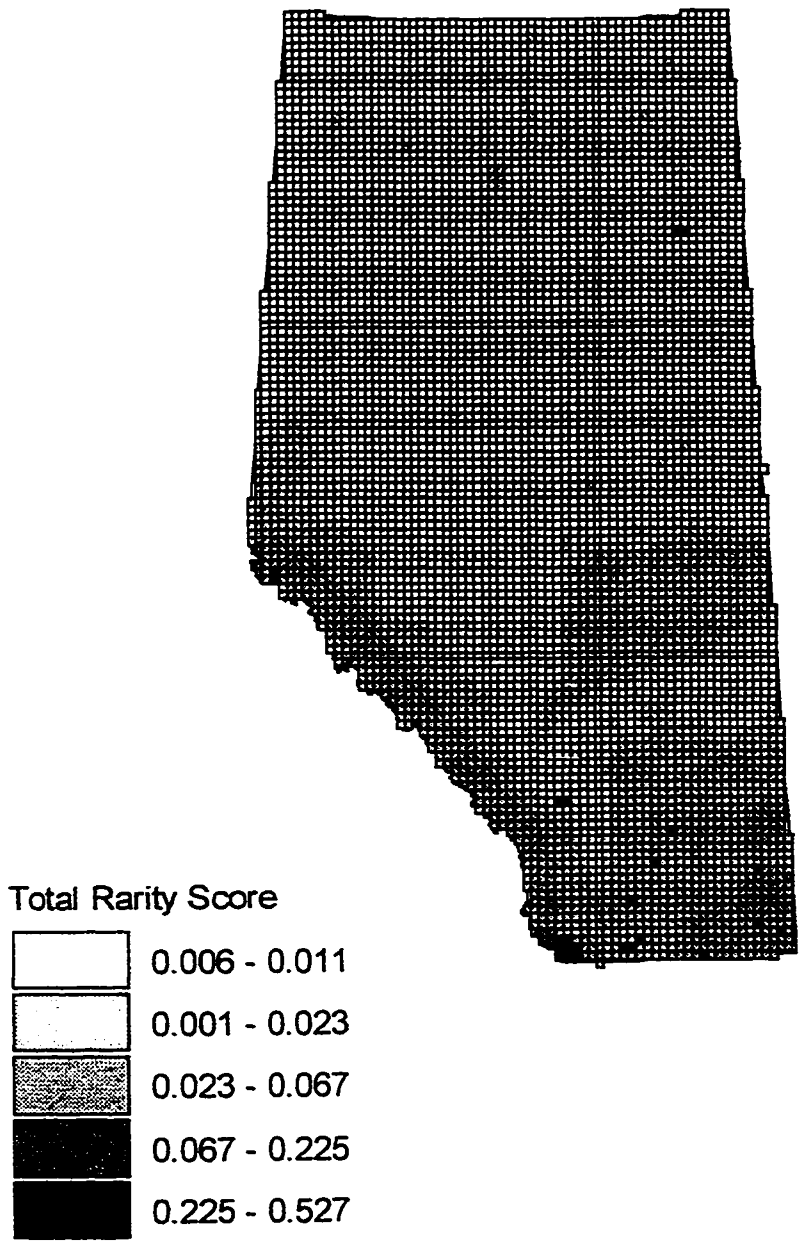


Figure 4. Distribution of total rarity score of mammals in Alberta per 100km² grid cell.

