Title of Thesis: Investigating Landscape Change and Ecological Restoration: An Integrated Approach Using Historical Ecology and Geographical Information Systems in Waterton Lakes National Park, Alberta.

Author: ________________________________
Lisa Marie Levesque

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Investigating Landscape Change and Ecological Restoration:

An Integrated Approach Using Historical Ecology and GIS in Waterton Lakes National Park, Alberta

by

Lisa Marie Levesque
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ABSTRACT

This thesis examines landscape change from 1889 to the present within the foothills-parkland ecoregion of Waterton Lakes National Park (WLNP) in southwestern Alberta, Canada. Land cover dynamics are explored qualitatively and quantitatively using Geographical Information Systems and a combination of historical and contemporary data sources including: (1) Dominion Land Survey (DLS) transect records (1889), (2) repeat oblique photographs (1914 and 2004) and repeat aerial photography (1939 and 1999). Results indicate a consistent increase in woody vegetation cover, particularly aspen forest cover, within the foothills-parkland since 1889, largely at the expense of native grasslands. The primary drivers of these changes likely include: climatic influences, changes to the historical grazing regime, the suppression of natural fire cycles and the cessation of First Nations' land management practices. This research illustrates the value of integrating multiple historical data sources for studying landscape change in the Canadian Rockies, and explores the implications of this change for ecological restoration in the foothills-parkland of WLNP.

Supervisory Committee:

Dr. Eric Higgs, School of Environmental Studies (Co-supervisor)

Dr. Peter Keller, Department of Geography (Co-supervisor)

Dr. Nancy Turner, School of Environmental Studies (Committee member)

External Examiner:

Dr. Phil Burton, Canadian Forest Service

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CHAPTER ONE

Introduction

1.1 Background

Despite remaining some of the most remote and unaltered landscapes in Canada, a combination of human and environmental forces have been continuously transforming the ecosystems of the Canadian Rocky Mountains for millennia. Understanding the magnitude, character and implications of ecological change over time is challenging, and requires thorough investigation into both human and ecological histories. This thesis explores such ecological change over the past century of Euro-Canadian settlement within the foothills-parkland ecoregion of Waterton Lakes National Park (WLNP) in southwestern Alberta, Canada. More specifically, it examines land cover dynamics, particularly aspen forest dynamics, using multiple historical and contemporary data sources (i.e., documents and photographs) in an attempt to tease out a nuanced picture of landscape history in this region of the Park, and considers the implications of long-term ecological change for ecosystem management and restoration within WLNP.

Notable shifts in vegetation patterns at the landscape scale over the past century are increasingly being recognized and studied by land managers and researchers across North America. Recent efforts (i.e., the past 10-15 years) in the Canadian Rockies have focused on describing and documenting ecological change with the goal of more effectively linking land cover patterns with the myriad causal processes affecting them. In Waterton Lakes National Park (WLNP) in Alberta, Canada, historical photographs dating from 1914 reveal very different landscapes in the early 20th century than those which exist today, over 90 years later. There remains, however, a distinct lack of detailed, spatially explicit information about these historical landscapes. If Parks Canada managers are to effectively fulfill their recent commitment to "restore vegetation dynamics and patterns reflecting long-term ecosystem states and processes" in

WLNP (Parks Canada 1999:4), thorough investigations into such long-term landscape dynamics and trends are needed.

Throughout the Rocky Mountain region, trembling aspen (*Populus tremuloides* Michx.; Salicaceae) ecosystems have been the focus of a substantial amount of research in recent years. Aspen dominated ecosystems are an important component of both the montane and aspen-parkland ecoregions, providing critical habitat for a diverse array of plant and animal species (Achuff *et al.* 2002; Stohlgren *et al.* 2002). Many researchers are concerned that these systems are in a rapid state of decline, both in vigour and areal extent, in a number of landscapes across western North America. Because of this, their restoration and conservation has become a major research focus and management priority in the Rocky Mountains (Bartos and Campbell 1998; Hessl and Graumlich 2002; Kay 1997; Kay *et al.* 1999; Manier and Lavin 2002; Ripple and Larsen 2000; Sheppard *et al.* 2001; Suzuki *et al.* 1999; White *et al.* 1998, 2003).

Conversely, other research has documented aspen expansion into grassland areas in the aspen-parkland (Bailey and Wroe 1974; Bailey *et al*. 1990), montane (Manier and Lavin 2002; Romme *et al.* 1997; Quinn and Wu 2001) and subalpine (Elliot and Baker 2004) ecoregions, indicating that the decline of aspen may not be universal across this species' wide geographical and ecological range. The seemingly contradictory evidence also suggests the need for focusing aspen-related research at a local scale, particularly in the Rocky Mountain Foothills where contemporary studies are scarce. The cessation of historical fire regimes, changes to historical grazing patterns, and differential responses to climate change are thought to be the most influential drivers of aspen population dynamics, although direct causal relationships often remain elusive (Bird 1961; Sheppard *et al.* 2001).

The foothills-parkland ecoregion in southwestern Alberta contains unique assemblages of vascular plants and provides crucial habitat for numerous bird and animal species in WLNP (Achuff *et al.* 2002). It also has significant cultural value as one of the most heavily used areas of the Park, both by present-day residents and visitors, and by First Nations people for thousands of years prior to the Park's establishment in 1895 (Reeves and Peacock 2001). Intense pressure from agriculture, ranching activities and infrastructure development throughout the prairies and aspen parklands of Alberta has irreversibly altered a large proportion of prairie ecosystems, and the native grasslands in the foothills-parkland ecoregion of WLNP constitute one of the few remaining tracts of federally protected native fescue (*Festuca* spp.*)* grassland in Canada (Bradley and Wallis 1996; Parks Canada 1999).

Forest expansion is a growing concern where the conservation and restoration of native grasslands and other openland habitat have been identified as management priorities (Barrett 1996; Bradley and Wallis 1996; Bruvn *et al.* 2001). The importance of "preserving areas of native grassland vegetation for study purposes in as nearly as possible their natural state" was recognized as early as 1917 when the Ecological Society of America (ESA) set up a committee for the preservation of natural conditions (Bird 1961:47). Despite these early warnings, intensive agricultural and human development have continued practically unabated, making it increasingly difficult to find sizeable areas of intact native grasslands in the Canadian Prairies. As Forsyth (1983:78) eloquently describes:

> "Within one human lifetime, the prairies have passed from wilderness to become the most altered habitat in this country, and one of the most disturbed, ecologically simplified and overexploited regions of the world. The essence of what we risk losing when the grasslands are destroyed is not a species here or a species there, but a quality of life, the largeness and wildness that made this country remarkable".

In WLNP, anecdotal evidence and historical photography suggest that forest expansion into grassland areas has been steadily occurring over the past century in many areas of the Park, and the foothills-parkland in particular. Current conservation objectives may therefore necessitate land management and restoration strategies that reduce the extent of aspen and restore historical levels of open grassland. However, the goal of restoring past ecosystem states and processes inevitably begs the question: to what are we restoring? In other words, what reference conditions can or should be used for restoration?

1.2 Defining Reference Conditions

Egan and Howell (2000:1) note that the fundamental aspect of ecosystem restoration is learning how to rediscover the past and bring it forward into the present – to determine what needs to be restored, why it was lost, and how best to make it live again. This complex question is perhaps the most contentious issue in current restoration discourse, and has led to considerable discussion regarding the identification of appropriate reference conditions for restoration initiatives, and the concept of identifying a "historical range of variability" for a particular ecosystem (Egan and Howell 2001; Higgs 2003; Hobbs and Norton 1996; Landres *et al.* 1999; Moore *et al.* 1999; Swetnam *et al.* 1999; White and Walker 1997). This is clearly a formidable task. The inherently dynamic and complex nature of ecological systems makes the mere delineation of the "ecosystem" for which these conditions should be identified unclear and open for debate. Moreover, whether or not changes observed over the past century are "significant" with respect to historical precedents is a question not easily answered, especially given the often incomplete or subjective nature of the historical proxy data used to make inferences about long-term (i.e., hundreds to thousands of years) historical conditions (Swetnam *et al.* 1999). Deciding upon the most appropriate temporal scale of inquiry is also challenging given the inherently dynamic nature of climate cycles and the sometimes poorly understood and potentially unforeseen ecological responses to climatic changes (Beaudoin 1999).

The many impacts of Euro-Canadian settlement in the Rockies over the past century have no doubt been influential in shaping landscape patterns. The forced relocation of First Nations peoples, increasing visitor pressure, the extirpation of ecologically critical species, the introduction of non-native species, and the intensification of agriculture, livestock production and resource extraction have all undoubtedly shaped the flow of people and processes on the landscape (Baron 2002). It is, however, very difficult if not impossible to precisely evaluate the relative importance of human and environmental influences in shaping the observed landscape changes. Caution is therefore critical in judging whether any historical condition at a particular point in history is absolutely an appropriate goal for restoration and management. Instead, identifying an appropriate range of historical conditions for a given ecosystem or geographical area will remain a largely adaptive process, one whose goals and direction will be strongly shaped by shifting management goals and priorities and the consideration of emergent information (Higgs 2003).

Using multiple lines of evidence from an array of disciplines will increase confidence in historical interpretations of environmental processes across temporal and spatial scales, and will likely be the most effective approach to studying and identifying reference conditions for conservation and restoration (Egan and Howell 2001; White and Walker 1997). To this end, a number of methods have been developed to reconstruct historical ecological trends, and elucidate the processes shaping them. The study of historic records (e.g., written and oral histories, aerial and oblique photographs, maps, land office surveys), archaeological studies, the analysis and interpretation of "natural archives" or proxy records derived from biological sources (e.g., tree rings, pollen deposits, ice cores), and modern field studies have been combined in various ways to study landscape history, and inform present-day management goals and restoration efforts (Egan and Howell 2001). Long-term vegetation dynamics continue to be a major focus of such research.

1.3 Investigating Forest History

While longer term data as derived from dendrochronology, fire history studies, palynology and ethnobiology, provide the context for defining the historical range of conditions that have existed on a landscape over hundreds or even thousands of years, more detailed information about recent landscape changes may be more applicable for immediate and near future management decisions. To this end, many forest history studies have relied on various combinations of archival materials such as time-series photography (e.g., Gruell 1983a; Kay *et al.* 1999; Rhemtulla *et al.* 2002; Steen 1999; Veblen and Lorenz 1988), historic survey records (e.g., Bickford and Mackey 2004; Bollinger *et al.* 2004; Cogbill *et al.* 2002; Delcourt and Delcourt 1996; Jackson *et al.* 2000, Radeloff *et al.* 1999), and repeat aerial or satellite imagery (e.g., Hester *et al.* 1996; Jackson *et al.* 2000; Kettle *et al.* 2000; Mast *et al.* 1997; Rhemtulla *et al.* 2002) to describe and document changes in vegetation cover over roughly the past century.

While qualitative data sources have provided invaluable information about the nature, extent and visual character of vegetation changes over time, particularly when communicating information to the general public, quantifying the magnitude and rate of this change at the landscape scale provides a measurable foundation for understanding how landscape patterns affect landscape level processes and vice-versa (Gergel and Turner 2002). Land cover mapping using Geographical Information Systems (GIS) or Remote Sensing (RS) programs have been widely used to this end, particularly for analyzing changes in the spatial patterns of forest cover over the past century of Euro-Canadian settlement in North America.

1.4 Thesis Goals and Summary

Despite widespread aspen-related research throughout the Rockies, and despite concerns regarding forest expansion and declining forest health in the lower elevations of WLNP, long-term, spatially explicit investigations into landscape change in southwestern Alberta are lacking. Further, most of the studies that have taken advantage of historic survey documents have been conducted in the eastern U.S. or Australia, and to my knowledge, no similar studies have been published in Canada to date. Analysis of historical data providing qualitative and quantitative information about the landscape history of the WLNP area could therefore provide valuable information for informing the future restoration and management of the unique ecosystem assemblages and processes found there. This study therefore has two main goals: (1) to investigate aspen dynamics in the foothills-parkland ecoregion, and (2) to experiment with combining historical data sources in new ways to study landscape change. Specifically, I addressed the following research questions and objectives:

Research Questions

- Has forest cover, particularly aspen cover, increased in the foothills-parkland ecoregion over the past century in WLNP?
- If an increase in aspen cover has occurred, what primary drivers – biotic, abiotic and cultural – are influencing these landscape dynamics in general, and aspen expansion in particular?
- What options exist for restoring historical ecosystem processes if an earlier ecosystem state is deemed preferable over at least a part of this area?

Research Objectives

- To investigate the potential of combining historical data sources (i.e. survey records and historical photographs) for estimating land cover patterns at the turn of the 20^{th} century.
- To use field observations and a comparison of historical and contemporary land cover maps derived from aerial photos to determine the nature and spatial extent of aspen expansion in the foothills-parkland ecoregion over the past century.
- To investigate the potential human and biophysical drivers of landscape change in the foothills-parkland over the past century.

Three existing data sources were used for this study: (1) Dominion Land Survey (DLS) records (1889); (2) repeat DLS oblique photographic images (1914 and 2004); and (3) repeat aerial photographs (1939 and 1999). Additional land cover data were collected in the field in the spring and summer of 2004. Quantitative analyses using GIS and qualitative observations were combined to characterize landscape change in a large portion of the foothills-parkland ecoregion. Historic (1939) and contemporary (1999) digital land cover maps were developed and analyzed using standard air photo interpretation techniques coupled with GIS. A third map of land cover along the historical (1889) DLS transects was also developed using information from archival field survey notes, and land cover between years was further analyzed using all three maps (i.e. 1889 → 1939 → 1999). Next, repeat oblique photographic imagery was obtained (1914 and 2004), and systematically reviewed to compare land cover between dates. Finally, a pilot study was attempted to superimpose historical DLS transects on both the historic and repeat oblique photographic images in order to explore new possibilities for quantifying land cover change using oblique photographic imagery.

This study is one of the few in Canada to study aspen dynamics at the landscape scale in the aspen parklands, and will contribute to the considerable body of research regarding this remarkably adaptable species. In order to offer some additional context, Chapter Two provides a detailed overview of the ecology and life history of trembling aspen, explores its ecological significance in the Rocky Mountain region, and discusses the factors controlling the vegetation dynamics of aspen-dominated ecosystems. This thesis is also one of the few studies to take advantage of the potentially valuable information available in historic DLS survey data in Canada, and the first that has attempted to combine historical data sources in this way. Chapter Three offers a comprehensive rationale for using multiple data sources to study landscape change, and a more detailed description of the materials and methods used in this study. The results from this research and their wider implications for current and future restoration and conservation in WLNP are provided in Chapter Four. A general discussion addressing the issues surrounding the use of historical information for informing ecological restoration follows in Chapter Five, and Chapter Six offers more general concluding reflections.

CHAPTER TWO

Aspen Ecosystems of the Rocky Mountains: Life History and Ecology

2.0 Introduction

Trembling aspen (*Populus tremuloides* Michx.), a member of the willow family (Salicaceae), is the most widely geographically distributed native tree species in North America, particularly in the western part of the continent where it spans approximately 40 degrees of latitude from northern Mexico to northern Alaska (Peterson and Peterson 1992) (Fig. 2-1). It is found across a remarkable range of environmental and elevational gradients from the drought-prone fringes of the Great Plains to the Arctic treeline in the boreal forest, and from sea level to the alpine treeline in the mountains of the West (Mitton and Grant 1996; Perala 1990).

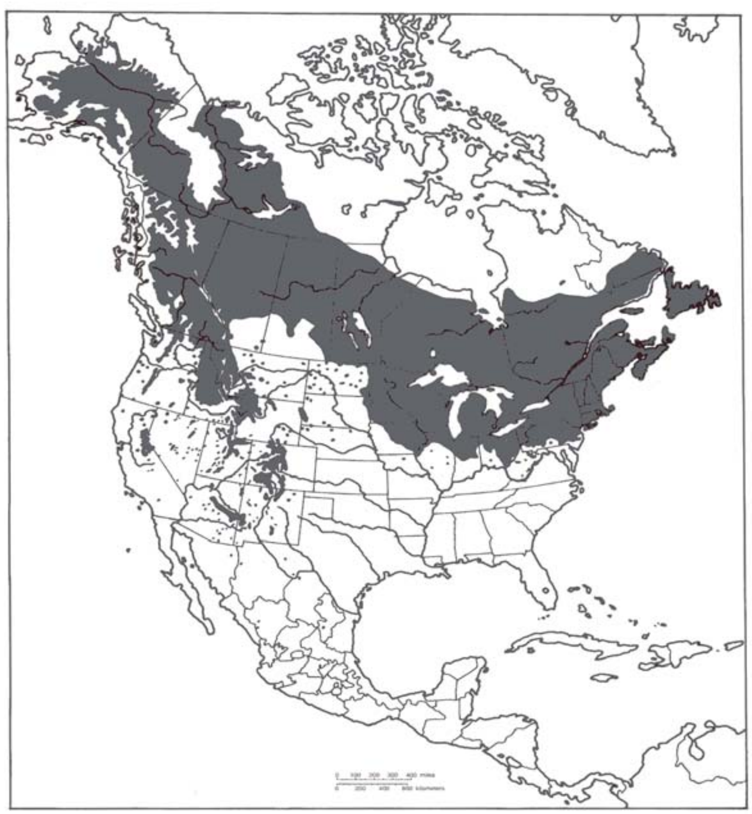

Figure 2-1: Current natural distribution of *Populus tremuloides* Michx. in North America (Peterson and Peterson 1992:4).

Ecologists attribute aspen’s exceptional adaptability to the extremely high genetic diversity characteristic of this species across its geographical range. Aspen may in fact be the most genetically diverse plant species studied to date, able to withstand a wide range of environmental stresses (Lieffers *et al*. 2001; Mitton and Grant 1996).

The majority of aspen-related research in the Rocky Mountains has focused on concerns about the species’ decline. In many areas, advancing forest succession in the absence of fire disturbance over the past century has resulted in the replacement of aspen by coniferous species (i.e., lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*)) (Bartos 2001; Hessl and Graumlich 2002; Kay 1997; Keane *et al.* 2002). Furthermore, growing elk (*Cervus canadensis*) populations are exerting increasing browsing pressure on aspen seedlings and preventing successful regeneration (Bartos and Campbell 1998; Kay *et al.* 1999; Ripple and Larson 2000; Romme *et al.* 1995; Suzuki *et al.* 1999; White *et al.* 1998,2003). Conversely, aspen invasion of grasslands has also been documented either in the absence of fire (Bailey and Wroe 1974; Brown and DeByle 1987; Manier and Lavin 2002) or following major fire events like those that raged through Yellowstone National Park in 1988 (Quinn and Wu 2001; Romme *et al.* 1997). A rare episode of aspen expansion into subalpine meadows has also been recently reported (Elliot and Baker 2004). Clearly, aspen dynamics vary considerably across the species’ wide range, and are invariably controlled by complex interactions with humans, animals, other tree species, climate and fire. Following a brief discussion of aspen life history and ecology, these interactions will be examined in more detail with specific reference to the management history, ecological changes and climate patterns that have shaped Rocky Mountain ecosystems over the past century.

2.1 The Life History of Trembling Aspen

Trembling aspen[1] reproduction can occur both sexually and asexually, and although the species is primarily dioecious (i.e., with male and female catkins on separate trees), some trees can bear a small percentage of perfect flowers (Perala 1990)[2]. Aspen flowers are small and relatively inconspicuous, produced in catkins, and wind-pollinated (Mitton and Grant 1996; Perala 1990). The entire flowering sequence, including pollination, fertilization and seed maturation, is completed in the early spring before the tree leafs out (Mitton and Grant 1996), and local variation in the timing of flowering among clones is common (Perala 1990). Aspen seeds are tiny, buoyed by silky white hairs, and may be carried considerable distances by wind as self-contained, parachuted dispersal units (Mitton and Grant 1996). Seed production begins after two to three years of age, and appears to be positively correlated with age and size of stem (Perala 1990). Large seed crops are produced every four to five years after approximately 20 years of growth, with some old stems being known to produce as many as 54 million seeds in a single season (Mitton and Grant 1996).

Seed viability can be short-lived, and successfully germinated seedlings are delicate and succulent, supported primarily by only a cluster of fine root hairs that require optimal conditions for establishment (Barnes 1966). Adequate moisture is critical for seedling establishment with rapid declines in germination rates corresponding to decreasing soil water potential (Lieffers *et al*. 2001). In relatively arid conditions where soil water holding capacity is low or where strong winds that can rapidly dry out the uppermost soil layer are common, seedlings usually wither and die before their roots reach an abundant and reliable source of water (Mitton and Grant 1996). The availability of safe sites for germination is also a limiting factor. Litter cover and competition

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[1] "Quaking" or "trembling" aspen was so named because of the fluttering of its leaves resulting from the strongly flattened petioles, even in a slight breeze. This fluttering reduces boundary layer resistance to heat transfer, which can cool the leaf and promote CO_2 uptake on hot days. This feature coupled with the small size of *P.tremuloides* leaves allows them to close stomata and avoid water stress during drought periods (Perala 1990).

[2] This percentage varies between sexes, with 20% of predominantly female trees and 5% of predominantly male trees bearing perfect flowers (Perala 1990).

with other species, especially aggressive shrubs and grasses, can greatly reduce seedling survival rates (Bailey *et al.* 1990; Fralish and Loucks 1975). Further, seedling success can be limited as a result of light competition in younger stands with dense canopy or understory growth (Finch and Ruggiero 1993). High soil surface temperatures, fungi, adverse diurnal temperature, and the unfavourable chemical balance of some seedbeds have also been suggested as potentially detrimental to seedling success (Perala 1990).

Despite the fact that aspen are prolific producers of viable seeds that are theoretically able to germinate successfully under a range of environmental conditions, the availability of suitable conditions appears to be limited, and sexual reproduction of aspen is widely believed to be rare in western North America. Authors have contended that little to no sexual reproduction has occurred in the Rockies since the last glaciation over 10,000 years B.P.[3] (Barnes 1966; Kay 1997; Mitton and Grant 1996), but a few studies have documented the appearance of new clones through seedling establishment in recent years (Elliot and Baker 2004; Romme *et al.* 1997; Quinn and Wu 2001). Although the relative importance of sexual success is debated, it is clear that the vast majority of aspen reproduction in the Rockies occurs through vegetative reproduction or clonal spreading (Barnes 1966; Mitton and Grant 1996). Although individual aspen trees (i.e. ramets) are relatively short-lived (usually <150 years in the West), it is believed that most aspen clones (i.e. genets) in the Rocky Mountains established when the climate was considerably wetter, and have likely persisted for thousands of years (Barnes 1966; Kay 1997; Mitton and Grant 1996). At present there is no direct way to test this hypothesis – it is impossible to estimate the exact age of a clone given that most clonal fragments thriving today would not have been in existence from the original seedling and somatic mutation would have occurred frequently enough to create some variation in the genome in different areas of the clone (Mitton and Grant 1996).

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[3] B.P implies before the present date.

Aspen clones found in the West today are often very extensive[4], particularly in comparison with their eastern counterparts, sometimes covering vast tracts of the landscape (Kay 1997). They either appear as contiguous stands or patches on the landscape of almost uniform size and age, or underlie vast tracts of land in a complicated underground root network, awaiting a disturbance event that eliminates competing conifers and/or stimulates suckering (Lieffers *et al*. 2001). Although genetic diversity across the entire range of *P. tremuloides* is extremely high, when considered on a more local scale, it can be extremely low, with one genet dominating or exclusively covering a large area of land.

Aspen forest in the parklands primarily encroaches on the prairie through sucker growth where there is adequate moisture and an absence of disturbance, with trees diminishing in size around the outer edge of a clone. The prairie edge of aspen groves often contains an undergrowth of snowberry (*Symphoricarpus* spp.*)* which extends outwards in advance of the clone and helps to crowd out grasses as the forest advances on the prairie (Bird 1961). Where soil has been disturbed by burrowing animals [e.g. Columbian ground squirrels (*Spermophilus columbianus*), badgers (*Taxidea taxus*) and coyotes (*Canis latrans*)] or intervening shrub growth occurs [i.e., Saskatoonberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), snowberry], wind-blown seeds or seeds deposited through sharp-tailed grouse (*Pedioecetes phasianellus*) droppings may survive and become established as new patches on the landscape (Bird 1961). Otherwise, it is extremely difficult for aspen seeds to become established in the open prairie because of competition with prairie grasses (Bird 1961).

[4] The most spectacular example for which detailed information is available is the single quaking aspen clone located in Utah, USA, which covers 43 ha., contains more than 47,000 individual stems, and weighs more than 6 million kg, making it the largest organism yet to be discovered on earth (Mitton and Grant 1996).

2.2 The Foothills-Parkland Ecoregion

2.2.1 General Description

Canada's aspen-parklands are situated between the Great Plains of central North America and the coniferous forests of the pre-Cambian shield, stretching northwestward from northern Minnesota through Manitoba, Saskatchewan and Alberta (Fig. 2-2), generally occurring where precipitation levels exceed evapo-transpiration levels (Hogg and Hurdle 1995).

Figure 2-2: Distribution of the aspen-parklands ecoregion in North America (Partners in Flight 2004)

The aspen-parklands ecoregion is a savannah-like ecosystem characterized by a dynamic mosaic of aspen forest (*Populus tremuloides*) and grassland communities. Historically in Alberta, the native fescue grasslands were dominated by rough fescue (*Festuca scabrella*), while the parkland communities to the east contain a complex mix of true prairie and mixed prairie grassland communities. At higher elevations, scattered Douglas-fir and lodgepole pine intermix with aspen stands (Bird 1961).

Underlying rich, fertile soils make the land extremely valuable from an agricultural perspective, and the vast prairies stretching from the east and directly abutting the WLNP boundary have been heavily altered by intensive agriculture and ranching pressure since the area was settled by Europeans in the late 1800's (Bird 1961; Getty 1972; MacDonald 2000). The remaining native fescue grasslands in southwestern Alberta, particularly those protected within the WLNP boundary, are therefore considered a unique and threatened ecosystem. Consequently, grassland conservation and restoration has been identified as a major management priority in the Park's most recent management plan (Parks Canada 1999).

The foothills-parkland ecoregion, a sub-region of the widely distributed aspen-parklands along the eastern slopes of the Rocky Mountains, forms the ecotone[5] between the dry fescue-dominated prairies to the east and higher elevation, conifer-dominated forests to the west (Achuff *et al*. 2002; Bird 1961). The location and relative extent of aspen forest is variable and dynamic throughout, controlled at this larger regional scale by the amount of available soil moisture. Forest cover generally increases with higher available moisture levels, while under more arid conditions, aspen groves are confined to micro-topographical depressions and north- and east-facing slopes.

2.2.2 The Biological Role of Aspen Forests

The open, sunny habitat of most aspen stands allows the development of a multi-layered understory of shrubs and herbs, which is an influential characteristic in making them especially valuable plant and wildlife habitat for a diverse array of species (Stohlgren *et al.* 2002). Different plant species thrive under variable light regimes and age-classes of forest, highlighting the ecological importance of maintaining structural and compositional heterogeneity in habitat across the parklands landscape.

Aspen stands generally have comparatively higher densities and diversities of birds than other plant communities. In mature aspen stands, stem decay results in the creation of tree cavities, creating attractive nesting opportunities for a number of bird species (Finch and

[5] The term "ecotone" refers to a transition zone between two adjacent ecological communities/habitats that contains characteristic species of each. These transition areas are typically very productive and biologically diverse zones.

Ruggiero 1993). Other species thrive along forest edges, using the sunny, open forests and shrub patches for protection and nesting opportunities, and the forest edge and surrounding grasslands for feeding or hunting. Indeed, the foothills-parkland contains some of the most important habitat for breeding and migratory birds along the eastern slopes of the Rockies (Achuff *et al.* 2002). Insect diversity is extremely high in aspen forests as well. High insect populations provide an important food resource for wildlife species, especially birds and bats (Stohlgren *et al.* 2002). A relatively high diversity of amphibians has been recorded in the foothills-parkland ecoregion in WLNP, and small mammals abound, including American badgers (*Taxidea taxus*), Columbian ground squirrels, and a number of other small rodent species (Achuff *et al.* 2002). In many areas, beaver (*Castor canadensis*) depend solely on aspen for food and wood for dam construction, which is an important consideration in understanding formation and perpetuation of riparian ecosystems (Finch and Ruggiero 1993).

Larger mammals are also common in aspen ecosystems, with coyote, elk, and white-tailed and mule deer (*Odocoileus virginianis* and *Odocoileus hemionus*) commonly frequenting these areas. Historically, Plains bison (*Bison bison*) were an important component of the aspen-parkland ecoregion and the prairie ecosystem in general, but were extirpated from the eastern slopes of the Canadian Rockies in the late 1800's (MacDonald 2000). Their disappearance undoubtedly left an important impact on vegetation dynamics in the region over the past century, and their re-introduction to the Park is currently being considered by Park staff (Burton 2003; Wood and Mirau 2003).

Aspen groves are often the only source of wildlife cover within grasslands (Finch and Ruggiero 1993), while the open grasslands themselves provide forage for many species (Bradley and Wallace 1996). Native fescue grasses retain much of their nutrient value through the winter which is crucial for over-wintering elk herds (Bird 1961). Nevertheless, both elk and deer favour aspen as a browse species when grasses are not available and use aspen groves as cover from predation by wolves (*Canis lupus*) (White *et al.* 2003). Indeed, many animal species require a diversity of cover for various life functions (i.e. thermal cover, protection, food and breeding), and aspen forests contribute significantly to these requirements.

2.2.3 Cultural Values

In addition to – and in part because of - its ecological importance, the foothills-parkland of WLNP and surrounding area is extremely significant culturally. WLNP is situated within the traditional territory of the Blackfoot Nation[6], who once occupied a vast area stretching from northern Alberta to central Montana (Fig. 2-3). Although some other aboriginal groups, particularly the K'tunaxa, also have historical ties to the WLNP area, most historical evidence shows that the Blackfoot have been the principal presence (McClintok 1910; Reeves and Peacock 2001). The language of the Blackfoot is the most ancient of the Algonkian languages, and the Blackfoot culture is considered by Reeves and Peacock (2001) to be the most complex of all the bison hunting cultures of the Northern Plains.

The traditional territories of the Blackfoot Nation extend to the Rocky Mountains to the west, the North Saskatchewan River in the north, the Yellowstone River in the south, and the Saskatchewan plains in the east (Fig. 2-3). Ancient stories passed down through oral traditions substantiate these boundaries, as do archaeological, linguistic, and genetic evidence. The evidence also suggests that for thousands of years prior to the creation of WLNP in 1895, these landscapes were heavily lived in and managed by First Nations people (Johnson 1987; Glenbow Museum 2001; McClintok 1910; Peacock 1992; Reeves and Peacock 2001).

[6] The Blackfoot Nation, also referred to as the Nitsitapii, or the "Real People" is a confederacy comprised of three tribes sharing a common language and culture: (1) the Kainaa, commonly referred to as the Bloods; (2) the Siksika, or the Blackfoot; and (3) the Piikani, often referred to as the Peigan or Piegan (Johnson 1987; Glenbow Museum 2001; Reeves and Peacock 2001). The Piikani are the oldest of the three tribes, and they are considered the "keepers of the culture" in the sense of having retained the greatest knowledge of tradition and tribal history related to this region (Peacock 1992; Reeves and Peacock 2001).

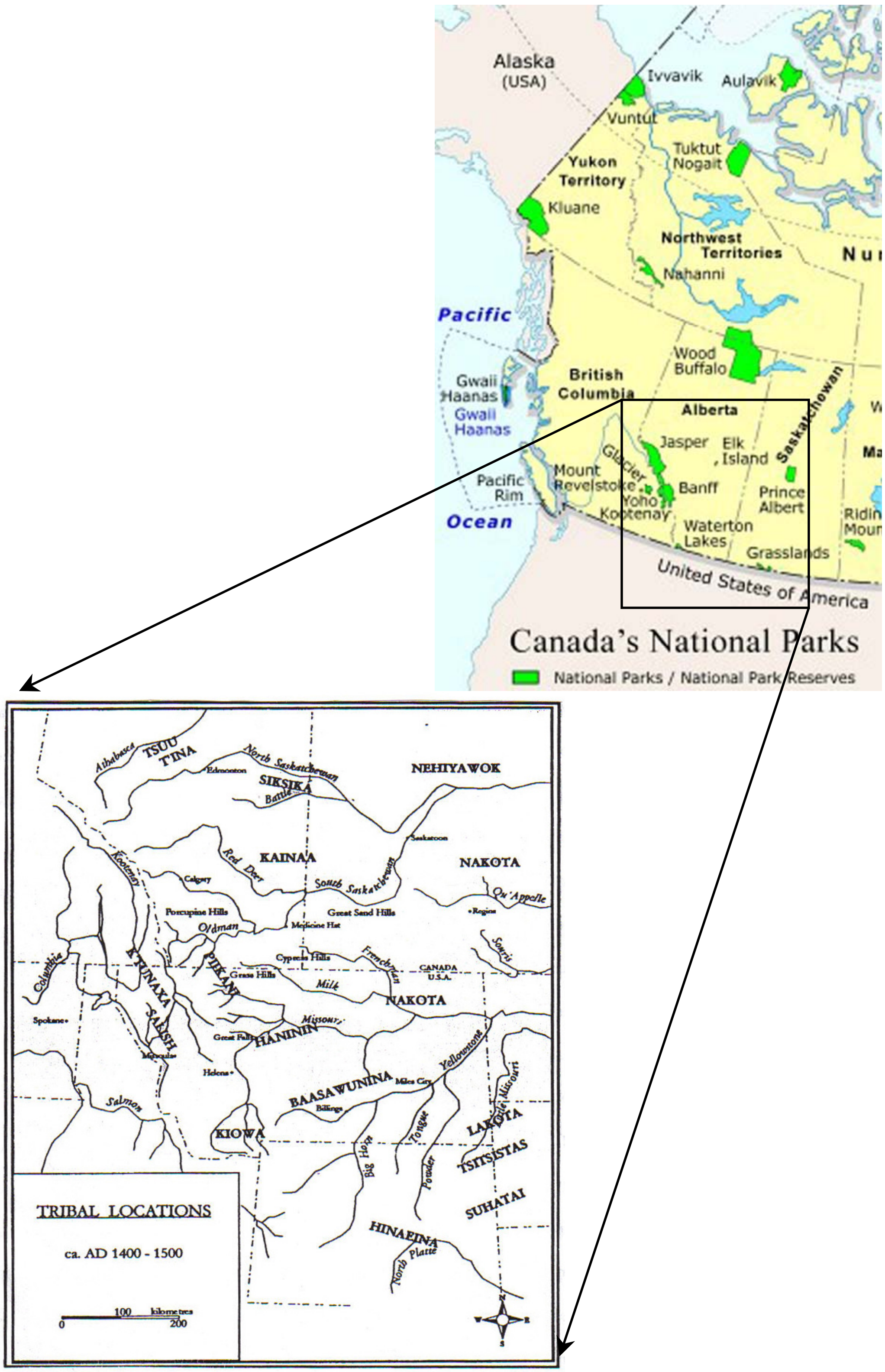

Figure 2-3: Location Map and Tribal Locations circa AD 1400 – 1500 (approximate enlarged area) (Reeves and Peacock 2001:10).

The Blackfoot were seasonally migratory people whose traveling traditionally reflected changing resource availability in a given area within their vast territory (Johnson 1987; Peacock 1992). Their movements often followed bison migrations closely, as they had strong material, social and ideological ties to this animal (Reeves and Peacock 2001). Although movements differed among bands, each of which had preferred wintering grounds, berry patches and Piksuns (buffalo jumps or corrals), all the Blackfoot peoples' wintering settlements were generally concentrated in the river valleys of the foothills, and their summer camps were found on the short grass prairies out towards the "Blood Clot" or Sweetgrass Hills (Peacock 1992).

Although wild game, particularly bison, is often considered the primary source of First Peoples' sustenance in the region, wild plants have also played a critical role (Johnson 1987; Hart 1972; Hellson and Gadd 1974; Peacock 1992; Reeves and Peacock 2001). Plants figure prominently in other aspects of Blackfoot life and culture as well, including: spiritual ceremonies and ritual practices, health and medicine (for both humans and horses), construction of tools and shelter and the creation of material goods such as art, clothing and decoration. Collection, preparation and management of these plant resources were complex and highly organized activities (Peacock 1992). Traditional, local knowledge of this kind, which is not necessarily restricted to indigenous groups, reflects an ecological awareness that is rare in modern society, an awareness that can only develop after years of working, experiencing and learning from a particular landscape.

With the arrival of horses, European traders and settlers in the early 1800s, and the competition for resources created by the thriving fur trade in the mid-1800s, traditional Blackfoot migration patterns were irrevocably altered (Peacock 1992). The collapse of the bison herds in the 1870s combined with the devastating spread of smallpox led to the decimation of the indigenous population who died from either starvation or disease. The dwindling populations had little choice but to settle on reserves and adopt a sedentary lifestyle. Tragically, the loss of seasonally migratory movements interrupted hundreds of years of cultural continuity, and removed the context in which knowledge of the land was needed and preserved. Although some elders have retained detailed knowledge of the botanical and animal resources in their area and still use these resources to this day (Peacock 1992), the progressive loss of Blackfoot language and culture is threatening the continuation of this knowledge, relegating it to written ethnologies and dwindling oral history accounts (Reeves and Peacock 2001).

Archaeological sites throughout the Rockies and in WLNP in particular have been found near aspen communities or in areas that historically supported aspen, indicating that these areas in particular likely played an important role for First Peoples in the region (Kay *et al.* 1999; Reeves 1975). The foothills-parkland historically supported a healthy buffalo population and several other game species, which drew numerous indigenous groups here for spring and fall hunts every year (Glenbow Museum 2001). In the winter months, the ecoregion was regularly inhabited due to its appealing protected valleys ideal for camping and abundant fuelwood sources (i.e. aspen and cottonwood stands found in river valleys and low-lying depressions). The foothills-parkland further supports a wide variety of culturally important plant species, which featured prominently in almost every aspect of Blackfoot life.

Aspen itself was a significant species within Blackfoot life. As well as being an important construction material and source of fuel, aspen wood was featured in several traditional ceremonies. Aspen bark was brewed as a tea for stomach or digestive tract disorders, and infusions were applied as eye medicine, while the tender inner bark was eaten as a treat in the spring. Also, the white powder that often dusts the outer layer of aspen trunks was used as a sunscreen. Several plants characteristic of the foothills-parkland were important components of the Blackfoot diet or were featured in ceremonial bundles[7] as well. Sweetgrass (*Hierchloe odorata*), or "siputs-sima" in Blackfoot, was used to purify virtually every holy artifact and

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[7] The Blackfoot developed a system of personal or group talismanic paraphernalia called "bundles" that were considered to be manifestations of higher power (Scriver 1990). Ceremonies featuring bundles were one way to contact the supreme creator – Natosi. Plants were featured in most of the medicinal and ceremonial bundles whose functions and contents were often kept secret and known to only a select number of individuals in the community (Scriver 1990).

accompanied the beginning of almost every holy ceremony. In addition to being a crucial staple food, the Saskatoon berry, or “real berry”, also figures prominently in sacred rituals (Johnson 1987). The prairie turnip (*Psoralea esculenta*), an important root vegetable, is also an integral component of the Natoas, or “holy turnip” bundle, which is featured in the Sundance, or “Okan” – the most important ceremony in Blackfoot culture (Peacock 1992). Finally, one of the most significant plants to the Blackfoot was tobacco (*Nicotiana attenuata*). Tobacco mixtures were included in all religious bundles, and smoking was central to most ceremonies. It is outside of the scope of this thesis to discuss in detail the extensive use of plants by First Peoples’ in this area, but suffice it to say that the relationships between plants and people within what is now WLNP were a prominent feature of Blackfoot culture [see Peacock (1992), Reeves and Peacock (2001) for a detailed discussion].

Presently, the foothills-parkland is one of the most heavily used areas of the Park, with the main access road to the Waterton townsite, the Park headquarters, a golf course, and many of the day visitor facilities located within it. Hiking, swimming, boating, wildlife viewing and horseback riding are all common activities that take place among low elevation aspen habitat in the Park. The area therefore continues to carry strong cultural connections for visitors and residents alike. The landscape-level ecological changes being studied in this thesis surely have not gone unnoticed by those most familiar with the area.

2.3 Factors Controlling Vegetation Dynamics

The vegetation dynamics of aspen-dominated forests are largely controlled by the complex interactions between climate, fire, herbivory, and humans (Bird 1961; Sheppard *et al.* 2001; White *et al.* 2003). Within the aspen-prairie mosaic characterizing the parklands, aspen forest is considered the ecological climax, replacing grassland and shrub patches on sites where moisture conditions are favourable and there are no disturbance agents to halt or reverse the successional process (Hogg and Hurdle 1995). At the upper elevation limit of the foothills-parkland, aspen are slowly replaced by slower-growing, shade-tolerant conifers (i.e., Douglas-fir) in mixed stands and along aspen forest patch edges in the absence of disturbance (Perala 1990; White *et al.* 2003).

In the montane ecoregion, although aspen is regarded as an important early successional species due to its tendency to rapidly colonize after a disturbance, aspen-dominated forests may also develop into climax stands (Kay *et al.* 1999; Peterson and Peterson 1992). Climax aspen stands lack invading conifers, and will successfully regenerate even in the absence of fire, through root suckering. As a stand matures, stand dieback and break-up[8] occurs, and young suckering trees will begin to fill these new gaps, producing mixed-age stands. The extent of stand break-up appears to vary throughout aspen's range, occurring more frequently along the southern limits (Peterson and Peterson 1992).

As in most forested ecosystems, ecological succession in aspen-dominated forests is largely controlled by a combination of climatic influences and disturbance agents (i.e. herbivory and fire) (Bird 1961). The following section discusses the potential influence of these factors on aspen forest dynamics in the foothills-parkland ecoregion at various temporal and spatial scales, drawing on specific information about regional climate trends and the pre- and post-European settlement management history of the WLNP area.

2.3.1 Climate

(a) The Influence of Climate on Aspen Forest Dynamics

Climate is recognized as one of the most influential determinants of global vegetation patterns, and is a crucial driver of aspen distribution in North America (Peterson and Peterson 1992). The range of trembling aspen is limited primarily by extreme temperatures and low water availability. The aspen-parklands in Canada represent a dynamic ecotone between the dry central

[8] The term "stand breakup" refers to the openings or gaps created in mature aspen forest stands resulting from the death and subsequent decay of old (>100 years) aspen ramets (Peterson and Peterson 1992).

prairies and the boreal forest along their northern and eastern limits, and upper elevation coniferous forests in the foothills along the eastern slopes of the Rockies (Hogg and Hurdle 1995). Several authors have pointed to the potential importance of shifting climatic conditions in determining past and future changes in the spatial patterning and behaviour of aspen stands throughout the species' geographical and elevational range (Elliot and Baker 2004; Fralish and Loucks 1975; Hessl and Graumlich 2002; Hogg *et al.* 2005; Romme *et al.* 1995).

In the montane ecoregion of the Canadian Rockies, aspen occupies moist, nutrient-rich sites and alternatively forms mature climax aspen stands, exists as a component of mixed composition forests, or forms small patches of uniform aged stems in gaps caused by forest disturbance such as wind, fire or grazing pressure (Perala 1990). In the foothills, aspen stands occupy similar sites but exist as the climax community within a drier grassland matrix, remaining limited in extent by moisture availability. In the more arid environment of the foothills and western prairies at the eastern limits of the parkland/grassland ecotone, aspen is often confined to north- and east-facing slopes and to depressions where moister conditions are found (Perala 1990).

Incidences of aspen stands suddenly dying back have not been uncommon in the past, but in the northern reaches of the parklands, the frequency and severity of these episodes may be increasing in recent years (Frey 2004; Hogg *et al.* 2005). The phenomena have been attributed to numerous influences, but the combination of extreme weather events (particularly drought) and defoliation by insects during outbreaks have been suggested as the most influential of these. The latter seems to have occurred more readily under abnormally warm spring conditions (Frey 2004; Hogg *et al.* 2005). Over the longer term, temperature increases have been implicated in the decline of aspen stands where they have resulted in trends of more arid conditions over several years, and have threatened the already marginal existence of aspen on drier sites (Fralish and Loucks 1975; Hogg *et al.* 2005; Lieffers *et al.* 2001). Conversely, aspen expansion may result where climatic conditions are favourable (i.e., warm and moist), and increased suckering and the advance of aspen stands into both low- and high-elevation grasslands during periods of increased precipitation have also been documented (Bailey and Wroe 1974; Elliot and Baker 2004; Romme *et al.* 1997).

In light of increasing evidence of climate change, namely warming trends over the past century in both the prairie ecosystems to the east (Case and MacDonald 1995; Wheaton 2001) and the slopes of the southern Canadian Rockies to the west (Luckman 1998), it is useful to examine both short-term (i.e., over the past 100 years) and long-term (i.e., within the Holocene period or the past 10 000 years) climate patterns of the region to elucidate the ongoing effects of climate on aspen ecosystems in WLNP.

(b) Long Term Regional Climate Trends

The earliest climate records in WLNP date back to 1928, although these older records are limited to spotty precipitation data from various stations in the eastern section of the Park. Inconsistent observations and relocation of climate stations have been a major problem with much of the data from the WLNP area and throughout the Canadian Rockies in general (Luckman 1998). Poliquin's (1973) study of instrumental climate data spanning the years 1951-1972 remains the only climate analysis completed for the Park to date. No obvious climate trends were observed during this short observation period. As such, larger scale regional climate data are the best available source of information for assessing medium- to long-term climate trends in WLNP.

At the Quaternary scale, researchers contend that the Hypsithermal Interval (approx. 8000-5500 B.P.) appears to be the warmest and driest period in Holocene history (10 000 years B.P.), with the last 4000 years showing generally cooler and moister conditions culminating in the most recent period of glacier advance, the Little Ice Age which occurred from the mid-14th to the mid-18th centuries (Beaudoin 1999; Luckman 1990). Available pollen evidence in North America suggests that drought conditions during the Hypsithermal led to large increases in grassland sediment deposits and perhaps even a northwards and westward extension of grasslands since tree growth (especially aspen) is limited largely by moisture (Beaudoin 1999). Bird (1961) further suggests that aspen forest in the parklands has been abundant for many decades, but not for many centuries as the soil on which the aspen forest is now growing is of the black grassland type rather than the grey wooded type. Other research has shown that some soils in southern Alberta have characteristic wood layers dominated by willow and aspen, suggesting that prior to this widespread grassland establishment but directly after the last major glacial retreat from the foothills and western prairies when elevated volumes of glacial meltwater were available (>8000 years B.P), aspen forest may have been more common throughout the prairies (Beaudoin 1999).

Temperature, especially summer temperature, has also exerted important control on tree growth. During this warmer period, the upper and lower coniferous forest treelines advanced upslope in the Canadian Rockies, and grasslands were able to spread into the floors of major valleys at lower elevations (Beaudoin 1999; Luckman 1990). Conditions during the Hypsithermal period appear to be the best historical analogue for future conditions projected by current climate models, and may therefore provide some clues about potential future ecological responses of aspen and other ecosystems (Beaudoin 1999; Luckman 1990).

A combination of instrumental records over roughly the past century, and various proxy data (i.e. tree-rings, pollen sediments) have been used to clarify more recent and shorter term climate trends throughout the southern Canadian Rockies (Luckman 1998). Data reveal a distinct and extended cold and wet period in the mid 19th century when glaciers reached their Little Ice Age maxima, and a subsequent warming trend throughout the 20th century, particularly during the winter months (Luckman 1990,1998). Mean annual temperatures have risen approximately 1.4°C over roughly the last 100 years, with two apparent temperature peaks in 1941 and 1987, and tree-ring reconstructions suggest that summer and spring temperatures during this period, particularly throughout the 1990s, are higher than any equivalent period over the past 900 years (Luckman 1990,1998; Watson and Luckman 2001).