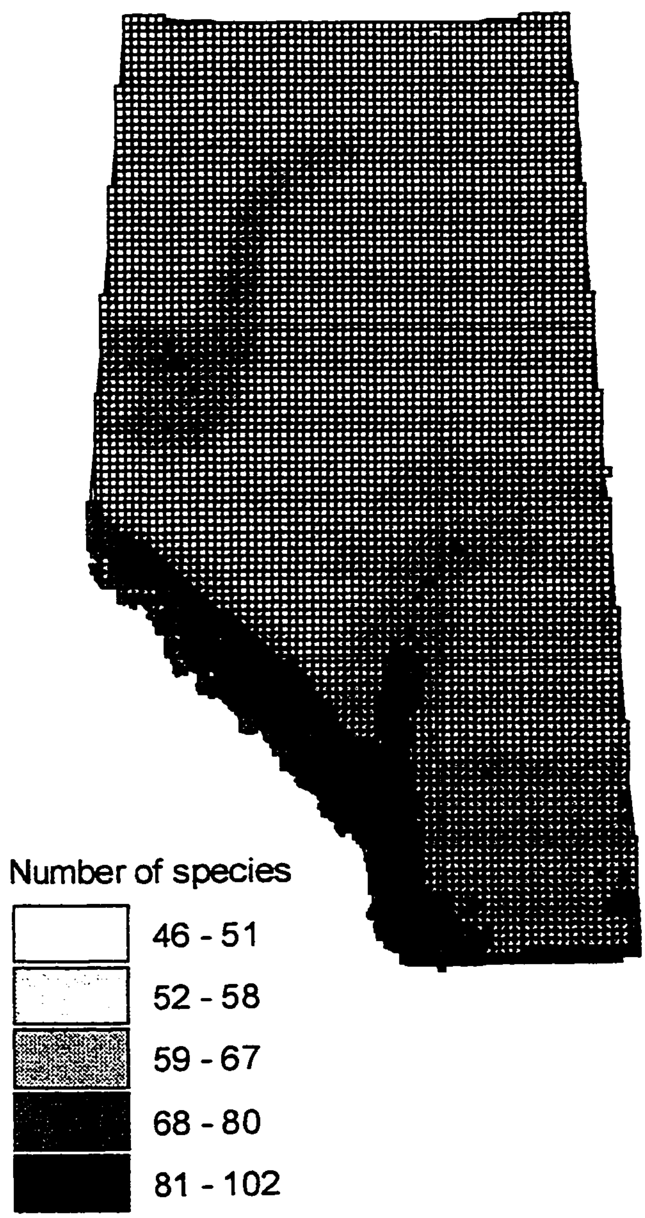


Figure 5. Distribution of butterflies species richness in Alberta.

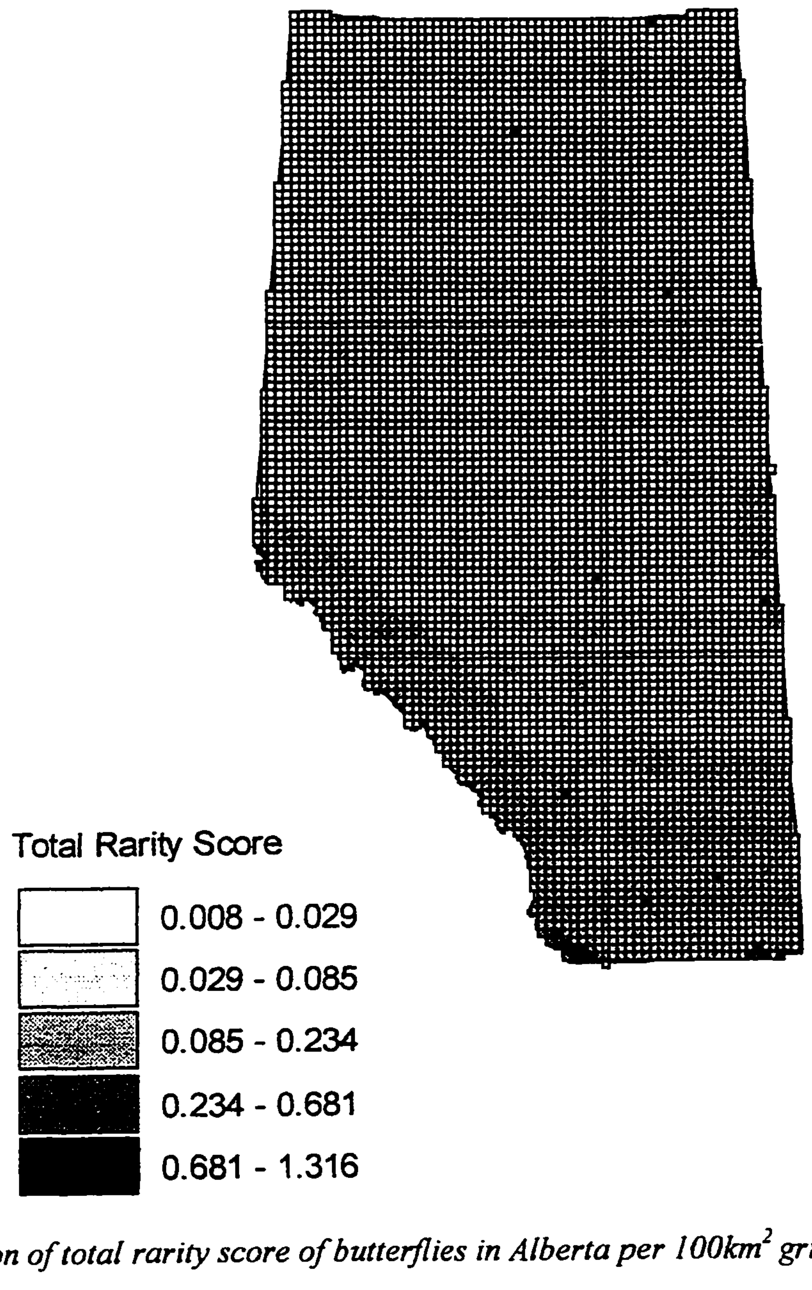


Figure 6. Distribution of total rarity score of butterflies in Alberta per 100km² grid cell.

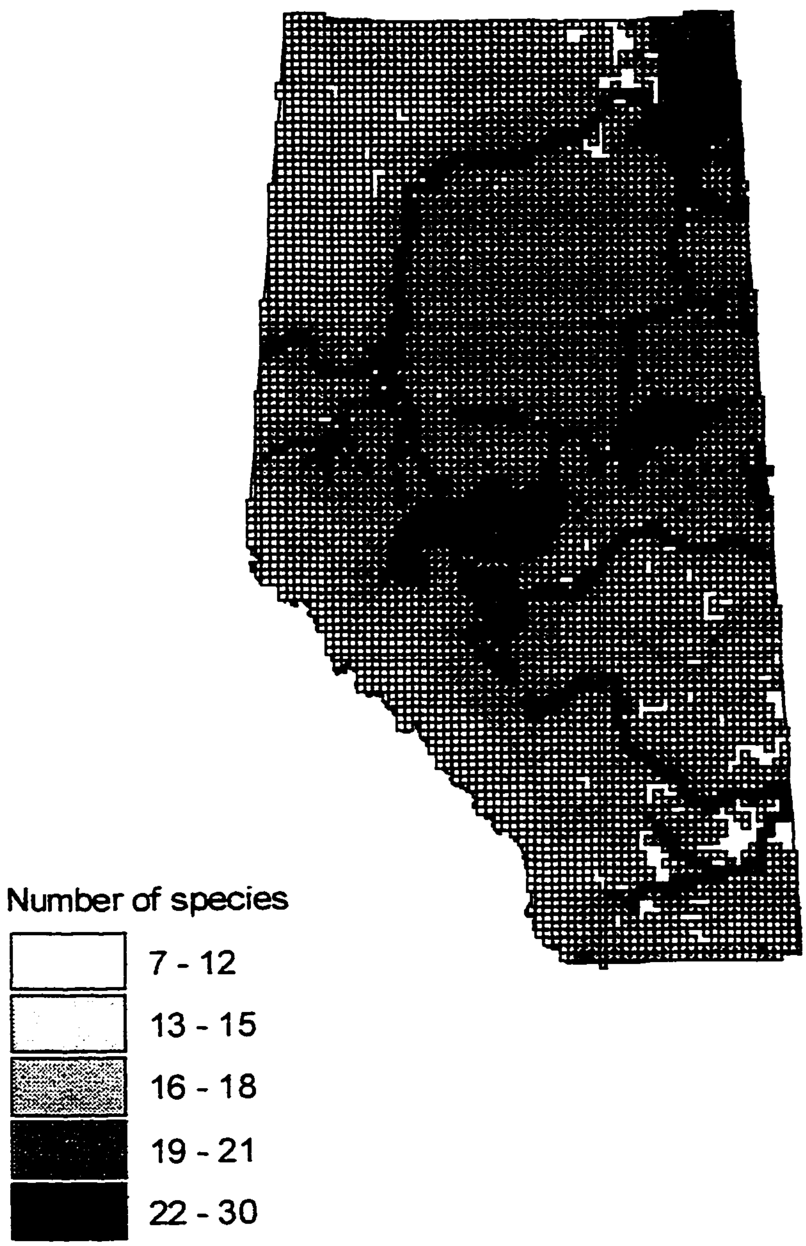


Figure 7. Distribution of fishes species richness in Alberta per 100km² grid cell.