Accompanying this clear warming trend are less conclusive and highly variable precipitation data derived from tree-ring analyses that show major wet intervals for the approximate periods of 1585-1610, 1660-1680, 1870-1885, and 1895-1910, and generally higher levels of precipitation in the latter half of the 20th century throughout the Rockies (Watson and Luckman 2001). Stations east of the Continental Divide show a peak in precipitation starting in the late 1940s and continuing through the 1950s (Luckman 1998). From this perspective, Euro-Canadian settlement in the western prairies occurred in what was arguably one of the coolest and wettest intervals of the last 10, 000 years (Beaudoin 1999; Luckman 1990).

In the foothills-parkland, prairie climatic influences are also extremely important to consider, particularly incidences of severe moisture stress. Tree-ring evidence for the region suggests that the severe droughts of the 1930s were not atypical of patterns over the last 500 years or so, and high variability in the occurrence of drought over this period does not provide conclusive evidence of an appreciable relative increase or decrease in the frequency of drought over the last century (Case and MacDonald 1995). More intense droughts than those detected by the instrumental climate record over the past 100 years occurred in the 1610s and 1790s, with the most severe incidents recorded from 1791-1800 (Case and MacDonald 1995; Luckman 1990). This evidence reinforces the fact that climatic observations made over the approximate 100-year scale of human settlement do not necessarily reflect long-term trends. Frequent drought has been the norm, not the exception in the prairies (Case and MacDonald 1995).

The effects of these drought events on aspen have likely been more pronounced when they occur in close succession. Aspen stands can often deteriorate rapidly (i.e. within 3-6 years), leading to tree death and stand breakup, and there is some concern, particularly at the northern limits of aspen’s range, that warmer and drier conditions predicted for much of western North America over the next few decades could lead to significant increases in aspen dieback and mortality (Frey 2004; Hogg *et al.* 2005).

There have been several efforts to link climate patterns in the Rocky Mountain region with historical fire regimes. Some researchers have concluded that cool, wet periods (i.e. Little Ice Age) have been accompanied by longer fire return intervals (i.e., lower fire frequency), and warmer, drier periods result in shorter fire return intervals (i.e., higher fire frequency) (Hallett and Walker 2000), but controversy remains regarding the relative importance of anthropogenic influences on these signals (Luckman 1998; Nelson and England 1971). Since most fire history studies rely on tree-ring analyses, fire histories reconstructed for the treeless prairies have largely been extrapolated from nearby forested areas, which given the high variability of climatic conditions in the grasslands, may not provide an accurate representation of the true conditions (Nelson and England 1971). Regardless of the lack of a clear climate-fire correlation, data show a distinct lack of significant fires in the 20th century compared to much more frequent fires in the past, despite clear climate warming trends (Luckman 1998). This suggests that fire suppression has indeed had some influence on fire regimes within the Canadian Rockies. The influence of fire, or lack thereof, on vegetation dynamics in the past century has therefore become a topic of considerable research in recent years.

2.3.2 Fire

Early historical accounts of fire activity in western Canada abound. Fire was considered so serious a hazard at the end of the 19th century that some of the earliest Canadian legislation was devoted to controlling the spread of wildfire, particularly on the prairies where agriculture and European settlements were rapidly establishing and grass fires were said to be frequent (Gruell 1983b; Nelson and England 1971). Although it is difficult to assess how representative these qualitative accounts are, or to glean reliable estimates of fire frequency from them, tree-ring analyses support the contention that historically, fire was considerably more frequent, particularly in the mid-19th century, and likely exerted a powerful influence on vegetation dynamics in both the prairies and the mountains. Progressively more successful fire exclusion and suppression policies over the past century have been implicated as the major factor in the advancement of forest cover into open habitats and the decline in early successional vegetation communities throughout the Rockies (Barrett 1996; Barrett and Arno 1999; Bird 1961; Gruell 1983a; Kay *et al.* 1999; Keane *et al.* 2002; Luckman 1998; Rhemtulla *et al.* 2002).

There is little doubt that over the long term, fire historically played a crucial role in maintaining aspen stands in the Rockies. The effective exclusion of fire from montane areas has often been suggested to be a major factor contributing to the recent decline of aspen in those areas (Hessl and Graumlich 2002; Kay *et al.* 1999; Sheppard *et al.* 2001; White *et al.* 1998,2003). Historically frequent fires at lower elevations maintained aspen stands by: (1) killing competing conifers, (2) top-killing old aspen stems creating opportunities for regeneration through replacement by younger seedlings, and (3) stimulating vigorous suckering from long-lived clonal aspen root systems (Brown and DeByle 1987). Conversely, while infrequent fires stimulate vigorous suckering from existing aspen clones, several authors have suggested that the frequent, low-intensity fires thought to be characteristic of the prairie ecosystem would have repeatedly suppressed or even killed new aspen growth, effectively maintaining a prairie sub-climax that would have otherwise been invaded by aspen (Bird 1961; Bailey and Wroe 1974). This effect was recognized as early as the mid-18th century by settlers of the area:

> *"If willows and aspen were permitted to grow over the prairies, they would soon be converted to humid tracts in which vegetable matter would accumulate, and a soil adapted to forest trees be formed. If a portion of the prairie escaped fire for two or three years, the result is seen in the growth of willows and aspen, first in patches, then in large areas, which in a short time become united and cover the country, thus retarding evaporation and permitting the accumulation of vegetable matter in the soil. A fire comes, destroys the young forest growth and establishes a prairie once more. The reclamation of immense areas is not beyond human power. The extension of the prairie is evidently due to fires, and the fires are caused by Indians, chiefly for the purpose of telegraphic communication or to divert the buffalo from the course they may be taking. These operations will cease as the Indians and buffalo diminish, event which are taking place with great rapidity."*
>
> **H.Y. Hind (1859)[9]**

[9] Quoted in Bird (1961:28)

> *"Everyone who is acquainted with the northwest knows how rapidly poplar and willows grow up in a largely settled country when prairie fires are checked. There is reason to believe that [ecological] change has been very marked in parts of the Red Deer and Edmonton districts. Consequently, rates calculated on the basis of the survey of 1885 and 1884 are necessarily low …"*
>
> **C.A. Magrath, DLS. (1892-1893)**[10]

Although many observations can be cited to support the contention that fires caused extensive destruction of aspen across the prairies, it is difficult to determine whether their frequency and extent may have actually resulted in the extension of grasslands at various times between 1750 and 1900, particularly when climatic conditions were favourable (Nelson and England 1971).

Although high frequencies of Chinook winds in the foothills and plains of western Alberta may make these grassland areas particularly susceptible to fire in all seasons, aspen is considered extremely fire tolerant, and only readily burns when trees are leafless and understory plants are dry – conditions that are more common in the early spring and late fall in the Rockies (Brown and DeByle 1987; Kay 1997; Nelson and England 1971). Lightning strikes during these seasons are rare in the region, and ignition efficiency in non-forested regions is restricted because the lighter fuels are readily wetted and fire starts are easily extinguished by precipitation accompanying thunderstorms (Gruell 1983b). Research in the northern U.S. Rockies has shown that the efficiency of lighting as an ignition source decreases tenfold from the forested mountains of Idaho to the plains of central Montana (Gruell 1983b). Grassland fires caused by lighting were therefore probably infrequent, indicating that the historically frequent fires recorded during these months in the area are conceivably a result of some other influence, namely human agency.

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10 This was in response to a complaint by C.A. Magrath, DLS, on his inability to re-establish the location of wooden posts used in earlier surveys. Magrath had declined to take on proposed additions to his survey instructions, as the pay rates were too low. Magrath was working in Township 2 Rg. 28 the previous season (1892) when this problem occurred (ie. just east of the park in the Payne Lake area).

There is considerable evidence that before the arrival of European settlers at the turn of the 20th century, anthropogenic fires were common on many North American landscapes and were a critical influence on the development of vegetation communities (Barrett 1996; Barrett and Arno 1999; Bird 1961; Boyd 1999; Keane *et al.* 2002; Kimmerer and Kanawha Lake 2001; Lewis 1993; Nelson and England 1971; Gruell 1983a,b; Pyne 1995; Turner 1999). Reviews of the historical literature reveal numerous references to First Nations' use of fire throughout the Rockies and in southern Alberta in particular. Fire occurrence probably varied greatly, depending on human population sizes, climate and available fuels, but Gruell (1983b) suggests that anthropogenic fires were most frequent and extensive in the major grassland valleys and plains where fuel was continuous and human use levels were highest.

Fire was commonly used by First Nations peoples in western Canada to enhance the availability of local plant resources by creating a habitat mosaic across the landscape that supported a diverse vegetation composition and thus stabilized the food supply (Turner 1999). Turner (1999) notes that many of the species whose growth and productivity are increased following landscape burning are species that require clearings or open canopy for optimum growth, or are at least reasonably tolerant of open conditions, including the several culturally important root vegetables in the WLNP region [e.g. prairie turnip, camas (*Camassia quamash*)] (Peacock 1992). Available ethnographic and fire history information suggests that landscape burning was likely frequently used by the Blackfoot in WLNP, and was a major influence on vegetation dynamics in the foothills-parkland (Barrett 1996; Reeves and Peacock 2001).

In the prairies, it was particularly common to ignite low-intensity grassland fires to influence game movement and thus facilitate hunting, and to rejuvenate young shoots, improving grazing for bison and livestock (Barrett and Arno 1999; Kimmerer and Kanawha Lake 2001). At the same time, the increase in grass fires in the early 1880s could have been associated with the elimination of bison as a wild animal on the plains. Large bison herds were present in considerable numbers on the western plains of Canada into the mid-1870s, and were known to have cropped the grass short over large areas, reducing the risk of fire by eliminating fine fuel loads (Nelson and England 1971). The historical relationship between bison, fire and aspen is therefore complex. This relationship, and new grazing influences that followed throughout the Rockies and in the WLNP area in particular require further examination.

2.3.3 Grazing

Evidence from the archaeological record, although insufficient for making conclusive animal population estimates, suggests that the prairies were heavily populated by bison, elk and pronghorn antelope (*Antilocapra americana*) (Gruell 1983b; Reeves 1975). Bison were present in significant numbers in the fescue grasslands in WLNP from at least 3000 years B.P. to the late-1800s when they were extirpated from the region (Mirau and Wood 2003; Reeves 1975). Bison preferentially graze the nutritious fescue grasses characteristic of the sheltered valleys found in the foothills-parkland ecoregion, making these areas ideal bison habitat (Burton 2003). As a keystone species in the prairies, they had a strong influence in shaping historic vegetation patterns (Knapp *et al.* 1999). In particular, bison may have suppressed aspen growth on the prairies by browsing on aspen shoots, wallowing and trampling aspen seedlings, and toppling mature aspen trees. Their continued exclusion from grassland ecosystems may have contributed to the observed expansion of aspen in western Canada (Campbell *et al.* 1994).

There is some general debate as to whether Canadian plains bison followed a seasonal migration pattern, moving to the xeric mixed grasslands of the open prairies in the summer, and returning to the protection of the foothills-parkland and fescue grasslands in the winter months. Archaeological work in WLNP suggests that some bison may have wintered in the lower main valleys but migrated upslope to higher elevation alpine grasslands in the warm season, while others regularly moved out to the open plains (Wood and Mirau 2003). Ethnographic evidence supports the view that some seasonal migration of bison occurred since the Blackfoot, whose diet and culture were closely linked to the movements of bison populations, are known to have followed a seasonal round that paralleled bison movements (Johnson 1987; Reeves and Peacock 2001). Wood and Mirau (2003) conclude that although the archaeological record in southwestern Alberta still has gaps, available data clearly allude to the seasonal presence of bison in the fescue grasslands and foothills since the establishment of suitable habitat in this area at the end of the Pleistocene over 10,000 years ago until their extirpation in the mid- to late-1800s (Reeves 1975; Reeves and Peacock 2001). As such, their presence probably exerted a significant influence on the patterns of aspen forest establishment in the WLNP area until this time.

The disappearance of bison from the prairies was caused primarily by over-hunting in response to a booming fur industry, and was facilitated by the introduction of guns and horses to the region and culture. The extirpation of bison coincided with the flourishing of a burgeoning livestock grazing industry in southwestern Alberta. Cattle and horse ranching at a large scale were permitted inside the Park boundaries from its inception until the late 1940s, and until grazing was phased out entirely in the early 1970s, small numbers of horses continued to be ranched in the parklands (MacDonald 2000). All grazing generally reduces the abundance of fine fuels on the landscape, lowering competition with shrubs and seedlings, and resulting in successional advances (Gruell 1983b). Conversely, the presence of large animal herds of any kind would likely result in some trampling of aspen and shrub seedlings. Cattle, as compared to elk and bison, however, do not browse aspen seedlings, are less mobile and more inclined to congregate near water courses, concentrating their impact to riparian zones where vegetation cover is disproportionately reduced (Burton 2003). In addition, patterns of bison migration were primarily climatically defined, whereas contemporary livestock management dictates the pattern, timing and intensity of grazing (Bradley and Wallis 1996).

Historic livestock grazing records for WLNP are scarce, and a review of existing grazing records in the Park library revealed that general licenses were granted for large portions of the study area, and were thus not specific enough to analyze at the scale of this study. The records did reveal that cattle and horses were present in large numbers (i.e. several thousand) up until the late 1940s when their numbers dropped to less than 100 animals.

Several authors have suggested that within the past few decades, increased browsing pressure due to rising elk numbers is leading to decreased aspen regeneration throughout the montane ecoregion of the Rockies (Hessl *et al.* 2002; Ripple and Larsen 2000; Romme *et al.* 1995; Suzuki *et al.* 1997; White *et al.* 1998,2003). A four-level trophic model has been proposed by White *et al.* (2003) linking humans, elk, predators [i.e., wolves and cougars (*Felis concolor*)] and climate through the complex processes of predation, herbivory, climate change, burning and differential wildlife behaviour in response to humans (see White *et al.* 1998 for a detailed discussion). Despite this increasing attention, few authors have directly addressed how these trends differ in the aspen-parklands where these same interactions are not being observed, and in fact aspen expansion rather than decline seems to be the dominant trend. Elk were extremely scarce to non-existent in the Park at the turn of the 20th century when mass elk culls were being encouraged by government policies designed to support the interests of the ranching community, and elk hunting levels were high. Their numbers did not rebound until the mid 1950s when elk were re-introduced and the laws were changed (MacDonald 2000). Numbers have remained more or less constant at 700-900 individuals in WLNP, significantly fewer grazing animals than were historically present. The herd migrates annually from their wintering grounds in the Blakiston Valley and on the Blakiston alluvial fan to areas of the parklands to the east of the Park (Watt, R. pers. comm. 2004).

Human influence on vegetation dynamics is not limited to changes in the grazing regime or control of fire dynamics in the aspen parklands, and as the following discussion illustrates, long-term human presence in WLNP may have contributed further to aspen forest dynamics.

2.3.4 Anthropogenic influences

Historical evidence and scholarly discussion suggest that even in some of the most ecologically intact landscapes in Canada, namely the Rocky Mountain national parks, humans have been an integral component of ecosystem processes. Oral histories, early settlers' accounts and paleoecological studies indicate that humans have been living in and managing Rocky Mountain landscapes for thousands of years (MacLaren 1999; Reeves 1975; Reeves and Peacock 2001). The human dimension of these Rocky Mountain landscapes has largely remained at the periphery of management discourse, however, and consideration of historical First Nations' uses and traditional management practices have the potential to further enlighten understanding of landscape change since the arrival of Euro-Canadian settlers in the mid-1800s. In addition, current aspirations of maintaining and restoring historical ecosystems should give serious consideration to the potential of re-establishing or mimicking traditional land management values and practices in Canadian national parks (Higgs 2003).

In addition to frequent burning for stimulating plant growth of selected species, First Nations' peoples in western Canada also used various mechanical techniques for managing plant resources including selective harvesting, replanting of seeds, and pruning or coppicing to stimulate vigorous plant growth (Peacock and Turner 2000). Adjustments to harvesting volumes were made depending on fluctuations in the annual productivity of plant resources, and were carefully controlled by various social mechanisms within the community (Peacock and Turner 2000). Beaudoin (1999), during her investigations into ecological and human responses to climate change in western North America, has come to the conclusion that plant use by aboriginal people would have definitely modified vegetation patterns, but also points out that the magnitude of the impact of these human activities is difficult to measure. Although their impact is difficult to quantify, it is certain that the presence of humans in the WLNP landscape has been influential on vegetation dynamics over the past 10, 000 years (Peacock 1992).

2.4 Concluding Thoughts

Aspen forest dynamics in the foothills-parkland are clearly complex. They have historically been, and continue to be, controlled by myriad factors, the relative influence of which is difficult if not impossible to determine. This is especially true of the past century during which humans have had an increasingly important impact on ecosystem dynamics throughout the Rockies. Aspen ecosystems in Canada are exceedingly variable, and their response to future climate change and land management decisions will be difficult to predict across their wide geographic and elevational range. It seems clear then, that further research is needed to reveal long-term ecosystem states and processes, particularly in the foothills-parkland where research concerning aspen forest dynamics is scarce.

CHAPTER THREE

Materials and Methods

3.0 Introduction

Ecological investigations are increasingly combining diverse data sources to reveal details about historical landscape composition and structure. Remotely sensed imagery is ideal for accurately quantifying landscape change over time, and both time-series satellite imagery (e.g., Franklin *et al.* 2002; Li *et al.* 2001; Lu *et al.* 2003; Sachs *et al.* 1998) and aerial photography coupled with GIS technologies (e.g., Bakker *et al.* 1994; Didier 2001; Hester *et al.* 1996; Kettle *et al.* 2000; Mast *et al.* 1997) have been widely used for this purpose. With commercially available satellite imagery being a comparatively recent development (late 1970s-80s), time-series aerial photographs, which can date back to the 1930s, are still commonly used where longer-term ecological information is desirable (Reithmaier 1999).

Researchers interested in assessing the historical range of variability for a given ecosystem are increasingly relying on other historical data sources for uncovering information about ecological conditions over even longer time periods, particularly in North America where investigation into pre-settlement vegetation patterns over large areas has become a research focus. The use of historic and repeat oblique photographic images is becoming a valued tool for reconstructing past environmental changes and for monitoring future ones (Hart and Laycock 1996; Higgs 2003; Reithmaier 1999). Although some researchers have attempted to quantify change using oblique photographic imagery (Manier and Laven 2002; Rhemtulla *et al.* 2002; Honda and Nagai 2002), the challenge of accurately correcting for the horizontal distortion created by the perspective angle of the images has not been fully resolved to date, and most studies remain focused on using these images qualitatively to assess landscape change over time at either individual sites (e.g., Elliot and Baker 2004; Steen-Adams 2002) or at the landscape scale (e.g., Hastings and Turner 1965; Gruell 1983a; Meagher and Houston 1998; Rhemtulla *et al.* 2002; Steen 1999; Veblen and Lorenz 1988,1991; Webb 1996).

Historical land survey records are also of particular interest when studying long-term ecological processes and subsequent landscape pattern. Several studies in the eastern U.S. have used witness tree data from the original Public Land Office Surveys (PLOS) to investigate pre-settlement land cover patterns over large geographical areas (e.g., Bollinger *et al.* 2004; Cogbill *et al.* 2002; Delcourt and Delcourt 1996; Manies and Mladenoff 2000; Radeloff *et al.* 1999), and other efforts in Australia have been made to model land cover patterns using a combination of remnant stand information and historical survey maps (Bickford and Mackey 2004; Fensham and Fairfax 1997).

Historical oblique images provide strong visual evidence of historical landscape conditions that is unavailable in vertical aerial photography, while the latter provide an opportunity to assess the magnitude and rate of landscape change over time and the potential for making measurable predictions about future landscape patterns. Other historical data sources including maps and early survey records can further complement the information available from photographic images, providing quantifiable information over even longer time periods at various scales of inquiry. By integrating all three of these data sources to investigate long-term ecological patterns in the foothills-parkland ecoregion of Waterton Lakes National Park, a more complete and nuanced understanding of the magnitude and character of landscape change over the past century is possible (Swetnam *et al.* 1999; White and Walker 1997).

3.1 Description of the Study Area

The study area (approx. 5140 ha), located in the central Waterton valley, is limited by the upper elevation boundaries of the foothills-parkland ecoregion to the south and west, and the Park boundary to the north, encompassing almost the entire ecoregion within the Park (Achuff *et al.* 2002) and occupying the lowest elevations in the Park (1300-1500 a.s.l.) (Fig. 3-1). The foothills parkland climate is transitional with both prairie and cordilleran influences, and tends to be the warmest and driest area of the Park. The area experiences long, cold winters and short, moderately warm summers, with maximum temperatures being reached in July and August. Annual precipitation is low, averaging 85 cm to 210 cm between 1951-1972 with 60% or more falling in winter (Poloquin 1973), although there is very pronounced local variation in precipitation patterns over short distances within the Park due to the complex and abrupt topography. Year to year precipitation levels are highly variable, and seasonal droughts are common. Wind is a major climatic element in the region. Very strong (i.e., from 125-160 km/hr) drying winds are common in the fall and winter, prevailing from the west and southwest (Achuff *et al.* 2002; Poliquin 1973).

Underlying bedrock on the foothills and plains east of the Lewis Thrust, which runs in a northwest to southeast direction, is Mesozoic in origin. Soil parent materials are primarily calcareous with a few localized exceptions, and are of glacial, fluvial, glacio-fluvial, glaciolacustrine and aeolian origin (Achuff *et al*. 2002). The main Waterton Valley is underlain primarily by flat-lying shales and sandstones that are mantled with glacial drift and outwash, and range from rapidly-drained to moderately well-drained (Achuff *et al.* 2002). The topography is flat to gently rolling, with some prominent drumlins and other glaciofluvial features to the west of the Waterton Lakes in an area of the Park historically referred to as the "Badlands" and presently referred to as the "eskerine complex".

The study area contains a range of habitat types. It is dominated by a mosaic of aspen forests in various stages of succession, shrub communities dominated by Saskatoonberry, chokecherry and western snowberry (*Symphoricarpus occidentalis*), and grasslands dominated by native prairie bunchgrasses - rough fescue (*Fescue scabrella)* and Idaho fescue (*Fescue idahoensis*) - and Parry's oat-grass (*Danthonia parryi*).