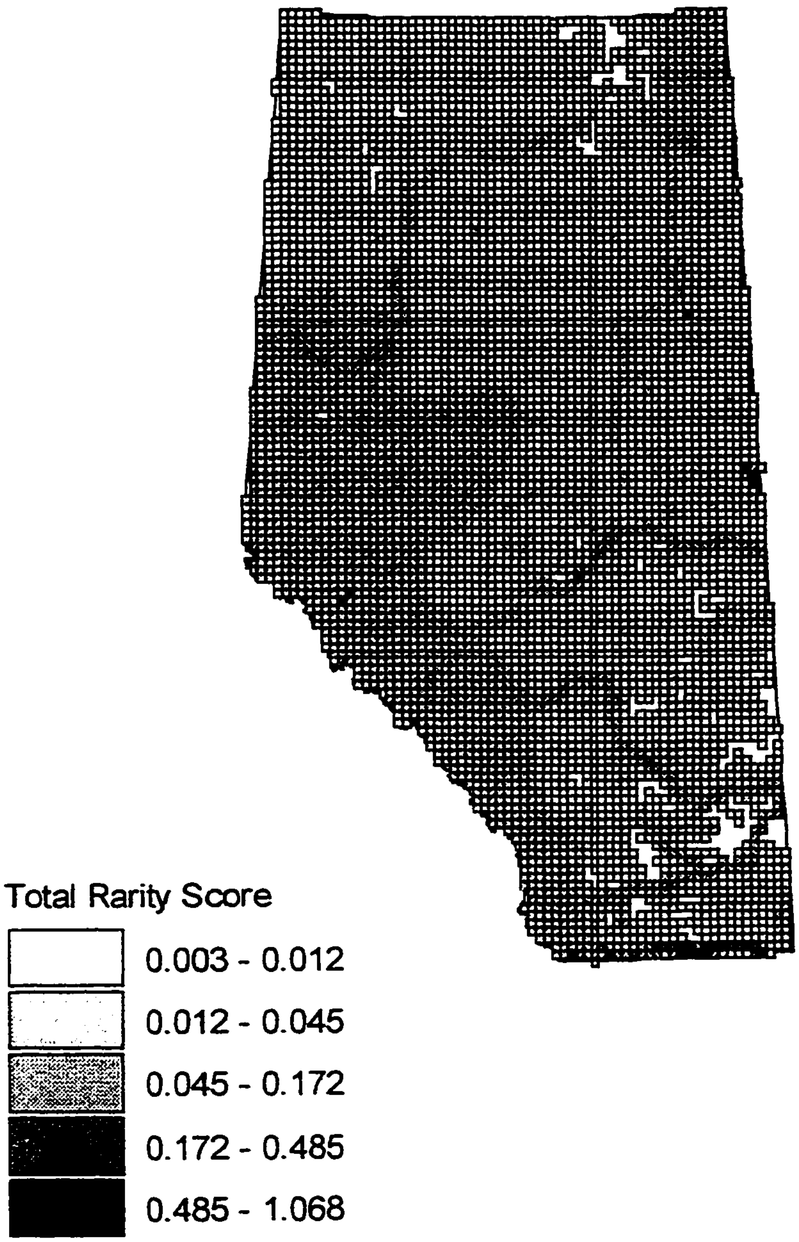


Figure 8. Distribution of total rarity score of fishes in Alberta per 100km² grid cell.

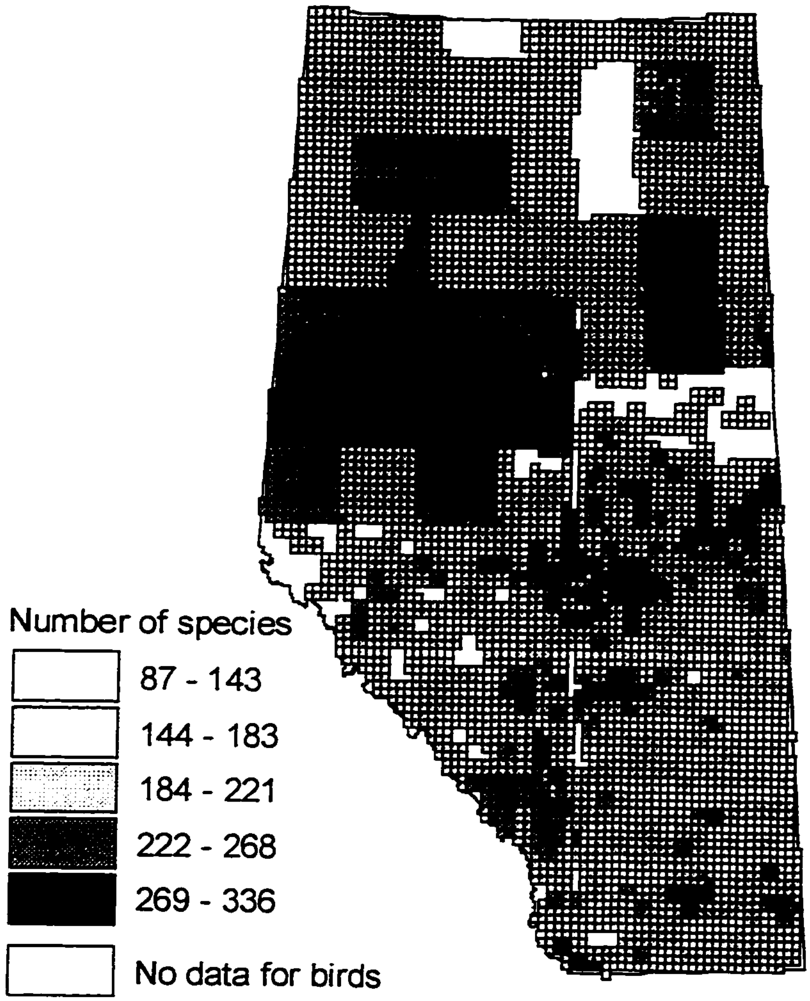


Figure 9. Distribution of centers of species richness of birds, mammals, butterflies, and fishes in Alberta per $100km^2$ grid cell.