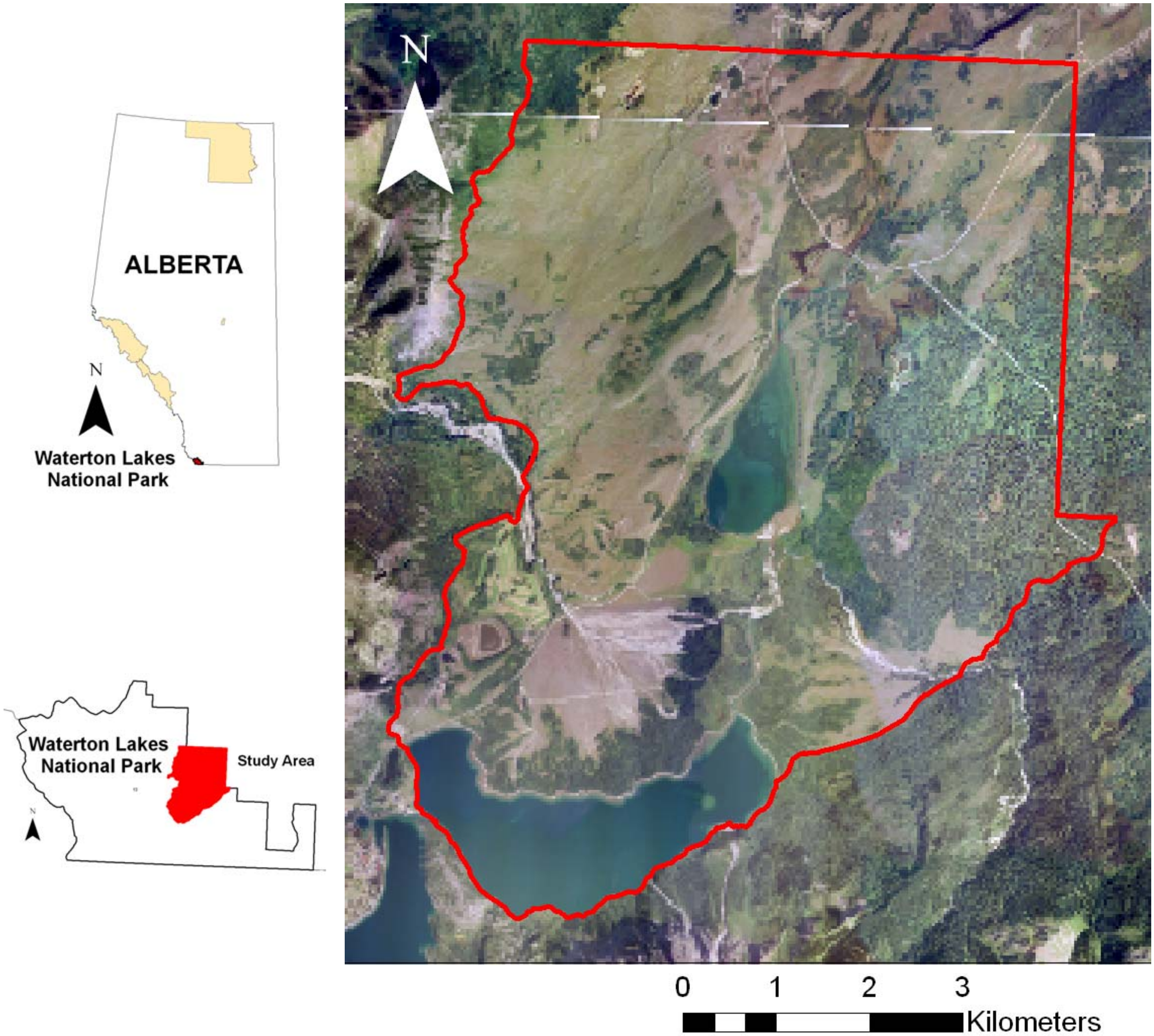

Figure 3-1: Location maps of Waterton Lakes National Park, AB and map outlining the study area within the Park.

Disturbed and heavily grazed sites are often invaded by nettle (*Urtica dioica*) or smooth brome/timothy communities (*Bromus inermis/Phleum pratense*). Small wetland complexes dot the area, and willow (*Salix* spp.) shrub complexes occur in lower-lying wet areas with wolf willow (*Elaeagnus commutata*) forming dense continuous patches on drier sites in the grasslands. Other forest types include Douglas-fir woodlands and mixed conifer-deciduous forests at higher elevations along the upper study area boundary, and cottonwood (*Populus trichocarpa*) and balsam poplar (*Populus balsamifera*) forests along waterways and lake edges, particularly on the lower Blakiston fan (Achuff *et al.* 2002; Kuchar 1973).

To the east of the lakes, the soils are moderately to poorly drained, and numerous small wetland and willow shrub complexes dot the area, surrounded by dense, mature aspen forest reaching ages of over 80 years (Achuff *et al.* 2002). To the west of the lakes, soils are well drained, and the hummocky glacial landscape characterized by drumlins, ground moraines and eskerine features is dominated by native fescue-grasslands and dotted with aspen and conifer forest patches. Aspen forest in this area appears to be more affected by the forces of the strong southwesterly winds, and many patches display stunted or twisted growth patterns.

The southwest corner of the study area has experienced the most human manipulation, with a golf course and the Park headquarters buildings located here. Two major highways run through the Park, with the main access road running along the west side of the Waterton Lakes towards the townsite to the south.

3.2 Quantifying Landscape Change: Aerial Photography (1939-1999)

3.2.1 Data Preparation and Map Creation

Two sets of aerial photographs flown in 1939 (1:23 000, B/W film, 18.5 x 23.5cm) and 1999 (1:15 840, colour film, 23 x 23 cm) were used for analysis in this study. Earlier images from as early as 1922 and 1928 were considered, but incomplete coverage of the study area and inferior quality undermined their usefulness. Scanned copies of both image sets (850 dpi and

1270 respectively) were obtained from digital Park archives, and hard copies of the 1939 images were obtained for confirmation of on-screen interpretation and classification.

Air photo interpretation of the 1999 air photos was completed in 2002 by an independent contractor (Bradley 2002) following guidelines outlined by the US Geological Survey - National Park Service (USGS-NPS) Vegetation Mapping Program (Nature Conservancy 1994) on which WLNP is basing their current vegetation mapping program. The minimum mapping unit was approximately 500 m^2. I obtained digital scans of the resulting mylar overlays from the Park, and converted them into .pix files for importation into PCI remote sensing software. The digital overlays were then georeferenced to an existing 1 m-resolution orthophoto derived from 1998 aerial photography. For each image, I located 15-40 control points by matching land cover polygon boundaries in the overlay image with vegetation boundaries in the orthophoto. A second order polynomial correction was used to geo-correct the overlays (Toutin 2004), and accuracy of the registration was assessed by how well polygon boundaries matched up at adjacent edges when a transparent mosaic of the overlay polygons was superimposed on the digital orthophoto. I estimated registration accuracy at about 1-3 m.

I then converted the geo-corrected overlays into .tiff files and imported them into ArcGIS software where polygon boundaries were digitized and labeled. I developed a classification system based on the NPS classification system. Some vegetation categories were generalized to reflect the level of detail distinguishable in the lower quality 1939 photographs as well as the level of detail required for this study (Appendix 3).

I then converted the scanned 1939 air photographs from .tiff to .pix format and imported into the PCI software program. Attempts were made to orthorectify the images using the OrthoEngine module, but a lack of identifiable ground control points given the homogeneous nature of the land cover and flat terrain, and a lack of camera calibration information, made these attempts inadequate for accurate functioning of the orthorectification software. Instead, I cropped the images (.tif format) in Adobe Photoshop 7.0, retaining only the center (approx. 1/3) of the image where the least radial distortion occurs (Colwell 1983), and imported them into ArcGIS. Six to twenty ground control points were distributed as evenly as possible throughout the cropped photograph (Colwell 1983) were collected using landscape features identifiable in both the 1939 and 1999 photographs such as: eskers, lakes edges, unchanged road intersections and evidence of old roads or oxbow lakes. I then geo-corrected the images using a first- or second-order polynomial equation (Toutin 2004). I assessed registration accuracy visually by superimposing a transparent 1939 image over the 1999 orthophoto and assessing how well the edges of the adjacent 1939 images, and obvious land features lined up. Registration was iteratively improved using more land cover points where necessary. Fewer ground control points were located in the eastern portion of the study area where homogenous aspen forest cover made it difficult to identify obvious features that were equally distributed throughout each image, introducing some error into the process.

I overlaid the 1939 images as an image mosaic over the 1998 orthophoto in ArcGIS. Air photo interpretation, digitizing and labeling of land cover polygons was performed on-screen. I referred constantly to hard copies of the 1939 images using an Abrams Stereoscope (10x magnification) to verify land cover classification and improve classification accuracy.

3.2.2 Ground-truthing

Repeat transect data (described in section 3.3.3) and three additional transects of 1.6 km in length were used to ground truth 1999 air photo interpretation. Crown closure and stand height were visually estimated for every isolated aspen patch encountered in open prairie areas, and at intervals of 100-200 m along each transect in dense aspen forest. At sites with mixed canopy composition, a 100 m^2 circular plot was established and all the stems > 1.3 m tall were identified to species and the diameter at breast height (dbh) measured. The dbh data were used to calculate basal area and estimate the relative composition of coniferous and deciduous canopy species. An estimated 10% of polygons of each cover type were visited in the field, and although an attempt was made to distribute these sample polygons throughout the study area, time restrictions and access considerations meant that some more remote areas could not be reached.

Although these plot data were useful in confirming and correcting the 1999 air-photo interpretation, they cannot be used to confirm the final accuracy of the 1999 map; corrections were made in an iterative fashion during the map creation process. The Park's Vegetation Mapping Program is expected to complete an error analysis in the summer of 2005, the results of which can be directly applied to assess the accuracy of the maps used in this study. The accuracy of the 1939 map could obviously not be assessed. Oblique photographs (see Section 3.4), however, were useful for clarifying some difficult interpretations (e.g., the distinction between young aspen forest stands and shrub cover).

3.2.3 Spatial Analysis

Descriptive statistics were calculated for each of the 1939 and 1999 land cover maps, and an overlay analysis was performed in ArcGIS to investigate landscape change between the two dates. Where land cover differed between dates, new "change polygons" were generated. Those change polygons less than the minimum mapping unit (< 500 m^2) were merged with adjacent 1939 polygons and relabeled. A change matrix was calculated from the results to show all "from-to" combinations. A series of overlay analyses were performed, and maps created to investigate the total area and spatial patterning of shrub and forest expansion, particularly aspen expansion.

Land cover maps were converted from vector to raster coverages, and an attempt was made to use the FRAGSTATS program (McGarigal *et al.* 2002) to perform a basic patch analysis. Generalization errors are inherent in converting vector data to raster data, and repeated attempts and interpretation of the results of the FRAGSTATS program indicated that the raster conversion was not successful, perhaps due to the small size of some of the polygons. Computer memory

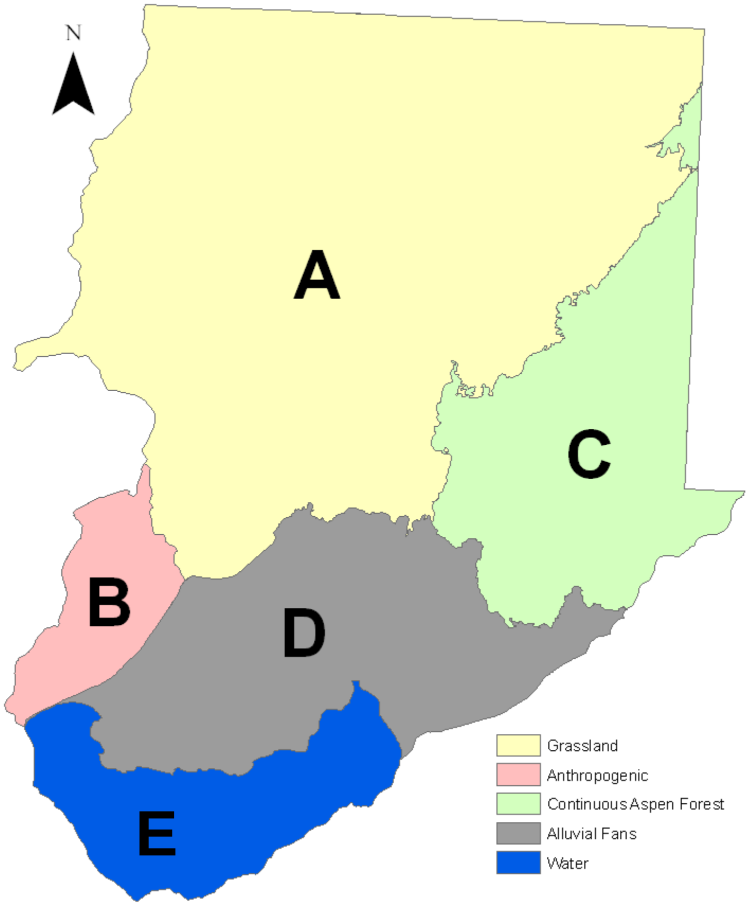

Figure 3-2: Map of ecological sub-areas within the study area: (A) Grassland; (B) Anthropogenic (i.e. area with the most human development encompassing the Park headquarters and golf course); (C) Continuous Aspen Forest, and (D) Alluvial Fans (E) Water.

requirements were also prohibitive. Instead, the VLATE[11] ArcGIS extension was successfully used to perform a vector-based patch analysis and calculate three simple area-based metrics[12]: (1) total patch area, (2) mean patch size, and (3) number of patches. The study area was then subdivided along 1939 vegetation boundaries into four separate sections (Fig. 3-2) that appeared to display distinctly different vegetation characteristics. The aforementioned area-based metrics

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[11] Vector-based Landscape Analysis Tools Extension downloaded at: http://www.geo.sbg.ac.at/larg/vlate.htm Land, S. and D. Tiede. 2003. "vLATE Extension für ArcGIS - vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse", ESRI Anwenderkonferenz 2003 Innsbruck, Austria.

[12] See McGarigal *et al.* (2002) for a detailed description of commonly used landscape metrics.

plus one additional edge metric, "total edge length", were calculated for both area A and area C (Fig. 3-2).

Limiting the patch analysis to these four simple metrics was done for a number of reasons. First, using more complex metrics when only two dates are available can lead to misinterpretations of the results (Manier and Lavin 2002) and many require specific parameterization and interpretation specific to a particular ecological question (Gergel and Turner 2002). In the absence of specific ecological questions related to the effect of pattern on process, more complicated metrics should be used with caution (Gergel and Turner 2002) and these four metrics have been identified as appropriate in similar studies investigating forest encroachment patterns into grassland areas (e.g., Manier and Lavin 2002; Russel-Smith *et al.* 2004; Endress and Chinea 2001).

Patch-level area data for the entire study area as well as for sub-areas A and C were log-transformed, and imported into SPSS 11.5 for statistical analysis. The change in average patch size between years (in log area) was analyzed for each cover type using standard t-tests, and for the overall landscape using a univariate analysis of variance (ANOVA).

Aspen expansion was analyzed in further detail. First, 1939 aspen cover maps for 1939 and 1999 were created. An aspen expansion map was created by subtracting the 1939 map from the 1999 map. The "distance/azimuth tools v.1.6" ArcView extension[13] was used to calculate the distance between new aspen forest (aspen expansion) from existing 1939 clones, as well as the distance between isolated aspen stands (i.e. only isolated aspen patches in the aspen expansion layer) and any nearest aspen patch. To investigate expansion patterns in relation to topography and elevation, a binary map of aspen expansion was created, converted to a 20 m raster file, and overlaid with both: (1) a 20 x 20 m 4-point aspect map and (2) a 20 m contour elevation map.

[13] Downloaded at: http://www.jennessent.com/arcview/arcview_extensions.htm
Developed by Jeff Jenness, 2005. Jenness Enterprises, Flagstaff, Arizona, USA.

Both were derived in ArcGIS from a 2004 DEM. The relative proportion of aspen expansion on each of north-, east-, south- and west-facing slopes, and at each elevation interval was calculated.

3.2.4 Sources of Error

There are various sources of error that may affect the accuracy of the map data. First, because two different interpreters identified land cover polygons for each of the 1939 and 1999 maps, inconsistency in the air photo interpretation was a consideration. It is assumed that this error is minimal in the 1999 map since the interpreter was a professional contractor, and the 1999 map was used to guide interpretation of the 1939 photographs to minimize error where interpretation was difficult or impossible from the photographs alone (e.g. distinguishing between aspen and cottonwood stands).

During the various stages of map creation, some degree of error was introduced. Overlay (1999) and image (1939) georeferencing was subject to registration error, especially in more homogenous areas where ground control points were difficult to locate (i.e. large expanses of continuous aspen forest, open grassland areas). In addition, when registering the 1999 overlays to the 1998 orthophoto, I made the assumption that little to no detectable ecological changes would have occurred over a period of one year. If change indeed did occur, some registration error would have resulted. Care was therefore taken to use stable landscape features wherever possible (e.g., eskers, road intersections, etc.). Visual inspection of the registration using transparent overlays was extensive and systematic and showed that such error was minimal (< 5m). RMS errors were kept low (< 5.0m) during the georeferencing process.

Finally, error is unavoidable in the on-screen digitizing process. To minimize this influence, the 1999 overlays were displayed as partially transparent during the digitizing process, care was taken to ensure the polygon boundaries were as precise as possible, and adjustments were made where needed. Visual inspection suggests that this error is minimal (< 3m). When interpreting the 1939 photographs, difficulty in discerning fine-scale details in the poorer quality black and white images may have led to some interpretation error, particularly where gradual vegetation boundaries occurred (e.g., between cottonwood forest and willow shrubland which both occur in low-lying wet areas adjacent to rivers and streams). This error was avoided to the greatest extent possible by using hard copies of the images and a stereoscope to confirm image interpretation.

3.3 Quantifying Landscape Change: the Dominion Land Survey (1889)

3.3.1 Description of the Data Source

Begun on July 10, 1871, shortly after Manitoba and the Northwest Territories became part of Canada, the Canadian Dominion Land Survey (DLS) set out to describe and document all new public lands in western Canada delineated under the new Canada Lands Act. Employed under the auspices of the Department of the Interior, the system was adapted from the Public Land Survey system used in the U.S. (Department of the Interior 1883), and was primarily used to assess agricultural and other land use potential.

Baselines and Meridians divide the land along east-west (latitudinal) and north-south (longitudinal) lines respectively. Starting at each intersection of a Meridian and a Baseline and working west, nearly square 6 x 6 mile townships were surveyed in each of these divisions, and each township was subsequently divided into 36 one-square-mile sections. The borders of each section were surveyed, and survey posts were set every half mile ("quarter-section corners") and every full mile ("section corners"). Meander corners were set at locations where survey corners met up with navigable rivers and lakes, and traverses along the water's edge were surveyed. Between one and four trees near corner posts were blazed in forested areas (bearing or witness trees), and stone cairns erected in prairie areas (Bollinger *et al.* 2001; Department of the Interior 1883).

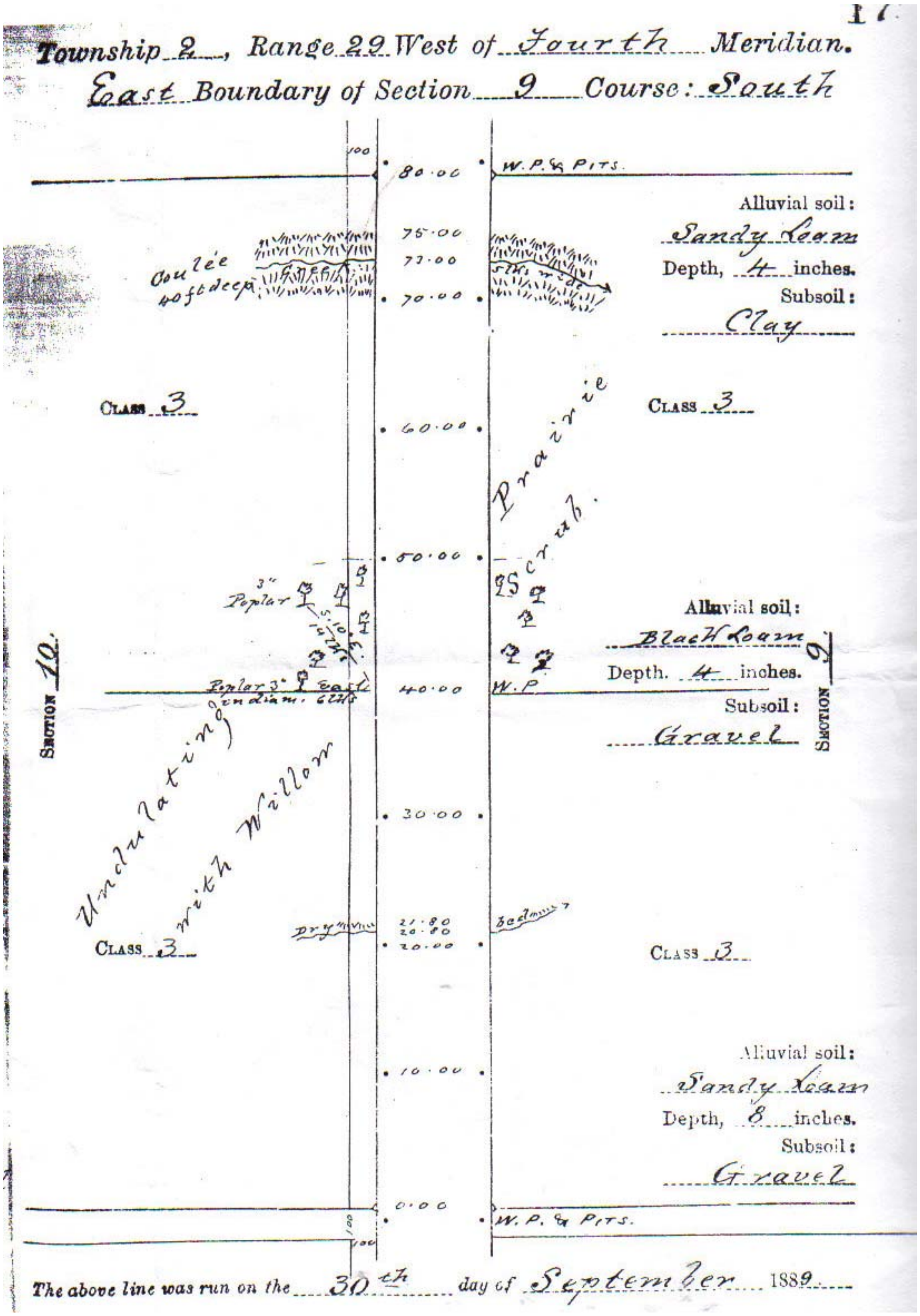

Figure 3-3: Example of Dominion Land Survey field notes along a 1-mile survey transect. (Township 2, Range 29, E boundary of section 9).

Along each mile transect, land cover was recorded at varying levels of detail depending on the experience and knowledge of each individual surveyor (Fig. 3-3). Topographical features, water bodies, and vegetation cover were recorded as a distance (in chains[14]) along each transect line, and several maps for each township were subsequently drafted which included general land cover descriptions, graphical depictions of the surveyors' more specific measurements, agricultural suitability of the soils, and forestry potential (Appendix 1a-d).

One of the most prolific and experienced of these surveyors in southwestern Alberta was C.F. Miles, well known for his skills as a naturalist (Watt, Rob. pers. comm. 2004), and although other surveyors returned to the WLNP in later years, it is his work completed in 1889-1890 that has been used exclusively in this study.

3.3.2 Data Selection

Canadian DLS records from the late 1880s provide excellent coverage for the study area. I examined the WLNP archives, and compiled and reviewed all survey records completed between 1883 and 1910 that were located within the study area. Several Dominion Land Surveyors worked in the Waterton area during this time period: G.J. Lonargan, T.W. Armstrong and C.F. Miles. Their work was combined and incorporated into the official township plans created for the area (i.e. Townships 1 and 2, Ranges 29 and 30) by the Department of the Interior in the early 20th century (Appendix 1). In order to minimize inconsistencies associated with differing timing, methods, experience, and land cover descriptions among surveyors, I selected only those transects compiled by C.F. Miles in the spring and summer of 1889 for this study. The other two surveyors either completed their work prior to (i.e. Armstrong in 1883) or following (i.e. Lonargan in 1901) that of Miles, and much of their work fell outside of the Park boundaries. Field notes compiled by C.F. Miles 1889 describe his traverses of a comprehensive series of one-

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[14] One surveyors' chain is equal to 20.1168 m or 0.0125 miles. Each one-mile transect was therefore approximately 80 chains in length.

mile transects covering a large contiguous area in the central Waterton valley spanning sections of Townships 1 and 2, and Ranges 29 and 30, West of the 4th Meridian.

3.3.3 Field Methods

In the summer of 2004, I made an attempt to locate all official existing Dominion Land Survey (DLS) monuments delineating township and range corners within the study area. The original survey monuments established in prairie areas consisted of either a wooden stake surrounded by four 1 square foot pits dug in the four cardinal directions, or a pyramidal stone cairn erected at the precise location of a township or range corner (Department of the Interior 1883). Many of these original monuments have been replaced with permanent steel pins established by the DLS in 1953, although evidence of two stone cairns and pits at three separate sites were noted in the field. GPS coordinates were obtained for each of the 12 steel monuments located within the study area.