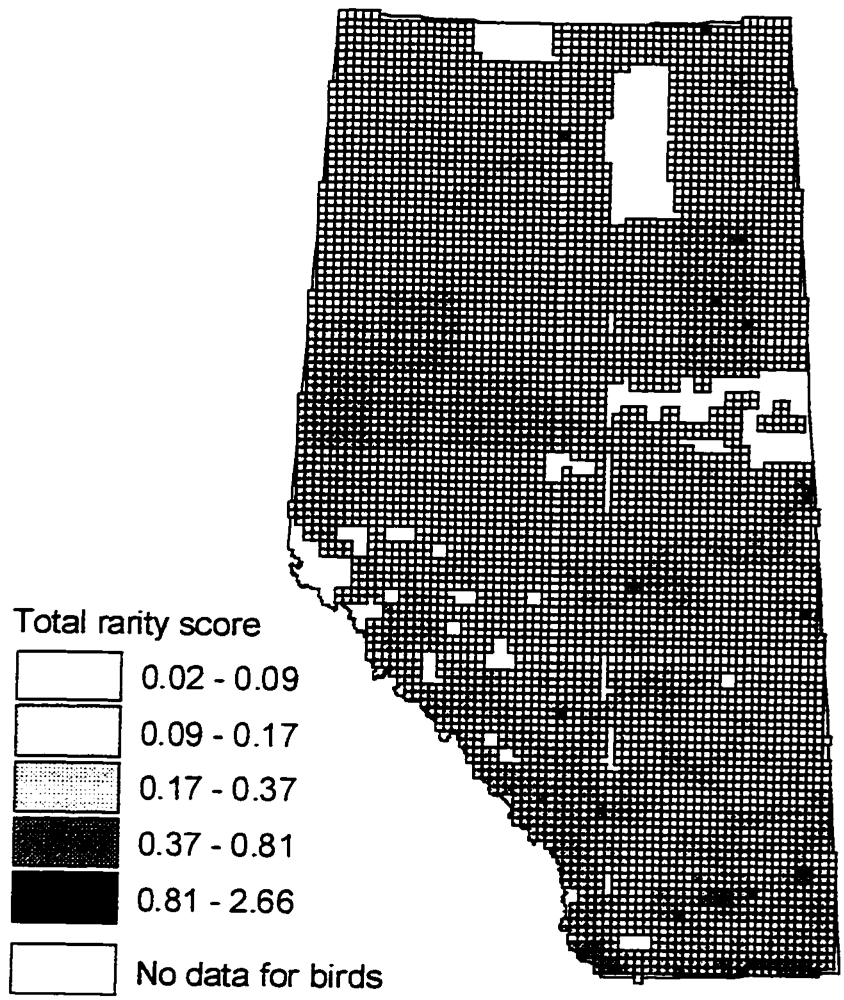


Figure 10. Distribution of total rarity scores of birds, mammals, butterflies, and fishes in Alberta per 100km² grid cell.

APPENDIX 4

Table. 1. List of natural features underrepresented in the current protected areas system based on 10% provincial species range representation goal.

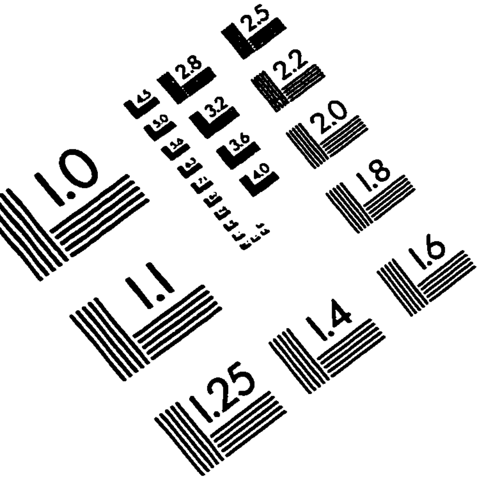
No.	Common Name	Representation goal (number of cells)	% range represented
1	Clark's Grebe	1	0.000
2	Common Poorwill	1	0.000
3	Sabine's Gull	1	0.000
4	Sage Thrasher	1	0.000
5	American Black Duck	1	0.000
6	Least Skipper	1	0.000
7	Purple Azur	1	0.000
8	Ochreous Ringlet	1	0.000
9	Moss' Elfin	1	0.000
10	Question Mark	1	0.000
11	Grizzled Skipper (W.)	1	0.000
12	Eyed Brown	1	0.000
13	Arctic Fox	1	0.000
14	Wandering Shrew	1	0.000
15	White-faced Ibis	2	0.000
16	Gyrfalcon	12	4.167
17	Ross's Goose	36	4.167
18	Northern Hawk-owl	161	4.348
19	Glaucous Gull	11	4.545
20	Bay-breasted Warbler	49	4.694
21	Harris' Sparrow	61	4.754
22	Lesser Golden Plover	91	4.945
23	Smith's Longspur	2	5.000
24	Hobomok Skipper	4	5.000
25	Whimbrel	12	5.000
26	**Canadian Shield**	16	5.000
27	Lapland Longspur	78	5.000
28	Snow Goose	109	5.046
29	**Foothills**	96	5.208
30	Yellow-bellied Flycatcher	126	5.397
31	Sharp-tailed Grouse	204	5.490
32	White-rumped Sandpiper	45	5.556
33	Sanderling	66	5.606
34	Redside Shiner	16	5.625
35	Yellow-bellied Marmot	23	5.652
36	Baird's Sandpiper	97	5.773
37	Buff-breasted Sandpiper	12	5.833
38	Greater White-fronted Goose	103	5.922
39	Blackburnian Warbler	41	6.098
40	McCown's Longspur	18	6.111