In order to compare historic and current vegetation cover, I repeated 9 transect surveys and recorded present land cover. Consistently using the survey monuments located in the field as starting points, one-mile (1.6 km) traverses were repeated using a Magellan GPS, compass and survey pole. Both topographical features (i.e., ridges, streams and ravines) and land cover were recorded using similar methods and descriptions as those used by Miles. Distance along the line (in miles) covered by each land cover type was measured. Vegetative characteristics including dominant overstory and understory species were noted for every forest patch in prairie areas, and at equal intervals along the line (100-200m apart) in relatively homogenous aspen forest. These data were further used to ground truth 1999 air photo interpretation as described in section 3.2.2.

3.3.4 1889 Map Creation

In ArcGIS, a one-mile grid (line shapefile) was generated using the “fishnet” extension module, and geometrically corrected using the coordinates of the monuments located in the field

(12 section corners) as anchor points for the section corners (Fig. 3-4). The larger grid was then split into one-mile segments at section corners, and each individual line segment was labeled with the appropriate transect identification number obtained from historical township records. An additional polygon grid was generated which subdivided each section equally into 100 squares (0.1 x 0.1 miles each) and similarly geo-referenced. This second grid was used for the pilot study as described in Section 3.5.

Survey notes were reviewed, and a land cover classification was developed based on both written descriptions and pictorial representations recorded by Miles in 1889 according to standardized techniques outlined by the Department of the Interior (Department of the Interior 1883) (Appendix 2). Total transect length and the total distance of each land cover type along individual transects were tabulated from both 1889 survey notes and 2004 field notes. Discrepancies were noted when the recorded 1889 transect lengths were compared to the transect length on the ground (i.e., distance between monuments located in the field). Applying a universal correction factor to adjust the distances was inappropriate because the discrepancies were not equal among transects, implying that they were not a result of a systematic calculation or procedural bias, but rather an artifact of the surveying techniques being used. Instead, the tabulated 1889 land cover distances were adjusted using a proportional distance calculation according to the following formula:

$$\mathbf{D_{actual} = (TL_{actual} \times D_{hist}) / TL_{hist}} \qquad \textbf{(equation 3-1)}$$

where: $\mathbf{D_{actual}}$ = the adjusted distance of each land cover type along a transect
$\mathbf{TL_{actual}}$ = actual transect length calculated using coordinates of physical monuments located in the field
$\mathbf{D_{hist}}$ = distance of each land cover type recorded by Miles (1889) along an individual transect
$\mathbf{TL_{hist}}$ = total length of the individual transect as recorded by Miles (1889)

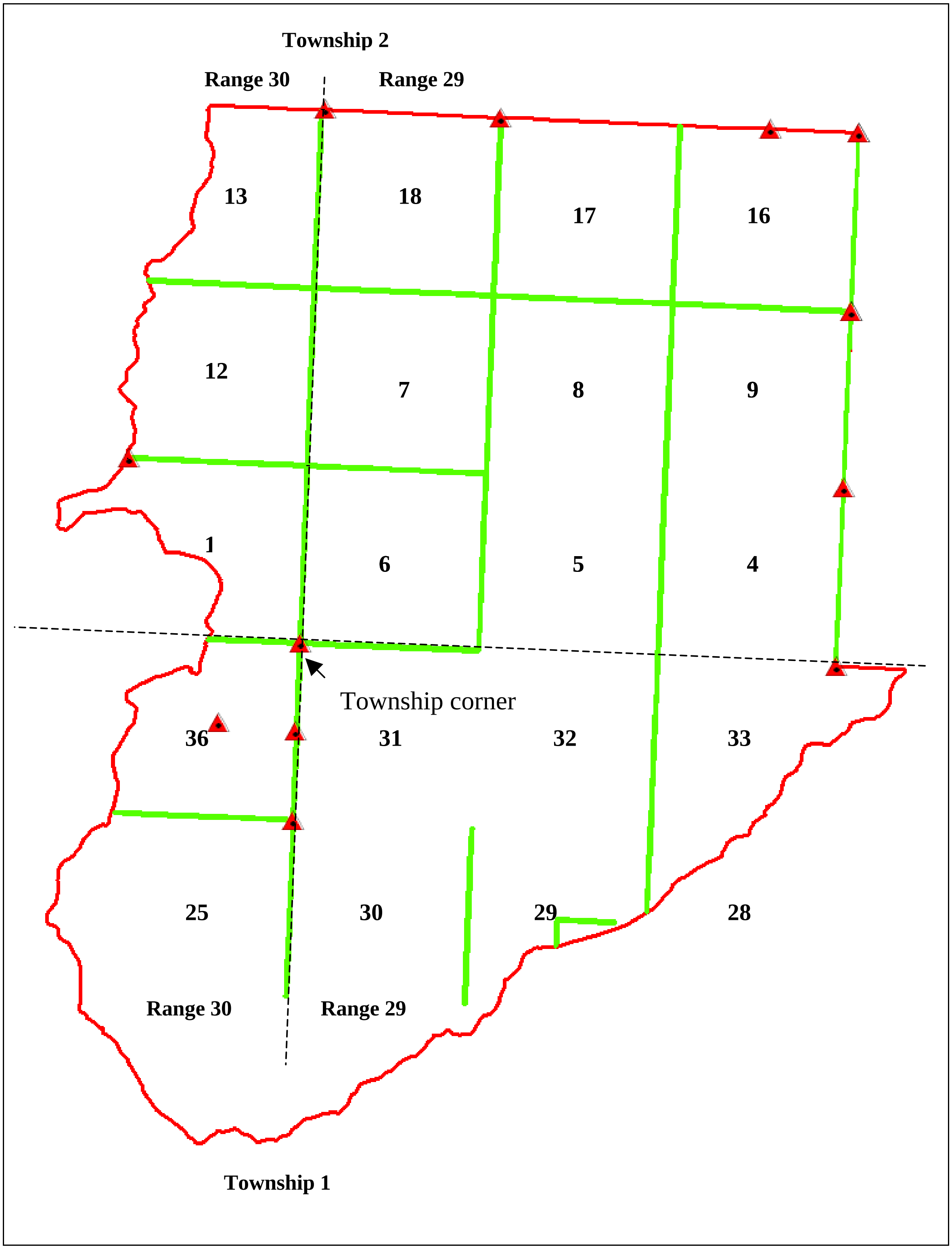


Figure 3-4: Diagram of study area with transects surveyed by C.F. Miles (1889) outlined in green, and sections labeled. Township (horizontal) and range (vertical) boundaries are delineated by the dotted lines. Missing transects were either not available or completed by another surveyor at a later date.

Each surveyed transect line in the 1889 township grid was then further split into segments corresponding to the new land cover distances (i.e., D_{actual}) and labeled, creating a final 1889 land cover grid (line shapefile). Topographical features recorded from the historical surveys were matched up with obvious features in an orthophoto derived from 1998 aerial photography to assess the accuracy of the grid registration, which was deemed to be accurate to approximately 5 m.

Based on field reconnaissance, I assumed that Miles' land cover descriptions would have extended beyond a one-dimensional survey line (i.e. he was describing land cover along either side of his survey line as well as directly on top of it). To reflect this assumption, and to facilitate comparison of land cover between years, a 10 m buffer (polygon shapefile) was generated from the 1889 land cover line grid (i.e. a polygon that extended 10 m on either side of the transect line). For example, a 20 m distance of "aspen forest" along the transect line became a 20 m x 20 m aspen forest polygon. A featureless 10 m buffer (polygon shapefile) was also generated from a blank line grid of the surveyed transects for subsequent overlay analyses using the 1939 and 1999 land cover maps.

3.3.5 Data Analysis

The total area of each land cover type within the surveyed area (i.e., 1889 land cover polygon layer) was tabulated. Next, an overlay was performed between the featureless 10m buffer and each of the 1939 and 1999 maps. The total area of each land cover type was then calculated for each of these years. All values were converted to a relative percentage of the total area surveyed.

The average annual rate of change (ha/year) for aspen forest and grassland cover types was calculated for each time interval (i.e. 1889-1939 and 1939-1999) within the surveyed transect area (76.3 ha) using the formula:

$$\textbf{Rate of change}_{transect} = (\textbf{area}_{t2} - \textbf{area}_{t1}) / \textbf{T} \qquad \textbf{(equation 3-2)}$$

where: $\textbf{area}_{t2}$ = total area of a given land cover type at the later date (ha)
$\textbf{area}_{t1}$ = total area of a given land cover type at the earlier date (ha)
T = elapsed time interval (years)

This value was extrapolated to get an average annual rate of change for the entire study area using the following formula:

$$\textbf{Rate of change}_{total} = (\textbf{Rate of change}_{transect} \textbf{ x 5140 ha}) / \textbf{76.3 ha} \qquad \textbf{(equation 3-3)}$$

Finally, four summary Township Plan (1891-1902) maps completed by the Department of the Interior (Appendix 1a-d) were reviewed. All general land cover descriptions recorded by Miles were tabulated, and compared to personal field observations of current land cover in the same areas.

3.3.6 Sources of Error and Bias

One important consideration is that the original purpose of these surveys was not to sample vegetation, but to survey land use potential in an area. Some surveyors likely had limited ecological skills, and their often ambiguous or vague vegetation descriptions (e.g., "open grassland") should therefore be interpreted with caution. Additionally, erroneous interpretation of sketches representing various land cover types may also have affected the study results. The various descriptions were generalized into broader categories during the classification to minimize this problem.

Although inconsistency between surveyors' descriptions was avoided by limiting data to one surveyor, there is a risk that systematic bias in Miles' descriptions may be present in the data. As a result, there may be an argument for using and comparing multiple surveyors' records, especially when they were completed over a short time period (< 5 years) during which ecological change would be minimal.

3.4 Investigating Landscape Change Using Repeat Photography (1914-2004)

3.4.1 Description of the Data Source

When Dominion Land Surveyors encountered the Rocky Mountains at the turn of the century, it was clear that standard surveying methods being employed to map the rest of the country could not be applied to the mountainous expanses of Western Canada. To accomplish the challenging task of accurately mapping these topographically complex areas, a new technique called "phototopographical surveying" was adopted.

The painstaking craft of producing some of Canada's first topographic maps directly from photographs of the mountain landscape required a systematic approach. Early Dominion Land Surveyors photographed the landscape from hundreds of discreet and carefully chosen photo stations located on mountain peaks, cliff edges and prominent points at lower elevations on the valley floor. Ideally, the crew obtained a full panorama of photographs from a single location, with each shot aligned along cardinal directions (e.g. north, southeast). Where this was impossible from one station alone, substations were selected in order to ensure that photographic coverage of the landscape was complete and extensive, depicting individual landscape features from multiple vantage points. Using hundreds of theodolite measurements and precise photogrammetric techniques, it was then possible to calculate the precise geographic location and elevation of specific landscape features (Bridgland 1924; Rhemtulla 1999).

One of the most prolific of Canada's early surveyors was Morrison Parsons Bridgland, who worked extensively throughout the Rocky Mountains at the end of the 19th and beginning of the 20th centuries, and compiled tens of thousands of large-format (4.5 x 6.75"), glass plate negatives of the mountainous west. His work in what is now known as WLNP was completed in 1914 as part of the 1913/1914 survey of the Crowsnest Forest Reserve, a swath of the eastern slopes of the Rockies from the International border north to present-day Kananaskis country. A collection of digital repeat photographic images taken from the exact original photo locations was created in the summers of 2003 and 2004 by the Rocky Mountain Repeat Photography Project[15] (RMRPP) using a sophisticated digital imaging system. Images were compiled in a digital database that at the time of writing is being served from the University of Victoria. Care was taken to replicate photograph location, camera position and seasonality of the images where possible.

3.4.2 Image Selection and Preparation

I systematically reviewed the RMRPP digital image archive for images depicting the foothills-parkland eco-region. Views from two ground-based and two high-elevation stations provide excellent coverage of the study area (Table 3-1) and 12 image pairs were selected for analysis. I overlaid high-resolution scans of the historic (1914) glass-plate negatives (800 dpi) and repeat (2003-2004) images (1000 dpi) in Adobe Photoshop 7.0, and matched up prominent features such as mountain ridges, lake edges and roads to facilitate a precise visual comparison between dates. I then cropped the images to decrease file size and isolate the area of overlap between the two images.

Table 3-1: Station names and plate numbers of repeat photographs depicting the study area

Station Name	Photographs Used
High Elevation	
Crandell	681-682
Vimy	687-688
Ground Based Stations	
Bison Paddock	536, 539-541
Blakiston Mouth	654-658

[15]See the RMRPP website for further information: http://bridgland.sunsite.ualberta.ca

3.4.3 Analysis

I developed a set of change indicators to address the specific research questions of this study. They therefore focus primarily on observed changes in forest and shrub cover both throughout the study area as well as on the hillslopes above and bordering the study area. Additional notes were made where associations with landscape features were observed (i.e. proximity to riparian areas, microtopographical features, alluvial fans). Observations for the ground-based photographs were completed for both the image foreground and image background because of the large discrepancy in scale created by the horizontal distortion away from the camera lens and the resulting difference in total area being evaluated. It is also assumed that foreground observations can be made with more confidence since landscape characteristics are much clearer. This is not as much of an issue with the repeat images which were very high resolution and quality, but in the historic images, foreground detail was often much better than background detail.

For each indicator, the direction of land cover change was recorded as either: increase (I), decrease (D) or no change (NC). To avoid ambiguity in using the “no change” class to describe changes in an image where the land cover was not present in either photo (e.g. no aspen cover in either image) a distinction of not present (NP) was used. Where the observation could not be made with confidence due to poor image quality or image angle, an additional “not applicable” (N/A) class was used. Results of this analysis were summarized and tabulated.

3.5 Integrating Multiple Data Sources: A Pilot Study

The following discussion outlines a preliminary attempt to test the efficacy of integrating two historical data sets: oblique historical photographs and Dominion Land Survey data. It was attempted using three high-elevation photograph pairs and two ground-based photograph pairs. The following discussion will outline the progress made, and a critical discussion of possible future directions will be outlined in the following chapter (see Section 4.4).

3.5.1 Data Preparation

Five cropped repeat photograph pairs were selected (Table 3-2) and opened in Adobe Photoshop 7.0. For each pair, the 1999 image was set as the background, and the corresponding 1939 image was overlaid as an image layer. Next, a blank image layer was added in which outlines of prominent landscape features (i.e. lake edges, mountain ridges) were traced using drawing tools (see Fig. 3-5 for illustration). This layer was made transparent so the outlines could be viewed concurrently with the 1939 and 1999 photographs.

In ArcScene, the 2004 DEM of WLNP was loaded and the two 1998 1 m orthophotographs were draped on the 3D surface. Within this geographically accurate 3D model of the landscape, prominent features such as lakes, road intersections and mountain ridges were visible to the viewer (Fig. 3-5). Additional layers were added including the line grid of surveyed 1889 transects and one line grid layer highlighting only eight specific transects that were properly visible in one or more photographs (Table 3-2). Each transect was exploded into 10 equal segments to facilitate estimations of distance (Fig. 3-5).

All photo station coordinates were obtained from the 2002-2004 RMRPP field notes and used as “viewer” location coordinates. Each individual photograph was studied and the apparent “target” location of the image was identified. Using elevations extracted from a topographic map of the area, elevation of the viewer was determined. Using this viewer and target information, the 3D landscape model perspective was iteratively adjusted to the corresponding photograph open concurrently in Photoshop.

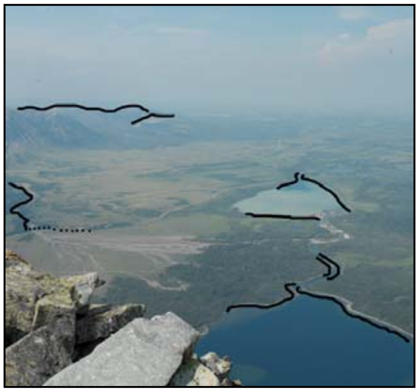
The transect grid was then overlaid in on the landscape model in ArcScene, and once this preliminary match was complete, two .tiff images were exported: (1) the landscape model image alone (model image), and (2) the transect grid alone. In Photoshop, the model images were cropped to match the width of the photographs, and resampled to equate the model image size to the image size of the photograph pair.

Table 3-2: Image pairs used and transects studied for pilot study attempting to locate DLS survey transects in historical and repeat oblique photographs.

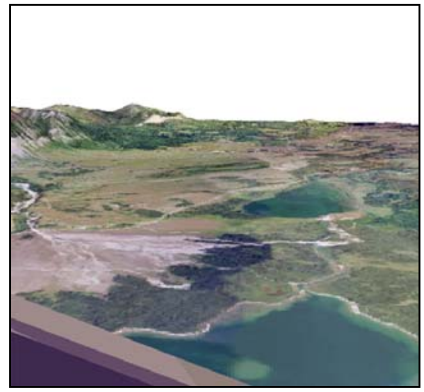
Bridgland Photo Station	Image Number	Transects Visible
Vimy	687	2-30-1E[16] 2-30-1N 1-30-36E 1-30-36N 1-30-31N
	688	2-29-16E 2-29-9E 2-29-4E
Crandell	681	1-30-36N
Blakiston Mouth	655	1-30-36N 1-30-36E
	658	2-30-1N

Next, the exported model image and transect grid image were added as additional layers to the original repeat photograph image file, bringing the total number of layers for each file to five: (1) the 1999 photograph, (2) the 1939 photograph, (3) outline of landscape features, (4) the matching landscape model image, and (5) the transect grid image. The new image layers were then superimposed as semi-transparent layers on the 1999 photograph and adjusted using the outline layer as a guide to match obvious landscape features and achieve as exact an overlay as possible. If the match was not acceptable, the process was iteratively repeated until an acceptable match was successfully accomplished.

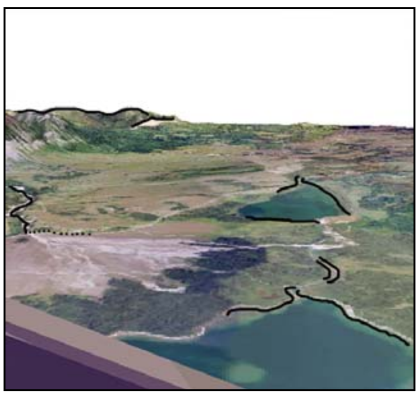
[16] Notation identifies Township-Range-Section numbers. (e.g. 2-30-1E refers to the eastern boundary of section 1 in Township 2, Range 30)



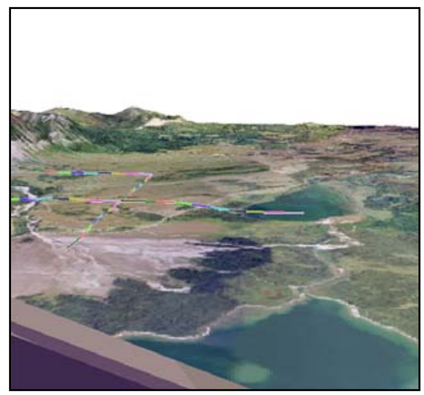
<u>Step 1</u>: Outline prominent features (Adobe Photoshop)



<u>Step 2</u>: Create 3D Model (ArcScene)

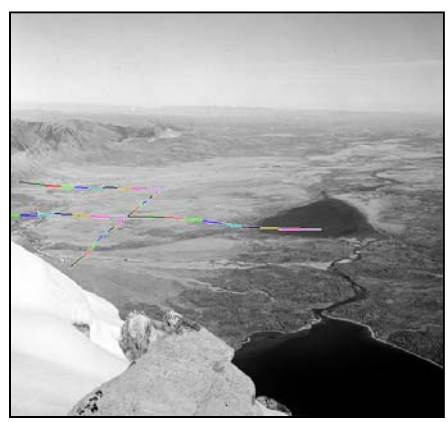


<u>Step 3</u>: Adjust 3D model using outlines of landscape features (ArcScene/Adobe Photoshop)



<u>Step 4</u>: Overlay transect grid on model image (ArcScene)

<u>Step 5</u>: Overlay transect grid on 1999 image (Adobe Photoshop)



<u>Step 6</u>: Overlay transect grid on 1939 image (Adobe Photoshop)

<u>Figure 3-5:</u> Flow chart of methods used for pilot project locating historical DLS transects in historical and repeat photographs.

3.5.2 Analysis

The goals of this exercise included: (1) determining if useful information could be extracted and quantified along transect lines in 1914, thus providing another time slice for analysis; (2) determining whether patches identified along each transect in 1939 were present in 1914; and (3) using the ground based images to verify surveyors' land cover descriptions near the turn of the century. To achieve these goals, specific transects were examined in detail concurrently in both Photoshop and ArcGIS to assess the accuracy of the transect location, and determine whether specific patches appearing in 1939 were present in 1914. General descriptions of land cover along the transects visible in the two ground-based images (#655 and #658) were made.

3.5.3 Sources of Error and Bias

Although extreme care was taken in the field to repeat images with a very high level of accuracy, the match was rarely exact, meaning that a transect accurately located in the 1999 image may not have been precisely in the same location as in the 1939 image and vice-versa. In addition, matching a digitally produced 3-D landscape model perspective with the actual photographs may have introduced some location error since digitally produced features were much grainier than the actual features in the photographs (i.e. lake edges, rivers, mountain ridges). Further accuracy errors will be discussed in more detail in Section 4.4.

CHAPTER FOUR

The Changing Landscape of Waterton Lakes National Park: Results and Discussion

4.1 A Tale of Two Surveyors: the Dominion Land Survey (DLS) in WLNP

4.1.1 Walking the Thin Red Lines: Repeating the DLS transects

The selected DLS survey transects were well distributed throughout the study area (Fig. 3-3) and the observed trends mirror results from aerial photograph analysis (see Section 4.2). Notable changes in the distribution of land cover along the surveyed transects (approximately 76.3 ha or 1.5% of total study area) between 1889 and 1999 were observed (Fig. 4-1). Forested area increased from 2.6% in 1889 to 18.9% in 1939, and 24.6 % in 1999 (Fig. 4-1), with the area occupied by aspen forest accounting for the majority of this increase (2.6% → 16.1% → 20.9%[17]). Although the rate of expansion was almost certainly not constant over this time period, these data suggest that the average annual rate of aspen expansion was considerably higher in the early part of the century (1889 to 1939) at 13.5 ha/year compared to 4.0 ha/year between 1939 and 1999.

Previously absent conifer forest (0% → 0.2% → 0.7%), cottonwood forest (0% → 2.5% → 2.9%) and mixed forest (0% → 0.1% → 0.1%) types also appeared on the landscape after 1939, and the number of patches encountered increased for all three forest types (Table 4-1), with the majority of new patches appearing along transects in the western portion of the study area (i.e. 2-30-1N/1E; 2-29-6N). The proportional area of the shrub complex cover type decreased slightly overall, initially declining from 9.5% (1889) to 8.4% (1939), then increasing slightly to 8.7 % (1999), while the total number of shrub patches increased considerably from 27 to 39.

[17] Refers to % of total cover in each year studied (i.e. 1889 → 1939 → 1999).

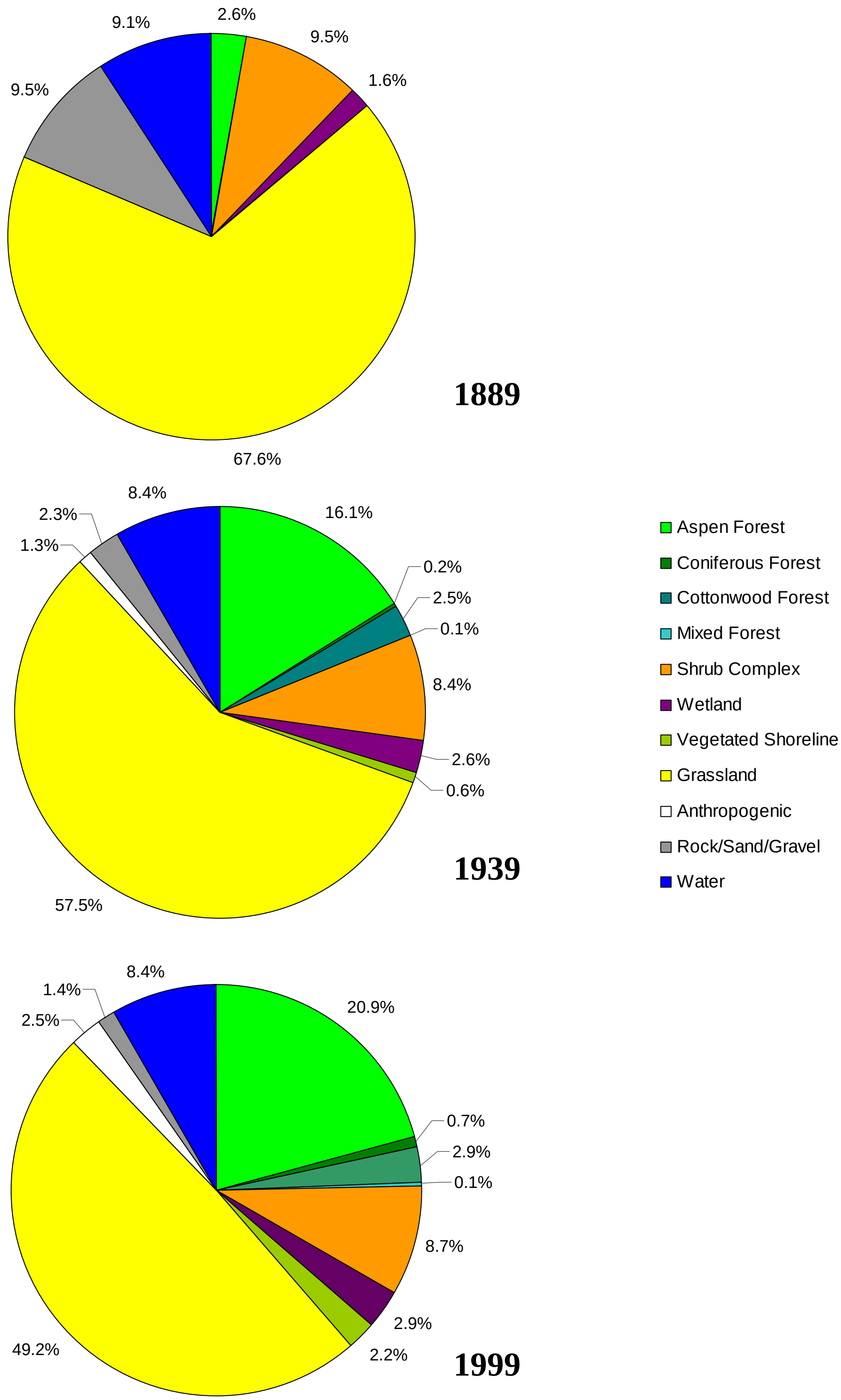


Figure 4-1: Comparison of relative land cover along surveyed DLS transects. Values are reported as a percent of the total area surveyed (76.3 ha).

Table 4-1: Number of patches (approx. >1600m^2) encountered along survey lines in 1889, 1939 and 1999.

		Number of Patches		
Landcover Description		1889	1939	1999
Vegetated				
1	**Aspen Forest**	10	29	40
2	**Coniferous Forest**	1	2	5
3	**Cottonwood Forest**	0	6	8
4	**Mixed Forest**	0	1	1
5	**Shrub Complex**	27	36	38
	5a. Willow Shrubland	8	9	9
	5b. Mixed Aspen-Willow Shrubland	11	0	0
	5c. Shrubland	8	27	29
6	**Wetland**	5	4	7
7	**Exposed Vegetated Shoreline**	0	3	5
8	**Grassland**	42	29	22
Unvegetated				
9	**Anthropogenic**	0	4	2
10	**Rock/Sand/Gravel**	13	8	7
11	**Water**	18	4	3

These results, along with visual inspection of the spatial data and field observations, suggest that although the total area of shrub cover has remained fairly constant, the location of shrub patches is constantly shifting as original patches are replaced by later successional forest types and new patches become established.

The proportion of grassland cover dropped by almost 20%, declining fairly consistently between 1889 and 1999 (67.6% → 57.5% → 49.2%) and the number of grassland patches declined by more than half (42 to 22). Wetland cover continued to increase over the study period and almost doubled overall (1.6% → 2.6% → 2.9%) with two new wetlands appearing in 1999 for a total of seven, perhaps in response to wetter climate conditions in the late 20th century. The relative cover of vegetated shoreline (0% → 0.6% → 2.2%) and anthropogenic (0.1% → 1.3% → 2.5%) cover types, unrecorded in 1889, increased steadily, although the total number of patches of each remained low, at five and two, respectively, in 1999.

The total area covered by open water initially declined slightly, then leveled out (9.1% → 8.4% → 8.4%), while the total number of visible water bodies (streams/rivers/lakes) decreased substantially from 18 to 3.[18] There was also a major decline in the amount of rock/sand/gravel visible on the landscape (9.5% → 2.3% → 1.4%), although the number of patches decreased less dramatically (13 to 7). Most of the rock/sand/gravel cover in 1889 was located along river beds and described as "stony flats" in historical records, and many of these areas have converted to common riparian vegetation types including vegetated shoreline, willow shrub, or cottonwood forest in subsequent years.

Table 4-2: Comparison of verbal land cover descriptions from Township Plans released by the Department of the Interior Topographical Surveys Branch (1891-1902) to observed contemporary (2004) land cover.

Location	DLS Land Cover Description (1891-1902)	Observed 2004 Land Cover
Township 1, Range 29	"Chiefly rolling prairie with scattered scrub, some poplar[19] and willow along the river and lakes"	Chiefly cottonwood forest and willow scrub with some small scattered grasslands on elevated sites
Township 1, Range 30	"Open rolling prairie"	Golf course
Township 1, Range 30	"Stony flats" with "Cottonwood, poplar and willow" along lake edge	Stony flats with cottonwood, poplar and willow along lake edge
Township 2, Range 29	"Rolling prairie with some poplar, willow and scattered scrub"	Continuous young poplar forest cover dotted with small grassland and scrub openings
Township 2, Range 29	"Thick and scattered poplar scrub"	Scattered mature poplar forest and scrub patches
Township 2, Range 29	"Chiefly poplar and willow"	Prairie with scattered poplar forest
Township 2, Range 30	"Open rolling prairie, some bush and scrub"	Chiefly open rolling prairie with scattered poplar forest and scrub
Township 2, Range 30	"Open rolling prairie"	Prairie with dense poplar forest and conifer woodlands

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[18] The large decrease in the number of water bodies or patches between 1889 and 1939 is likely not due to an actual loss of water on the landscape, but rather due to the fact that many of the streams and rivers distinguishable during ground-based surveys are not visible from aerial photographs because they are either covered by vegetation, or are simply indistinguishable at that resolution.

[19] Refers to aspen.

The comparison of general land cover descriptions appearing on historical Township Plan maps (Appendix 1) to contemporary land cover descriptions of the same areas indicates increased forest cover across the study area as a whole (Table 4-2). Changes were most pronounced in the Blakiston river area (Township 2, Range 30) and Township 2, Range 29 along the eastern Park boundary, where in both cases, woody vegetation cover appears to have increased considerably.

4.1.2 Repeating the Bridgland Legacy

The qualitative visual analysis comparing 14 sets of historical (1914) and repeat (2003-2004) oblique images from 4 photo stations (see Appendix 4) revealed two localized trends: (1) increased shrub and forest cover; and (2) no apparent change (Table 4-3). Change in the image foreground of ground-based photographs was the easiest to describe and document. It was difficult to discern changes in the image background of the ground-based images, and to assess changes in stand height or density in the high-elevation images. An “indistinguishable” category was used in these cases.

The largest increase in woody cover occurred at the mouth of the Blakiston Valley where the character of the landscape changed dramatically (Appendix 4a), whereas little to no change was apparent in the grasslands in the northwest portion of the study area (i.e. the “Badlands” or “eskerine complex” area) (Appendix 4b). In the foreground of roughly half of the ground based images, forest and shrub cover increased, transforming the landscape from a distinctly open rolling prairie to a patchy mosaic of aspen and conifer forest stands and shrub patches dotting the open grassland (Table 4-3).

Table 4-3: Summary table showing results from comparison of historical (1914) and repeat (2003-2004) photographs. Numbers indicate the number of photographs in which each direction of change was observed. Please see Appendix 6 for more detailed observations from this analysis.

Direction of Change	**Forest Cover**				**Shrub Cover**	
	Stand Height	**Stand Density**	**# of patches**	**Patch size**	**# of patches**	**Patch size**
Ground Based Stations						
Image Foreground						
Increase	5	4	5	5	5	4
Decrease	0	0	0	0	1	1
No Change	4	5	4	4	3	4
Image Background						
Increase	6	5	5	9	3	3
Decrease	0	0	0	0	3	2
No Change	3	2	2	0	0	1
Indistinguishable	0	2	2	0	3	3
High Elevation Stations						
Increase	3	3	3	3	0	0
Decrease	0	0	0	0	0	0
No Change	0	0	2	2	0	0
Indistinguishable	2	2	0	0	5	5

Many of the small, isolated, scrubby aspen patches that are visible in the historic images in the western prairies have expanded and connected to form a few larger, contiguous forest patches. In the background of several ground-based images, the increase in forest cover was considerable, particularly along the bases of the mountains surrounding the study area where conifer cover has increased substantially over the past century. This was especially obvious on the north side of Crandell Mountain where a large fire scar covering the entire north-facing slope is obvious in the historic images, and has been replaced with thick coniferous forest in the repeat images (Appendix 4c).

Evidence of advancing succession was also observed as many of the stands matured into taller, dense aspen forest (Appendix 4d). Forest height, cover and density increased dramatically along riparian zones where the historic community of sparse and scrubby deciduous cover dotted with a few mature conifer trees changed to dense, mature cottonwood or mixed forest along river edges. Areal expansion of these riparian forests was evident in both the ground-based and high-elevation imagery (Appendix 4a).

Conversely, no change in forest or shrub cover was observed in several of the ground-based image pairs taken from near the bison paddocks, which are located near the northeast corner of the study area. Typically, there was very little to no forest or shrub cover visible in either the historic or repeat images in this area. In a few cases, the shrub patch location shifted slightly, but there was no obvious increase in the total cover or physical characteristics of the woody vegetation. Forest cover did not decrease in any of the image pairs, and a decrease in shrub cover was observed in a few image pairs, largely as a result of succession to aspen forest.

4.1.3 Combining Historical Data Sources

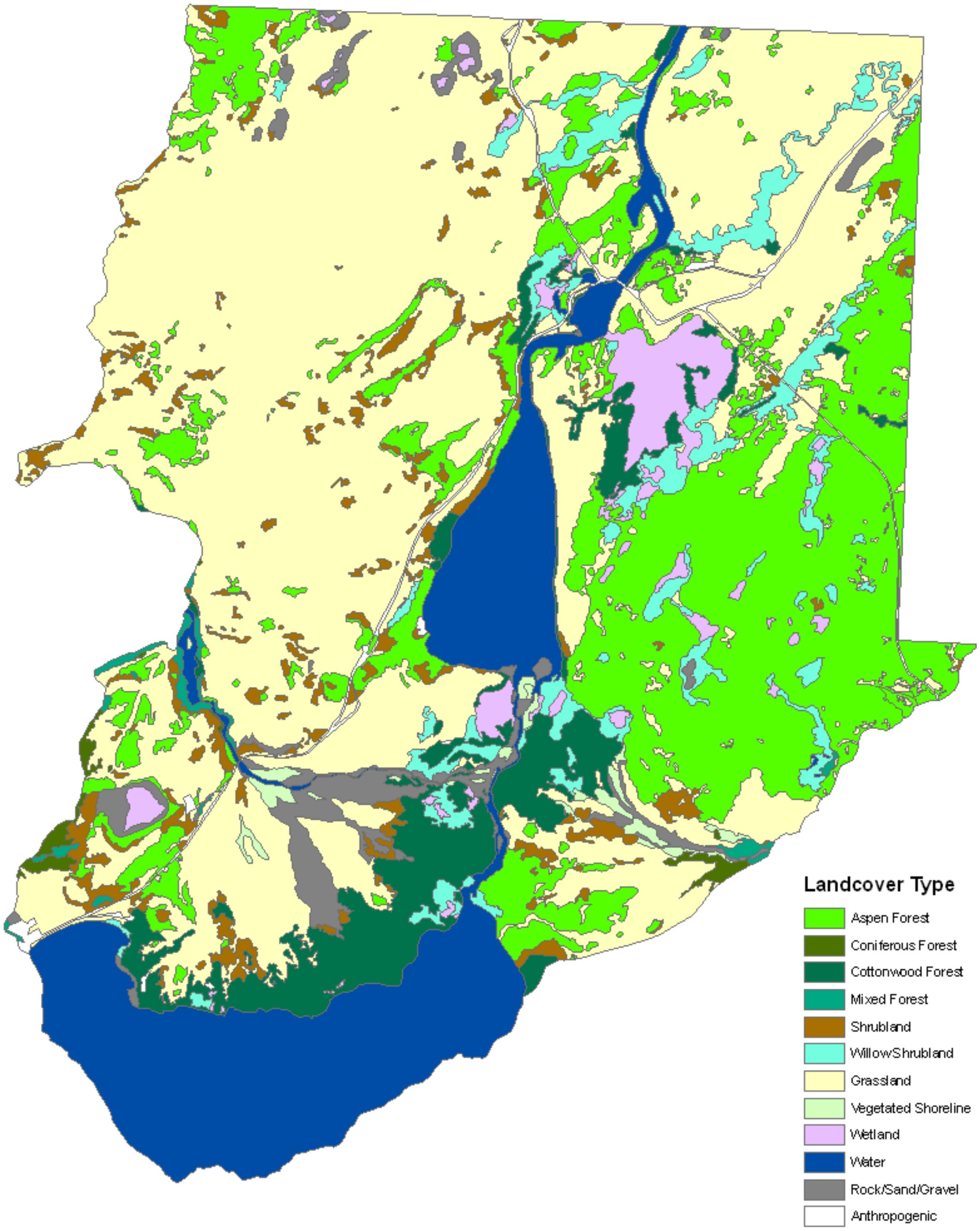
Along all eight transects reviewed in detail by overlaying historical transects (1889) on the repeat photograph pairs (1914 and 2004) and subsequent vegetation maps (1939 and 1999), all but one shrub patch present in 1939 had already established by 1914. The heavily forested upland area in Township 2, Range 29 (sections 16E, 9E, 4E) (Fig. 3-3), which had no forest cover in 1889 (Fig. 3-3), appeared to already be forested in 1914, but forest cover was clearly patchier at the earlier date (1914) than in the 2004 images along these transects. One sizeable grassland that was present in 1914 had disappeared by 1939 while two of the grassland patches that were mapped in 1939 were not visible in 1914 (2-29-9E). The three images showing transect 1-30-36N indicated an expansion of the riparian forest community along the Blakiston River. These images showed a distinct change from a transect line passing entirely over open rolling prairie in 1914, corroborating Miles' 1889 description, to a transect passing through several conifer woodland patches and a dense mixed riparian forest, and beside mature aspen clones. In general, a large proportion of the woody vegetation establishment that was identified along transect lines in the 1939 imagery had already established as early as 1914.

4.2 A Bird's Eye View: Investigating Landscape Change using Aerial Photographs

Results from the air photo analysis revealed similar trends to those observed using the other two historical data sources while providing more spatially explicit information (Fig. 4-2a,b). Aspen forest and grassland were by far the most common land cover types within the study area, representing over 20% and 40% of the total land cover respectively at both dates (i.e. 1939 and 1999) (Fig.4-3). There was an increase in the areal extent of all forest and shrub cover types, and a decline in the amount of open grassland within the study area between 1939 and 1999 (Fig. 4-3). New aspen forest (+236 ha) comprised the majority of all forest expansion (+299 ha), establishing at a rate almost equivalent to that calculated from historical transect data: 3.9 ha/year.

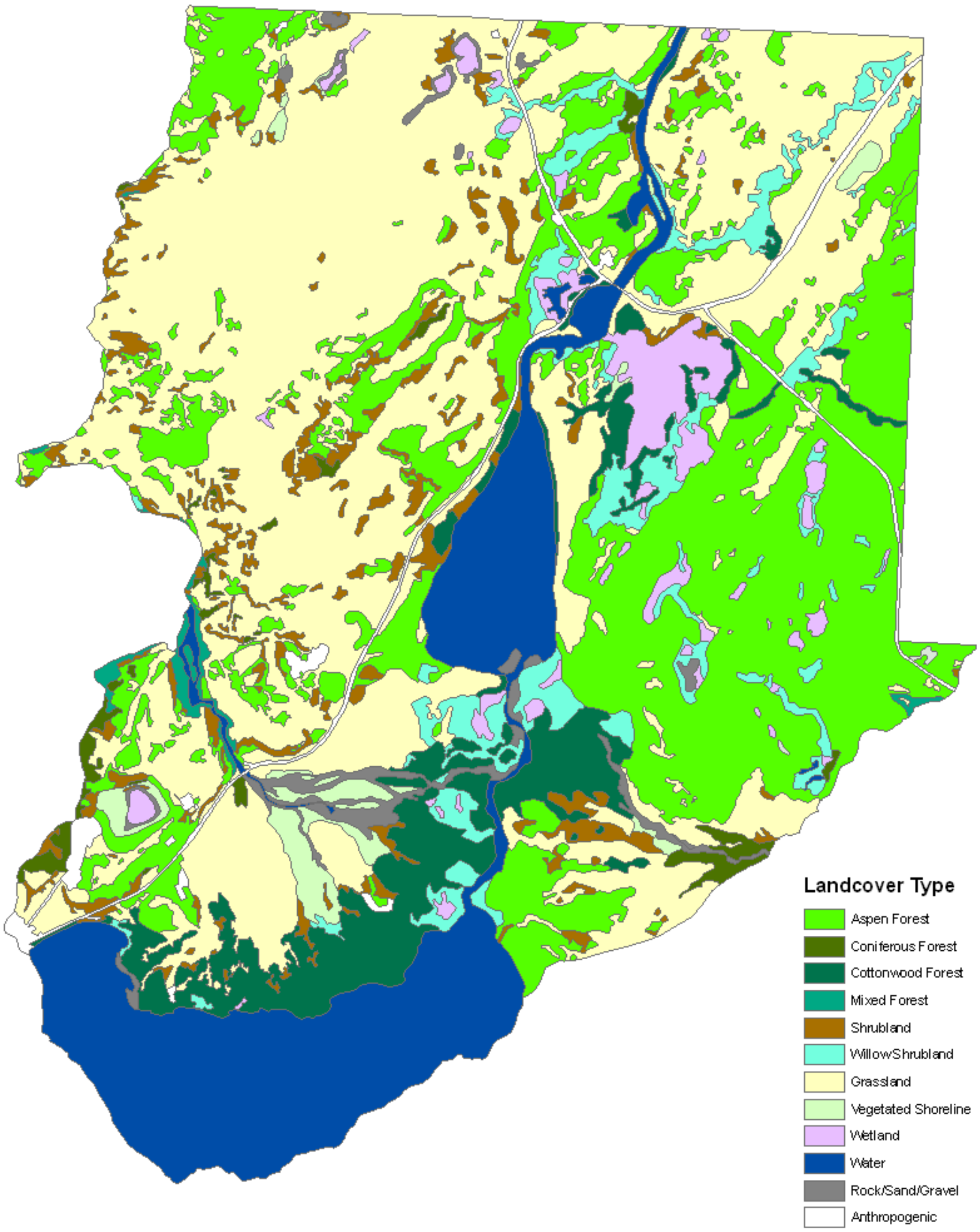
Despite making up a comparatively small proportion of the total forest cover, the areal extent and number of patches of conifer forest more than doubled (Table 4-4). There were also increases in the amount of wetland, vegetated shoreline and anthropogenic land cover types, and a considerable decrease in land occupied only by rock/sand/gravel. The amount of water in the study area remained largely unchanged, and one small burned area appeared in 1999 (Fig. 4-3), indicating that fire disturbance was responsible for at least a small fraction of the change being observed.

Results suggest a progression from early to late successional vegetation types throughout the study area (Table 4-5). Of the 373 ha of lost grassland, 47% (175 ha) was replaced by aspen forest, 38% (140 ha) by mixed shrubland communities, and 7% (26 ha) to willow shrubland cover (Table 4-5). Approximately 62% of shrubland and 30% of willow shrubland in 1939 converted to various forest types, particularly aspen forest, in 1999 (Table 4-5). Slightly over 31% of mixed forest changed to conifer forest, while in one area affected by a slope failure, close to 9% of 1939 conifer forest was replaced by new shrubland. The results also provide evidence for the dynamic nature of riparian vegetation communities, with comparably sized transitions between willow shrubland, wetland and cottonwood forest communities in low-lying wet areas, and a trend



1939

Figure 4-2a: 1939 land cover map derived from standard air photo interpretation.



1999

Figure 4-2b: 1999 land cover map derived from standard air photo interpretation.

Table 4-4: Comparison of number of patches, mean patch size (ha) and standard error between 1939 and 1999 within the study area. An asterisk (*) indicates a statistically significant difference at the 0.05 level of mean patch size between years (1939→1999) (see Appendix 5 for details of statistical analysis).

Landcover Description	Number of Patches		Mean Patch Size (ha)		Standard Error	
	1939	1999	1939	1999	1939	1999
Vegetated						
Aspen Forest *	167	162	6.26	7.91	3.39	3.68
Coniferous Forest	11	25	1.91	2.10	0.72	0.57
Cottonwood Forest	38	37	7.82	8.78	4.23	4.72
Mixed Forest	15	12	1.44	2.00	0.30	0.62
Shrubland *	201	197	0.90	1.09	0.10	0.09
Willow Shrubland	53	49	3.81	4.51	0.75	0.91
Grassland *	181	118	13.16	17.02	7.22	9.52
Vegetated Shoreline	21	18	1.48	4.04	0.34	1.32
Wetland	45	47	2.67	2.80	1.48	1.23
Non-Vegetated						
Anthropogenic	7	9	5.91	8.36	4.84	6.57
Rock/Sand/Gravel	37	18	3.45	3.82	1.41	1.55
Burned	0	2	0.00	0.86	0.00	0.29
Water	9	7	74.40	94.85	65.95	85.51
TOTALS	785	701	123.22	158.14	90.73	116.58

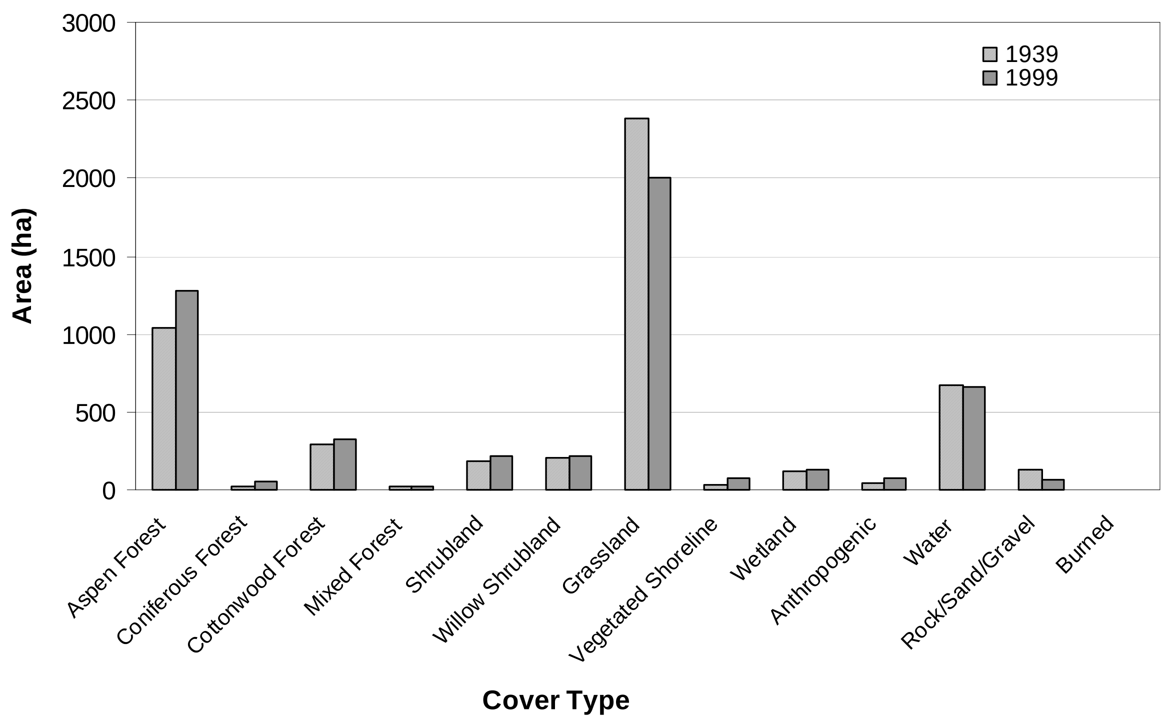


Figure 4-3: Total land cover of each cover type compared between years (1939-1999) measured as total area (ha).