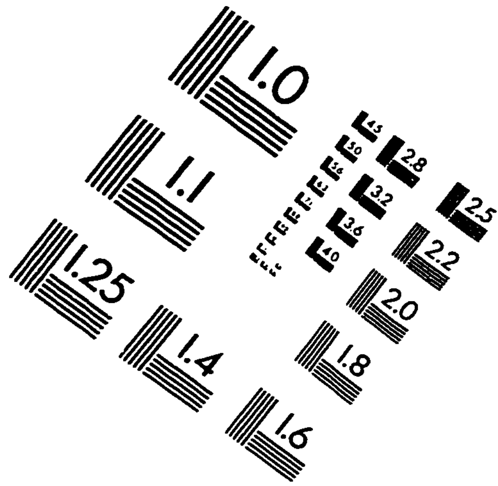
41	**Grassland**	96	6.146
42	Great Gray Owl	186	6.183
43	Chestnut-collared Longspur	53	6.226
44	Dunlin	11	6.364
45	Oslar's Roadside Skipper	28	6.429
46	Rough-legged Hawk	114	6.491
47	Oldsquaw	41	6.585
48	Black-bellied Plover	88	6.591
49	Northern Shrike	69	6.812
50	Old World Swallowtails (P.)	22	6.818
51	Alexandra Sulphur	93	6.882
52	Least Sandpiper	104	6.923
53	Pearl Crescent	99	6.970
54	American Avocet	145	7.103
55	Short-eared Owl	129	7.132
56	Ferruginous Hawk	47	7.234
57	Connecticut Warbler	120	7.250
58	Nuttall's Cottontail	68	7.353
59	Pronghorn	66	7.424
60	Uncas Skipper	105	7.429
61	Prairie Vole	47	7.447
62	Eared Grebe	213	7.465
63	Red Knot	12	7.500
64	Long-Billed Curlew	53	7.547
65	Burrowing Owl	83	7.590
66	Western Kingbird	84	7.619
67	Long-billed Dowitcher	60	7.667
68	Western Sandpiper	13	7.692
69	Sagebrush Vole	88	7.727
70	Delaware Skipper	62	7.742
71	Prairie shrew	142	7.746
72	Say's Phoebe	116	7.759
73	Northern Grasshopper Mouse	55	7.818
74	Brewer's Blackbird	423	7.825
75	Acastus Checkerspot	51	7.843
76	Upland Sandpiper	99	7.879
77	House Sparrow	321	7.882
78	Raccoon	172	7.965
79	Cape May Warbler	91	8.022
80	Aphrodite Fritillary	213	8.028
81	Ruddy Copper	61	8.033
82	Trumpeter Swan	133	8.045
83	Willet	101	8.119
84	Silverspotted Skipper	165	8.121

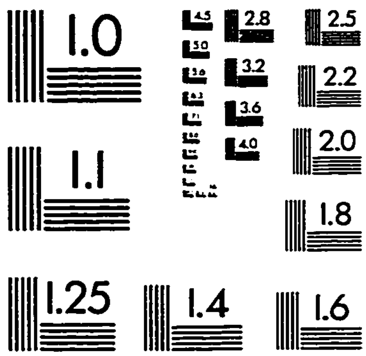
85	Striped Hairstreak	203	8.128
86	Baird's Sparrow	44	8.182
87	Dotted Blue	28	8.214
88	American Tree Sparrow	101	8.218
89	White-tailed Jack Rabbit	158	8.291
90	Evening Grosbeak	238	8.319
91	Red-breasted Merganser	143	8.322
92	Western Meadowlark	259	8.378
93	Lark Bunting	38	8.421
94	Pectoral Sandpiper	96	8.438
95	Marbled Godwit	109	8.440
96	Northern Oriole	328	8.476
97	Gadwall	282	8.511
98	**Parkland**	63	8.571
99	Old World Swallowtails (M.)	121	8.595
100	Peck's Skipper	164	8.598
101	Tawny-edged Skipper	167	8.623
102	Horned Lark	168	8.690
103	Albrta Arctic	192	8.698
104	Common Branded Skipper (L.)	174	8.793
105	Eurasian Wigeon	25	8.800
106	Surf Scoter	105	8.857
107	Vesper Sparrow	298	8.893
108	Tawny Crescen	234	8.932
109	Double-crested Cormorant	196	8.980
110	Lake Trout	10	9.000
111	Lark Sparrow	40	9.000
112	Long-eared Owl	64	9.063
113	Red-throated Loon	11	9.091
114	Garita Skipper	167	9.102
115	House Wren	324	9.105
116	Blue Jay	249	9.116
117	Gray-cheeked Thrush	23	9.130
118	Silver-bordered Fritillary	104	9.135
119	Western Small-footed Bat	49	9.184
120	Great Gray Copper	176	9.205
121	Gray Partridge	129	9.225
122	Mourning Dove	234	9.274
123	Richardson's Ground Squirrel	197	9.340
124	Ring-necked Pheasant	123	9.350
125	Afranius Duskywing	81	9.383
126	Olympia Marble	81	9.383
127	Loggerhead Shrike	82	9.390
128	Barred Owl	74	9.459