Table 4.-5: Matrix showing land cover transitions from 1939 to 1999 between all cover types within the study area (5140 ha). Values are reported as the % of the 1939 cover for each from/to combination (e.g. 0.11% of conifer forest cover in 1939 changed to anthropogenic in 1999) and shaded cells indicate the amount of each cover type that did not change between years.

1939 \ 1999	Anthro	Conifer Forest	Aspen Forest	Cottonwood Forest	Mixed Forest	Vegetated Shoreline	Grassland	Water	Rock/Sand /Gravel	Shrub	Burned	Willow Shrub	Wetland
Anthro	60.60	3.49	0.93	0.11	4.22	0.06	1.26	0.06	1.07	3.25	0.00	0.43	0.00
Conifer Forest	0.00	81.78	0.23	0.14	31.40	9.66	0.71	0.00	0.34	1.84	0.00	1.08	0.00
Aspen Forest	4.66	1.19	90.40	8.05	1.28	0.18	7.33	0.11	0.92	50.79	0.00	19.44	1.67
Cottonwood Forest	2.94	0.00	1.69	76.34	0.00	18.92	0.94	0.57	5.65	8.95	0.00	9.73	3.33
Mixed Forest	0.44	1.67	0.39	0.37	44.91	0.25	0.19	0.37	0.00	0.93	0.00	0.00	0.00
Vegetated Shoreline	0.00	0.00	0.02	0.05	0.00	17.42	0.42	0.12	40.85	0.99	0.00	0.01	1.88
Grassland	28.68	2.65	1.72	1.27	2.61	14.07	81.52	0.09	5.83	7.52	0.00	2.61	0.76
Water	0.64	0.46	0.18	1.63	3.92	2.25	0.03	96.65	1.96	0.30	0.00	0.93	2.01
Rock/ Sand/ Gravel	0.00	0.15	0.01	0.90	1.27	13.98	0.49	0.95	29.01	0.79	0.00	0.64	2.83
Shrub	1.28	8.62	0.81	2.14	10.10	11.02	5.89	0.07	4.55	22.87	0.00	1.45	0.28
Burned	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Willow Shrub	0.68	0.00	2.65	7.98	0.29	9.50	1.08	0.84	4.31	1.74	0.00	54.75	12.92
Wetland	0.09	0.00	0.80	1.01	0.00	2.70	0.16	0.15	5.50	0.02	0.00	8.94	74.32
TOTAL AREA 1939 (ha)	**41.38**	**21.04**	**1045.10**	**297.27**	**21.53**	**31.07**	**2381.75**	**669.62**	**127.68**	**181.22**	**0.00**	**202.05**	**120.22**
% of Total Area (1939)	0.8	0.4	20.3	5.8	0.4	0.6	46.3	13.0	2.5	3.5	0.0	3.9	2.3
TOTAL AREA 1999 (ha)	**75.23**	**52.60**	**1281.01**	**325.02**	**24.05**	**72.78**	**2008.50**	**663.97**	**68.70**	**214.05**	**1.71**	**220.86**	**131.44**
% of Total Area (1999)	1.5	1.0	24.9	6.3	0.5	1.4	39.1	12.9	1.3	4.2	0.0	4.3	2.6

towards the re-vegetation of rocky shorelines by forbs, shrubs, and cottonwood forest along lakes and rivers (Table 4-5, Fig. 4-2a,b).

The results also suggest an overall increase in homogeneity across the landscape. The total number of patches dropped overall from 785 to 701, and decreased for all but three land cover types: coniferous forest (11 to 25), wetland (45 to 47) and anthropogenic (7 to 9), with two small burned patches appearing in 1999 (Table 4-5). There was a corresponding increase in the mean patch size for all patch types, most notably the significant changes in the patch size distributions of aspen forest, shrub and grassland cover types.

When the study area was subdivided into ecologically distinct sections (Fig. 3-2), some additional patterns of land cover change became evident (Table 4-6). In the northeast portion of the study area (Area C), the landscape is dominated by an aspen forest matrix dotted with patches of grassland, shrubland and wetland, whereas Area A is characterized by a grassland matrix dotted with patches of woody vegetation (Fig. 3-4).

Table 4-6: Number of Patches, Mean Patch Size and Total Edge Length for grassland and woody vegetation forest types in two ecologically distinct areas. A * indicates a statistically significant difference (see Appendix 5 for results of statistical analysis).

	Area A Grassland						**Area C Continuous Aspen Forest**					
Landcover	**# of Patches**		**Mean Patch Size (ha)**		**Total Edge Length (km)**		**# of Patches**		**Mean Patch Size (ha)**		**Total Edge Length (km)**	
	1939	**1999**	**1939**	**1999**	**1939**	**1999**	**1939**	**1999**	**1939**	**1999**	**1939**	**1999**
Conifer Forest	2	15	0.08*	0.96*	0.22	7.53	0	1	0.00	1.41	0.00	0.67
Aspen Forest	122	133	2.03*	3.25*	92.36	133.02	12	7	57.45	100.28	76.4	60.62
Cottonwood Forest	19	21	3.16	2.54	28.34	21.74	3	6	1.38	2.01	2.63	6.00
Mixed Forest	3	8	1.20	0.91	2.70	5.48	1	1	0.00	0.00	0.62	1.32
Grassland	68	58	27.53	27.62	192.48	207.84	84	38	0.62	0.89	34.03	18.87
Shrub	151	148	0.66*	1.03*	68.36	81.50	12	3	1.04	0.22	5.82	0.86
Willow Shrub	20	22	4.88	4.70	36.54	37.54	19	24	3.07	2.01	24.56	22.25
Wetland	17	21	4.79	4.42	16.31	18.82	13	21	1.05	1.12	6.08	9.42
TOTALS	402	426	44.32	45.41	437.3	513.48	144	101	64.62	107.93	150.1	120.01

In area A, the number of all forest patches increased, and, with the exception of cottonwood forest, so did their size (Table 4-6). Although data reveal the appearance of only 11 new aspen forest patches overall, a visual inspection of the maps suggests that many more smaller patches have established while several small, individual patches have merged to form larger, contiguous stands. Also notable are the 13 new conifer woodlands which have clearly added a new character and habitat component to the landscape. The decrease in mean patch size as well as edge length of cottonwood forest suggests that some forest breakup has occurred as a result of either succession to mixed forest or flooding and replacement by earlier successional communities (i.e. wetland, willow shrubland). The total amount of forest edge habitat on the landscape has increased by 44.15 km (+36%) overall, with the majority of the increase due to the 42 km (+44%) of new aspen forest edge. Although the number of shrub patches has decreased, the significant increase in mean patch size and corresponding increase in edge length (Table 4-6) suggests that isolated patches have merged to form larger patches. Willow shrublands, which are mostly confined to streambanks and low-lying areas, have not changed markedly, although the data suggest a similar merging of smaller patches.

In area C, data indicate that forest expansion has resulted primarily in the loss of small grassland openings and an increase in landscape homogeneity. The total number of patches dropped from 144 to 101 (-30%). Forty-six small grasslands (-55%) and nine shrublands (-75%) have disappeared while the mean aspen forest patch size has increased by 75%. Close to 16 km of aspen forest edge habitat has been lost, and grassland edge length has also decreased by half (-15.16 km). Conversely, there was an increase in wetter habitat types, with eight new wetlands (+54%) and five new willow shrublands (+26%) creating new forest openings or expanding on the landscape, suggesting wetter conditions in 1999 than in 1939.

Aspen forest expansion was examined in greater detail to determine the patterns of aspen establishment as well as the influence of environmental factors (i.e. aspect and elevation) on those patterns. The vast majority of aspen expansion (87%) occurred adjacent to or within 50 m of an existing aspen patch, providing evidence for the dominance of clonal spreading over seedling establishment in the species' reproductive ecology (Fig. 4-4a). Although establishment did not decline steadily with increasing distance from an existing 1939 aspen patch, the relative area of new aspen forest dropped and hovered around 3% up to a distance of 400m, then dropped off with no patches establishing more than 600 m away from an existing 1939 aspen patch.

To investigate the possibility of aspen establishment from seed, the proximity of all isolated 1999 aspen forest patches to the nearest aspen forest patch was analyzed. The number of patches dropped steadily with increasing distance from other existing patches (i.e. possible seed source or parent ramet) (Fig. 4-4b). Two patches appeared over 400 m away from the nearest aspen forest patch.

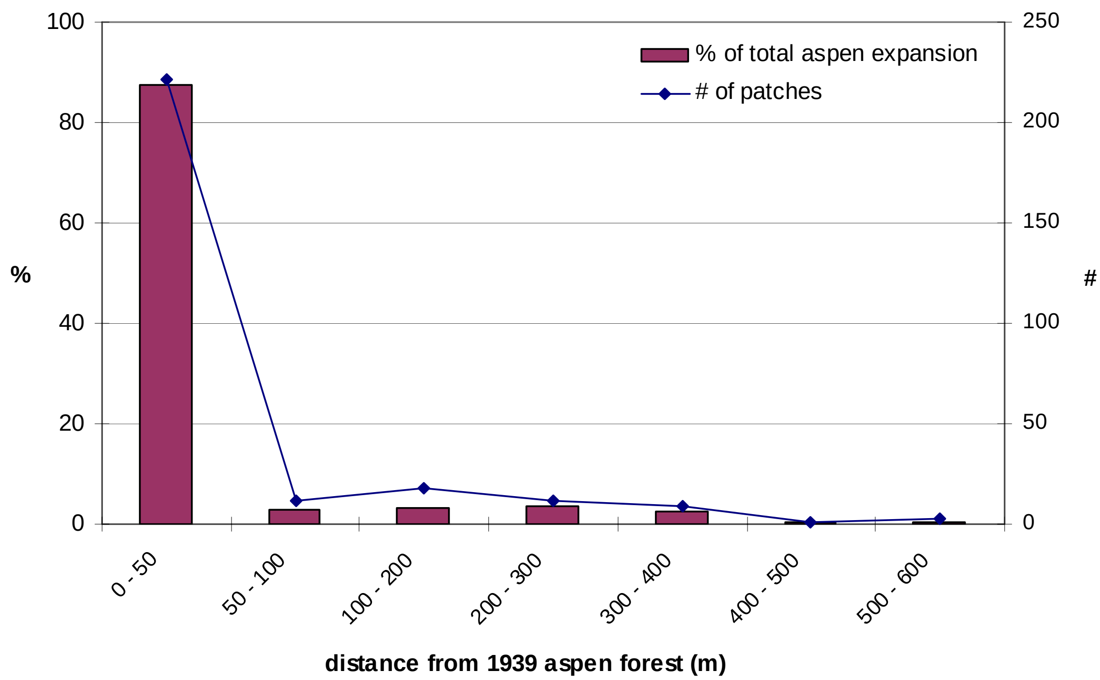


Figure 4.4a: Proportion of total aspen expansion (%) and number of aspen patches visible in 1999 as a function of increasing distance from existing 1939 aspen forest cover.

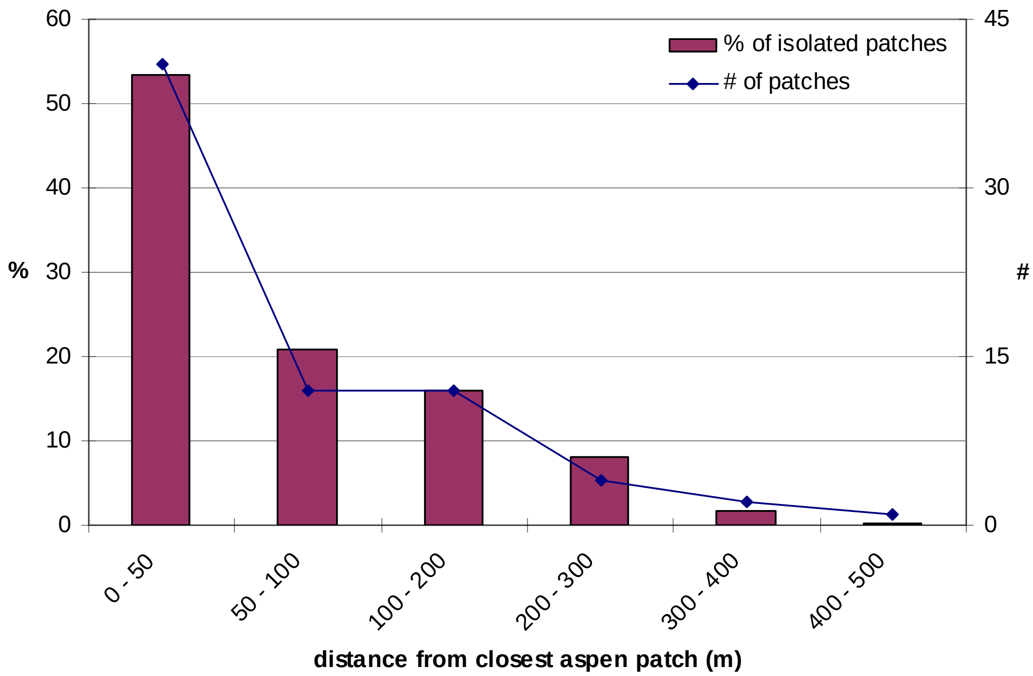


Figure 4.4b: Proportion (%) of isolated 1999 aspen patches (i.e. patches that are not adjacent to either 1939 aspen cover or to new forest spreading adjacent to this 1939 cover) found within an increasing distance (m) away from the closest 1999 aspen patch.

The influence of aspect on aspen expansion did not appear to be substantial (Table 4-7). Expansion was marginally more common on warmer and dryer south and east facing slopes compared to wetter north and west facing slopes, an expected result given the species' affinity for wet conditions.

Table 4-7: Effect of aspect on aspen establishment (% of total).

Aspect	Area (% of total expansion)
Flat	0
North	16.48
West	32.16
South	17.34
East	34.01

The effect of elevation was much more apparent (Fig. 4-5). At elevations between 1260 m and 1280 m, aspen expansion was minimal, likely due to the fact that these low-lying areas were mostly found in close proximity to lakes and rivers and are more commonly colonized by cottonwood and willow. The patterns of expansion closely mirrored the original (1939) pattern of aspen forest cover (Fig. 4-5). It was most common between 1280-1320 m, and dropped off above 1480 m where conifer forest was more likely to dominate.

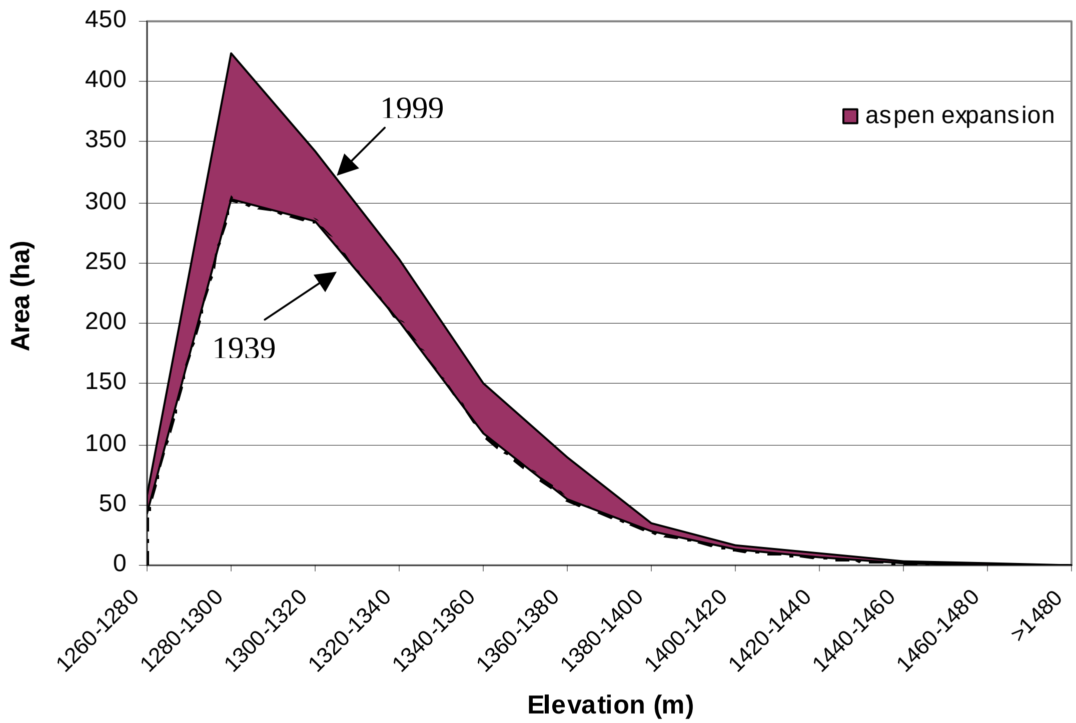


Figure 4-5: Relationship between aspen expansion (ha) and elevation (20m intervals) within the study area. Lower limit represents total 1939 aspen cover, and upper limit represents 1999 aspen cover in (ha).

4.3 Landscape Change in WLNP: General Discussion

4.3.1 General trends

The results from all three data sources provide evidence for the long-term replacement of native fescue grasslands by later successional shrub and forest communities throughout the study area. This trend has dramatically changed the appearance of the landscape, particularly the historically open grasslands in the northern and western portions of the study area where numerous new shrub and forest patches have established between 1889 and 1999. Strong winds from the south appear to be dispersing conifer seeds from higher elevation forests to safe germination sites created by new shrub patches (see Table 4-5) on the landscape, resulting in a northerly spread of woodlands into this area. The abundance of young conifer seedlings identified through field reconnaissance and inspection of the repeat images in this area suggests that conifer woodlands will likely continue to appear on the landscape in the absence of disturbance agents. Many of the previously scrubby, open young aspen patches have matured and merged into larger, mature aspen forest stands. Where denser aspen forest dominates in the northeastern portion of study area, several of the small openings created by grasslands and shrublands have disappeared due to forest closure. There is also evidence of a down-slope shift of the boundary between the foothills-parkland and montane ecoregions, as aspen and mixed forests are slowly being replaced by shade-tolerant conifer species.

Although there were only small overall increases in the cover of riparian vegetation communities in low-lying wet areas, there were indications of dynamic transitions between all three cover types (i.e. cottonwood forest ⇔ willow shrubland ⇔ wetland) due to the processes of erosion and deposition during floods. Overall, these historically scrubby young cottonwood forest communities have changed into mature aspen and cottonwood forest ecosystems, particularly on the Blakiston alluvial fan. Largely as a result of the sparse revegetation of rocky shorelines by forbs and young shrubs, there was a considerable replacement of bare ground (i.e. rock/sand/gravel) by various vegetation communities. This may suggest more stable river conditions in the absence of any major flood event since 1964, seasonal water level fluctuations, or an overall drop in water levels over time. Conversely, the slight increase in total area and number of wetlands identified in both the transect data and the air photo interpretation, and visually in the repeat imagery, may suggest wetter conditions overall. Indeed, there is instrumental evidence to indicate that the regional climate has been slightly wetter in recent years

(Watson and Luckman 2001). It may also suggest an increase in beaver activity within the Park due to a population recovery in the absence of hunting pressure. It is difficult to clarify the long-term local climate trends in the absence of complete temperature and precipitation data, although regional trends would suggest that conditions have indeed been wetter over the last half century (see section 2.2.3 for a detailed discussion).

The increase in anthropogenic cover resulted mainly from the expansion and relocation of highways and other vehicle transportation corridors, although some new buildings also appeared on the landscape and the Park headquarters complex expanded between 1939 and 1999. Although not obvious from the land cover data itself, but important to note, is the presence of a golf course within the study area. Although classified as "grassland", the golf course is regularly groomed, covered by introduced grasses and unlikely to be affected by normal successional processes. As such, the decline in grassland cover in other sections of the Park represents a slightly greater loss of native grassland area than is indicated by the results of this study.

4.3.2 Patterns of aspen expansion

Contrary to the trend being observed in several montane areas of the west (Hessl and Graumlich 2002; Romme *et al.* 1995; Suzuki *et al.* 1999; White *et al.* 1998,2003), these data show that aspen forest in the foothills-parkland ecoregion of WLNP is expanding, and probably has been for over a century. The rate of aspen expansion calculated from transect data for the first half of the century (1889-1939) - 13 ha/year - was found to be over 4 times greater than the rate calculated using both transect and aerial photo analysis for the latter half (1939-1999) - 4 ha/year. It seems contradictory that expansion rates would be less rapid given the warmer temperatures and wetter conditions in the late 20th century (Case and MacDonald 1995), which suggests the relative importance of other ecological controls on aspen dynamics.

First, the fires that swept through the Rockies in 1887-1889 had a significant impact on low elevation areas in WLNP, evidence of which can be found in Miles' 1889 survey journals, and is still visible in historical photographs of the area 16 years later (Appendix 4c). No fires of consequence (> 1 ha) have since occurred or been documented in the foothills-parkland zone of WLNP (Barrett 1996). Given aspen's propensity for vigorous vegetative reproduction following fire disturbance (Brown and DeByle 1987), it is conceivable that these rapid changes were a direct response to the fires of 1889. The effect may have been exacerbated by the absence of any sizable populations of native or domestic grazers at the turn of the century, especially bison, or subsequent fire events to check this new growth. The response appears to have been extremely rapid in the eskerine complex, as many of the new aspen forest patches detected in early air photographs (1939) had already visibly established by 1914. In the eastern portion of the study area where soils are moist and poorly drained, an almost contiguous cover of young aspen scrub forest was evident in these early 1914 images, again suggesting very rapid expansion at the turn of the century.

Another plausible contributing factor is the absence of First Nations' peoples in the area. Particularly near the mouth of the Blakiston Valley, archaeological evidence suggests heavy human use over hundreds of years (Reeves 1975). If early surveyors' records and early photographs are indeed indicative of longer term landscape patterns, aspen would have been scarcer, and confined primarily to riparian areas. Its heavy use as a preferred fuel wood in these areas could have affected forest patterns before the forced relocation of native inhabitants to reserves north of the Park. Human use of landscape burning (see section 2.3.2 for an extended discussion) was likely common in this area as well.

The rate of forest expansion has almost certainly not been constant over the study period, so these numbers calculated from discrete points in time must be viewed with some caution. It is possible that during the climatically wetter periods of the late 1870s-1890s and after 1950 (Watson and Luckman 2001), aspen growth was in fact more rapid. It is also likely that little to no expansion occurred, or that significant dieback occurred during the extreme drought years of the 1920s and 1930s (Case and MacDonald 1995). Once livestock numbers increased in the early

1900s, and especially when elk returned to the Park in the 1920s, herbivores likely began to control the spread of new aspen ramets and seedlings through trampling and browsing of young shoots, which may also have slowed the rate of forest expansion during the latter part of the 20th century.

Snowberry and wolf willow (*Elaeagnus commutata*) can both form extensive patches in the prairies, providing favourable conditions for both the spreading of aspen ramets, and the germination of conifer seedlings (Bird 1961). There is evidence that annual or frequent fires are probably detrimental to the establishment of shrub cover, but with an absence of major fire over the last 100 years to reset the successional clock, the appearance of new shrub patches and the subsequent spreading of existing aspen clones are expected trends.