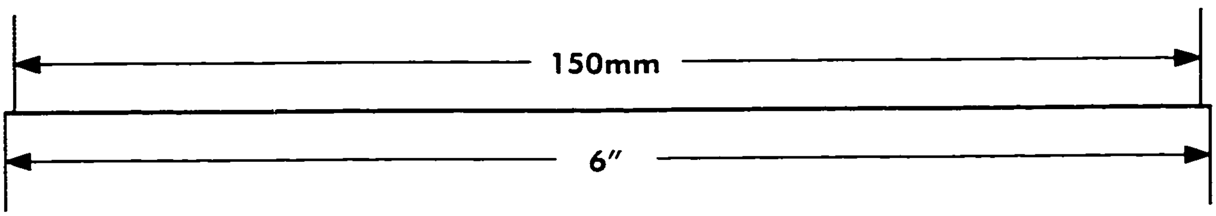
129	Swainson's Hawk	168	9.464
130	Virginia Rail	20	9.500
131	American Redstart	329	9.514
132	Acadian Hairstreak	48	9.583
133	Bobolink	26	9.615
134	Redhead	260	9.654
135	Sprague's Pipit	69	9.710
136	American Goldfinch	301	9.767
137	Checker Skipper	167	9.820
138	Lesser Yellowlegs	373	9.866
139	Uhler's Arctic	236	9.958

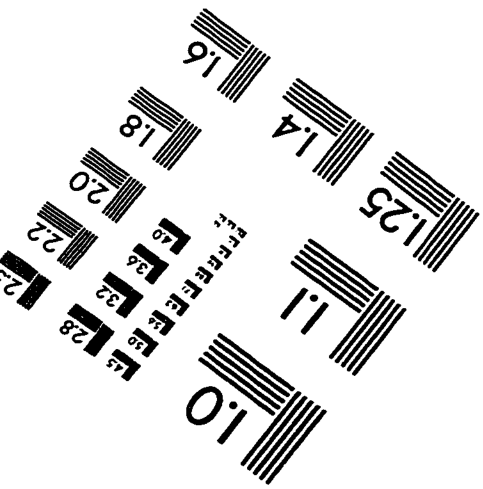
IMAGE EVALUATION TEST TARGET (QA-3)

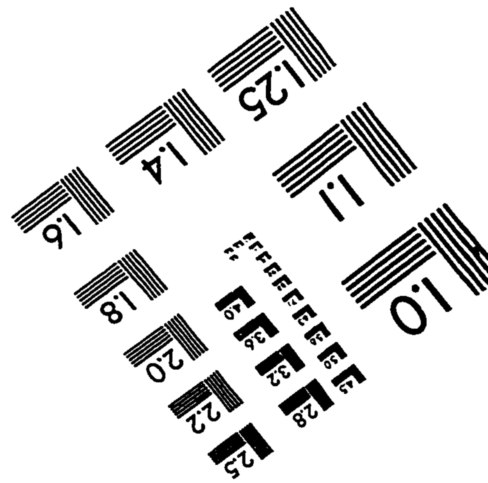












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