Although it is theoretically possible for aspen clones to travel long distances or to survive for long periods of time underground (Mitton and Grant 1996), it is highly unlikely that they would do so in an open grassland environment where there is little competition from other trees. The appearance of isolated patches up to 400-500 m away from any possible parent ramet suggests the likelihood that successful aspen seedling germination is indeed occurring in the study area. Despite the oft-described rarity of sexual reproduction of aspen in the literature, these data support more recent studies suggesting that establishment from seed may be more common than previously recognized (Elliot and Baker 2004; Quinn and Wu 2001; Romme *et al.* 1997).

Although aspect apparently had no effect on the spread of aspen, this might be due to the coarse resolution of the available DEM (20 m) being unable to detect microtopographical hills and depressions in the hummocky terrain of the Badlands. Field observations indicate that young aspen stands generally do indeed establish in small depressions or on the moister lee-side of drumlins and eskerine features, although mature forest did not appear to be restricted to these areas. Elevation had a more pronounced effect, with the majority of aspen growth occurring between 1280m-1320m, which is unsurprising given that most aspen expansion occurred through clonal spreading adjacent to existing aspen forest (Fig. 4-4a). The fact that there was such a strong relationship between elevation and aspen cover in 1939 is an interesting relationship to explore. It may suggest that rapid aspen expansion will be limited to certain elevations where the most favourable soil conditions exist and therefore may slow or even cease once these areas are under forest cover. A changing climate may have a pronounced effect on the distribution of aspen in the future, and the relationship between aspen expansion and aspect/elevation.

4.3.3 Loss of native grasslands

Relative to other ecoregions in Canada, the prairie ecoregion has a very high proportion of the birds and terrestrial animals that are threatened or endangered. In Alberta, 73% (16 of 22 wildlife species) that are now considered at serious risk rely on prairie habitats, and about ¼ of the 324 vascular plant species considered “rare” are prairie species (Bradley and Wallis 1996). Habitat loss and degradation are considered the principal reasons for these declines. Due to the mixing of mountain and prairie elements in the foothills-parkland, WLNP protects a remarkable assemblage of vascular plants (approximately 180 species) and animal species, many of which are rare or endangered in Canada (Achuff *et al.* 2002; Kuchar 1973). As such, the protection of the native grassland ecosystem has been identified as a major priority area for the Park (Parks Canada 1999).

With both transect and air photo data showing a 15% reduction in grassland cover between 1939 and 1999, and transect data indicating a reduction of 27% between 1889 and 1999 in WLNP, there is convincing evidence that this important habitat has become threatened. These direct losses are compounded by the threat of aggressive invasive species including Kentucky bluegrass (*Poa pratensis*), and smooth bromegrass (*Bromus inermis*), particularly along Park boundaries where some illegal grazing continues to occur, and adjacent to the Waterton Lakes where historic grazing pressures were most intense. The absence of disturbance, particularly fire, has led to the buildup of dead plant material in grasslands, which may further reduce species diversity (Kuchar 1973).

4.3.4 Wildlife Movement and Landscape Pattern

The loss of small grassland and shrubland openings and the corresponding loss of aspen forest edge habitat in the northeastern part of the study area due to successional advances may have a significant impact on wildlife use of, and movement within, this area. Many animals, especially bird species, thrive along aspen forest edges, requiring both forest and openland habitat for survival (Bird 1961; Finch and Ruggiero 1993). One study of on-farm wildlife habitat and biodiversity found the largest variety of plant and animal species in the transition area between aspen groves and open grassland (Godwin *et al.* 1998). Grassland areas themselves provide crucial foraging areas for many small mammals including ground squirrels, various raptors and sharp-tailed grouse (*Pediocetes phasianellus*) (Gruell 1983a), while shrublands are important for some native grazers (i.e. deer). This is especially true where dense forest canopy or shrub understory inhibits the growth of palatable grass and forb species, forcing herbivores that might occasionally forage in forest patches into more open grassland areas. It is important to note, however, that field observations and previous vegetation studies in WLNP (Achuff *et al.* 2002; Kuchar 1973) reveal very high heterogeneity at the stand level among aspen stands in terms of canopy/stem density and understory composition, so these relationships are likely complex, and might warrant further investigation.

Aspen forest also serves a crucial function in the foothills-parkland. It provides important protection from predators, thermal cover and calving sites for native herbivores (i.e. elk and deer), and nesting sites for several bird species (Bird 1961). Successional changes that have resulted in new aspen and conifer patches establishing in the more open Badlands may therefore be beneficial for some birds and small mammals, but may also change the patterns of habitat use by these animals.

The increased cover of forest and berry-producing shrub patches (i.e. chokecherry and Saskatoonberry) in the Badlands may be an interesting development in terms of bear activity and movement in the Park. Both black bears (*Ursus americanus*) and grizzly bears (*Ursus arctos* *horribilis*) regularly feed on berries, especially in the fall months, and can often be seen at low elevations gorging themselves in preparation for the long winter ahead. With increased forest cover for protection, facilitating movement across the landscape, and with the allure of ripening berries in areas that were historically open grassland, bear activity may be increasing in the foothills-parkland. This trend could be cause for concern in this highly used corridor of the Park, and may be contributing to the higher incidence of bear encounters in recent years. Since bird and wildlife movements could clearly be affected by both past and future changes to landscape pattern in the aspen parkland mosaic within WLNP, more research is needed to clarify the relationships between animal behaviour and movement (process) and landscape pattern (Gergel and Turner 2002).

4.4 Methodological Considerations: Combining Historical Data Sources

The attempt to locate historical transects in oblique photographs (1914 and 2004) was only marginally successful. No quantitative data were obtained, but some revealing qualitative information was gained regarding the rapid rate of woody species establishment at the turn of the century (1889 → 1914) and the dramatic aesthetic changes that have occurred around the Blakiston Mouth area since 1914.

One major problem is that the methodology developed was time-consuming because of its iterative nature. Since specific viewer location and target information (i.e. specific landscape features focused at the center of a photograph) was not available for all photos, several attempts were needed to match the model and photograph perspectives with any accuracy. This problem could be overcome in the future if additional field notes denoting the following are taken: (1) elevation of the photo station; (2) the orientation of each photo taken (i.e. cardinal direction) and the photograph target (i.e. a particular landscape feature; a certain mountain for example); and (3) the precise angle or tilt of the camera lens in relation to the ground. Although some of these measurements were taken during the 2004 field season, the records were not entirely complete and many of the photo stations used in this pilot study were missing such information.

Accuracy was compromised during the process of matching features (photographic image to digitally modeled image) and cropping images by eye, which was affected simply by the limited visual quality of the 3-D modelling. Further, the exported digital image of the transect grid was highly pixellated, especially in the high elevation images, with increasing distance from the camera. In ground based images, the transect lines appeared a few meters above the ground, making it difficult to determine whether the transect was accurately located. Experimenting with other 3-D modeling programs that are either able to export higher quality 2-D images, or have georeferencing capabilities could be a promising avenue.

A final problem was that the historic and repeat images were not always precisely lined up, and therefore the transects were not in precisely the same location in both photographs. This problem might be overcome if image to image registration was performed between the historic and repeat images prior to overlaying the transect lines.

One avenue to explore might be to follow the above methodology, but drape a polygon grid over the repeat photographs. Using descriptors (i.e. increase, decrease, no change), the relative vegetation cover in each square could be recorded from various camera perspectives. This would likely be extremely time-consuming to complete manually, however, and the method would not necessarily yield more information than visually comparing a pair of photographs as described earlier in this thesis. If this procedure could be accomplished digitally using image classification techniques, it may prove to be more practical. Experimenting with digital image classification, of a selection of random grid cells viewed from different angles for example, could also yield useful results.

Overall, the methodology thus far is only useful for yielding limited additional qualitative information. There are some promising possibilities for further development of the technique using other more sophisticated programs that are capable of maintaining higher image quality.

4.5 Concluding Thoughts

The use of multiple pieces of historical evidence has shown that the landscape that greets visitors to Waterton Lakes National Park today is very different from the landscape that early surveyors encountered at the end of the 19th century. The causes of these changes are likely complex, and the consequences may not be fully understood. It is also unclear whether these changes are particularly remarkable given the dynamic fluctuations in grassland and forest cover that are suspected to have occurred in this region over the past several thousand years. As such, caution must be used when interpreting these data, but they can serve as useful references for future conservation and restoration goals. At the very least, these data provide some clear information about what this landscape has looked like and how it functioned in the past. How the information is interpreted or used to make future decisions, however, warrants further discussion.

CHAPTER FIVE

Using Historical Information as a Crystal Ball: the Challenge of Ecological Restoration

5.0 Introduction

Central to any restoration effort is the clear identification of desired goals. This presents a formidable challenge because to select so-called "original" conditions at a specific point in time on which to base restoration goals would not reflect the variation inherent in landscape level ecosystem functioning. Consequently, selecting and using appropriate reference information is a complex process that requires a detailed and thorough understanding of the patterns and causes of ecological variation at multiple temporal and spatial scales (White and Walker 1997). Moreover, undertaking restoration projects with a narrow focus exclusively on ecological or technical objectives may not be the most effective approach. Instead, a more expanded vision of restoration that incorporates the ecological, cultural, social, political and moral aspects of the practice has been proposed (Higgs 1997, 2003) and increasingly adopted in both theory and practice (e.g. Anderson e*t al.* 1999; MacDougall *et al.* 2004). This compelling perspective recognizes that cultural and ecological histories are not mutually exclusive, but are instead constantly interacting to shape the landscapes we are experiencing today. Ultimately, identifying an appropriate range of historical conditions for a given ecosystem or geographical area must remain a largely adaptive process, one whose goals and direction will be strongly shaped by constantly shifting management goals and priorities and the consideration of emergent information (Higgs 1997; Hobbs and Harris 2001).

With respect to this study, perhaps the most relevant deliberations in the restoration literature revolve around the validity of, and approach to, using historical information for informing restoration goals. The debate centers around four main issues: (1) the relevance of historical ecological conditions and processes given contemporary environmental, political, and social constraints; (2) identifying an appropriate time-scale for inquiry; (3) a lack of clear reference information or doubt about the quality or completeness of existing historical data; and (4) the relative importance of cultural and environmental (i.e. non-human) influences (Higgs 2003; Hobbs and Norton 1996; Landres *et al.* 1999; Swetnam *et al.* 1999; White and Walker 1997). The following discussion will touch on these concerns in light of the information gleaned from this study.

5.1 Ecological restoration in WLNP: To what are we restoring?

It will be interesting to see if and how the information resulting from this study contributes to restoration planning in WLNP. One option is for one of the ecological snapshots that have been investigated to be used at face value as a target for future restoration goals. For example, managers could simply strive to reduce aspen cover to near pre-European levels, estimated by 1889 surveyors notes at around 1/7 of what it was in 1999 (Fig. 4-1). I argue that it may be more useful to consider this information as a piece of a larger puzzle rather than a prescription. The data reveal some information about what former ecological conditions and patterns have existed in the past and are possible in the future under specific management regimes and environmental conditions. This information can aid managers in shaping an evolving restoration plan for this particular area of the Parkas these social, political, ecological and climatic influences continue to change.

Clearly, the foothills-parkland has undergone some notable aesthetic and ecological changes with the spread of woody vegetation, especially aspen forest, into grassland areas. This information alone, however, does not determine whether or not these changes are significant with respect to historical precedents, and whether restoration is needed. One could argue that the information discovered through this thesis is incomplete, and may only represent a selection of ecological snapshots of the past. Further studies investigating aspen dynamics in nearby areas of the parkland under different management regimes, the examination of more time slices, more detailed information about longer term (i.e. multiple centuries) aspen distribution patterns (i.e. local paleoecological research), or field studies to correlate stand dynamics with climate patterns (i.e. tree ring studies) could all be informative in this respect.

Ultimately however, the significance of the landscape change that has occurred over the past century can really only be measured within the context of contemporary ecological, social and political conditions. A loss of 373 ha of grassland may only be significant today because the Park protects one of the last vestiges of native fescue grassland in Canada. Such a change may have been insignificant when the prairies covered all of southwestern Alberta, or may become less significant in the future if more fescue grasslands on private lands become protected or restored. As MacDougall *et al.* (2004) note, rather than defining restoration targets based directly on historical evidence, the implications of retrospective data should be integrated with contemporary ecological, social, and logistical considerations.

The potential importance of climate, fire and grazing on historic aspen dynamics in WLNP have been explored in detail elsewhere in this thesis, and will not be repeated here (see Section 2.3). Their future influence on vegetation patterns in the foothills-parkland however, is interesting to consider. Most climate models predict a warmer climate in the coming decades, while patterns of precipitation have been more difficult to forecast (Beaudoin 1999). Warmer, drier conditions would likely lead to the dieback and loss of aspen forest in WLNP, particularly if major drought events become more frequent, or high spring temperatures lead to the proliferation of pests (Hogg *et al.* 2005). If warmer and wetter conditions prevail, aspen may be able to colonize previously uninhabitable microsites, and coniferous forest could continue to move down-slope, replacing aspen forest at the upper ecoregion boundary (Achuff *et al.* 2002). These changes could result in a geographical shift of the entire foothills-parkland ecotone, eliminating almost entirely the fescue grasslands protected within the National Park system.

Under favourable climatic conditions, could the rate of aspen expansion approach that identified for the beginning of this century? Perhaps, especially if historically influential fire and grazing disturbance remain absent or minimal. Infrequent burning may simply stimulate more vigorous aspen reproduction from existing roots instead of checking the continued spread of aspen and conifer forest (Brown and DeByle 1987), but cost prohibitive safety restrictions and concerns about damage to adjacent land holdings may limit the achievable intensity or frequency of prescribed burns. The feasibility of reintroducing bison to WLNP has been explored in detail by Burton (2003), but the effects of this strategy given current ecological conditions are largely unpredictable. The success of such a program will likely hinge on political (i.e. relevant legislation) and social (i.e. cooperation from ranching community) factors, and the impact on the foothills-parkland will be inextricably linked to the effects of climate and prescribed fires. Another consideration is that while the reintroduction of fire or grazing to these prairies may inhibit or even reverse woody species expansion, it may now encourage the spread of invasive, non-native species, further threatening native prairie ecosystems (Achuff *et al.* 2002; MacDougall *et al.* 2004).

The above speculation begins to illustrate the unpredictable nature of vegetation dynamics at the landscape scale over long time periods, and the inherent challenges associated with undertaking ecological restoration projects in WLNP and beyond. While the Park's goals of maintaining ecological integrity and restoring long-term ecosystem states and processes (Parks Canada 1999:4) illustrate laudable aspirations, what exactly constitutes "ecological integrity" (see Winterhalder *et al.* 2004 for extended discussion), or what specific ecosystem processes are desirable or even possible to restore, are open to debate (Hobbs and Harris 2001). Broad restoration goals are difficult to achieve because of the challenge of how exactly to measure how successful one has been. While this study may only provide limited measurable information about what balance of land cover has existed during certain environmental and cultural conditions, it can also be used to shed light on such a debate.

One certainty is that succession to aspen forest and areal expansion of forest cover has proceeded over at least the past century, and in the absence of large-scale disturbance, will likely continue. Active management is almost certainly needed if one particular ecosystem state or landscape pattern is deemed preferable. The range of possible past conditions and future outcomes highlights the need for a well-planned, adaptable restoration monitoring program that is based on and continuously calibrated by clear restoration goals (Hobbs and Harris 2001).

5.2 Eco-cultural Restoration

The importance of the human dimension in shaping historic and contemporary land cover patterns has largely remained at the periphery of park management discourse (MacLaren 1999). Historical evidence and scholarly discussion suggest that even in some of the most ecologically intact landscapes in Canada, namely the Rocky Mountain National Parks, humans were a widespread and integral component of ecosystem processes. Oral histories, early settlers' accounts and archaeological and paleoecological studies indicate that humans have been living in and managing Rocky Mountain landscapes for thousands of years (Higgs 2003; MacLaren 1999; Reeves 1975; Reeves and Peacock 2001). Kay *et al.* (1999), in a recent study investigating long-term ecosystem states and processes in the Canadian Rockies, suggest that a comprehensive archaeological research program needs to be initiated that focuses on how aboriginal peoples interacted and used their environment in order to better evaluate the importance of humans in shaping ecological processes.

There has been a First Nations presence at most official events in the Waterton-Glacier Peace Park. This presence is regarded by some as a token gesture, but Reeves and Peacock (2001) observe that many elders view it as an affirmation of the Piikani's long-time relationship with the Rockies or "Mistakis" – the place where most things begin and continue to be sustained. Given how pervasive human influence has been in shaping contemporary land cover patterns, a challenge for modern park managers is to ensure that respect for thousands of years of aboriginal presence in the Waterton area is more than a token gesture, and that traditional ecological knowledge is viewed as a potentially influential component of modern management decisions (Reeves and Peacock 2001).

As Berkes (1998) points out, while it is dangerous to idealize traditional resource management approaches as the result of some infallible connection with nature, it is useful to consider the ecological knowledge accumulated over thousands of years of intimate association with the land when attempting to understand the ecological processes that have shaped modern landscapes. Some may argue that this knowledge has been lost among some indigenous groups in Canada as they too adopt modern technologies and partake in industrial resource extraction activities, but it is still important to consider traditional land management ethics and practices as potentially valuable sources of knowledge and wisdom. As Berkes *et al.* (2000:1252) comment:

> "*Whether a practice is traditional or contemporary is not the key issue. The important aspect is whether or not there exists local knowledge that helps monitor, interpret or respond to dynamic changes in ecosystems and the resources and services they generate.*"

Several National Parks in North America were established on land that is traditionally very important practically and spiritually to local First Nations people, or to local inhabitants that may also have had a multi-generational presence on the land following European settlement. Anderson *et al.* (2003) have proposed a detailed model for collaborative management within protected areas, and have convincingly argued for the importance of incorporating traditional knowledge into ecological restoration planning within National Parks. There are several co-management agreements currently in place between First Nations groups and National Parks in the U.S. (e.g. Hawa'ii Volcanoes, Badlands, Zion, Yosemite, Lassen Volcanic) (Anderson *et al.* 2003), and a number of examples of managers attempting to re-establish or mimic traditional land management practices in prairie or parkland ecosystems specifically (e.g. Underwood *et al.* 2003, Wray and Anderson 2003). This approach recognizes that ecological diversity is often closely linked to, and indeed enhanced by, cultural diversity.

This approach questions focusing exclusively on the outcome of restoration initiatives, and illustrates the potential importance of emphasizing the process, particularly the inclusion of multiple stakeholders with diverse views (Higgs 1997). As Anderson *et al.* (2003) note, "If land managers, ecologists and archaeologists understand the intricacies and mechanics of how and why native people shaped ecosystems, this will enrich their inventory of management methods, and they will be in a better position to make informed, historically based decisions." Expanding on this idea, Higgs (2003) proposes the concept of "focal restoration", or the reframing of restoration as a practice that can build value through participation, in turn strengthening human communities and restoring both nature and culture simultaneously. He further contends that restoration has the potential to directly engage people with a landscape or a place, perhaps even more fully than other forms of environmental action (Higgs 2003). Although species conservation and habitat preservation are crucial activities, their planning and management often remain outside of the general public sphere in the distant realm of politics, or in the hands of a few passionate organizations (Higgs 2003). By contrast, community-based focal restoration has the potential to reconnect people to their local landscapes through a common sense of creating something new; integrating elements of a place's history, both cultural and ecological, with a contemporary, collective vision of what landscape values are important now and in the future.

How could these more integrated visions of eco-cultural or focal restoration manifest themselves in the foothills-parkland of WLNP? Although the restoration of landscape level processes and patterns certainly requires further scientific investigation into historical conditions, restoration planning could begin to give serious consideration to the cultural dimensions of these landscapes as well. Local knowledge of past landscapes and what values have been lost is indispensable and could be utilized. For example, perhaps there are community elders, native or non-native, who recall important plant harvesting sites in the Badlands. At the very least, some of this information could be communicated to the local community through on-site educational materials, presentations, or art installations. Taking it a couple of steps further, perhaps Park managers could move towards mimicking or even re-introducing some form of community harvesting and management of plant resources in the Badlands, with the participation of, or ideally guided by, individuals within the surrounding communities. Outside of the Park, some local ranchers have been living in, working on, and protecting the foothills landscapes for generations. This knowledge could be communicated to the public to illuminate the fact that restoration and conservation extends far beyond the Park boundaries, and to reinforce the importance of habitat connectivity within the wider goal of biological conservation. There may also be room for incorporating some of this historically-rich wisdom into restoration planning within the Park. These more integrated approaches would give residents and visitors the opportunity to make a personal, as well as shared, connection with the landscape and the influences that shaped those places, while working towards a vision of what those places could look like in the future. People may begin to perceive Park spaces not merely as scenic backdrops or pristine ecological legacies, but as dynamic landscapes that have been shaped and re-shaped by humans, animals, and changing environmental forces for centuries.

As more knowledge is gained, restoration planning should continue to evolve to incorporate it. As climate patterns shift and human use of the Park and surrounding areas continues to change, restoration plans will need to be adapted. Ultimately, good restoration in WLNP will not only involve the reintroduction of plants and animals known to exist in the area historically, and the reinstatement of environmental processes, but the restoration of cultural values and influences as well (Anderson *et al.* 2003; Higgs 1997, 2003).

CHAPTER SIX

General Conclusions

This study has made use of multiple lines of historical evidence to describe and quantify landscape level changes, especially in aspen ecosystem dynamics, in the foothills-parkland of Waterton Lakes National Park. Historical survey records have provided some measurable information that predates the earliest air photographs available for the area by 50 years. Historical and repeat photographic images have made powerful visual evidence of changing landscapes available for scientific inquiry while simultaneously invoking meaningful contemplation about what the effects of Euro-Canadian settlement really looks like, even in our supposedly "pristine" National Parks. Quantitative analysis of repeat aerial photography has resulted in measurements of the rate and magnitude of landscape change over roughly the past century in WLNP, providing some basis for predicting the scale of ecological change possible in the future. Individually, each data source could have provided some information, but by combining them in new ways, a more complete picture of landscape change in WLNP over the past century has been painted.

Among the most salient observations are these. First, the aspen dynamics in WLNP appear to be unique within the National Parks in Canada. Where the loss of aspen-dominated ecosystems in some other Canadian National Parks (e.g. Banff National Park and Jasper National Park) has led to concerns about habitat loss and increasing landscape homogeneity, aspen cover has been increasing in the foothills-parkland of WLNP, at the expense of native grassland and other openland habitat, for the past century (1889 → 2004). The rate of aspen expansion at the end of the 19th century (1889 → 1939) was close to four times greater than the rate between 1939 and 1999. Conifer woodlands are becoming an increasingly conspicuous element of the landscape, as are shrub patches that could be providing ideal conditions for the continued establishment of conifer and aspen forest, particularly in the Badlands. The area covered by native fescue grasslands has declined with yet poorly understood consequences for the diverse assemblage of plants and animals that rely on this unique and threatened habitat for survival. The complex interactions between climate, fire, grazing and humans prior to, and since the Park's inception, are difficult to disentangle. Consideration of all the available human history and environmental data suggest that fire exclusion and the extirpation of bison, a keystone species, from the area have had strong influences on all of the aforementioned changes.

Landscapes and vegetation patterns have evolved over centuries, and the template of the underlying ecological and cultural processes has changed considerably over their period of development. It is an extremely complex challenge to determine the most effective way to incorporate knowledge of past landscapes into current management decisions. The elimination of keystone species, the cessation of historical fire regimes, the current political climate, unforeseen human pressures and potentially unprecedented climate conditions make it difficult to evaluate this historical information in a contemporary context. It could be argued that historical and spatial references may therefore be of limited value for shaping restoration goals (Hobbs and Harris 2001). I argue however, that it is a challenge that does not negate the importance of illuminating historical processes and conditions, but that instead necessitates an adaptive approach that is open to an ongoing re-evaluation of clearly defined restoration goals as new information is revealed, and the social, political and environmental intricacies of park management continue to evolve. Knowledge about historical landscape dynamics provides an invaluable starting point for thinking about ecological restoration; it gives us an example of what has been, and more importantly, of what could be.

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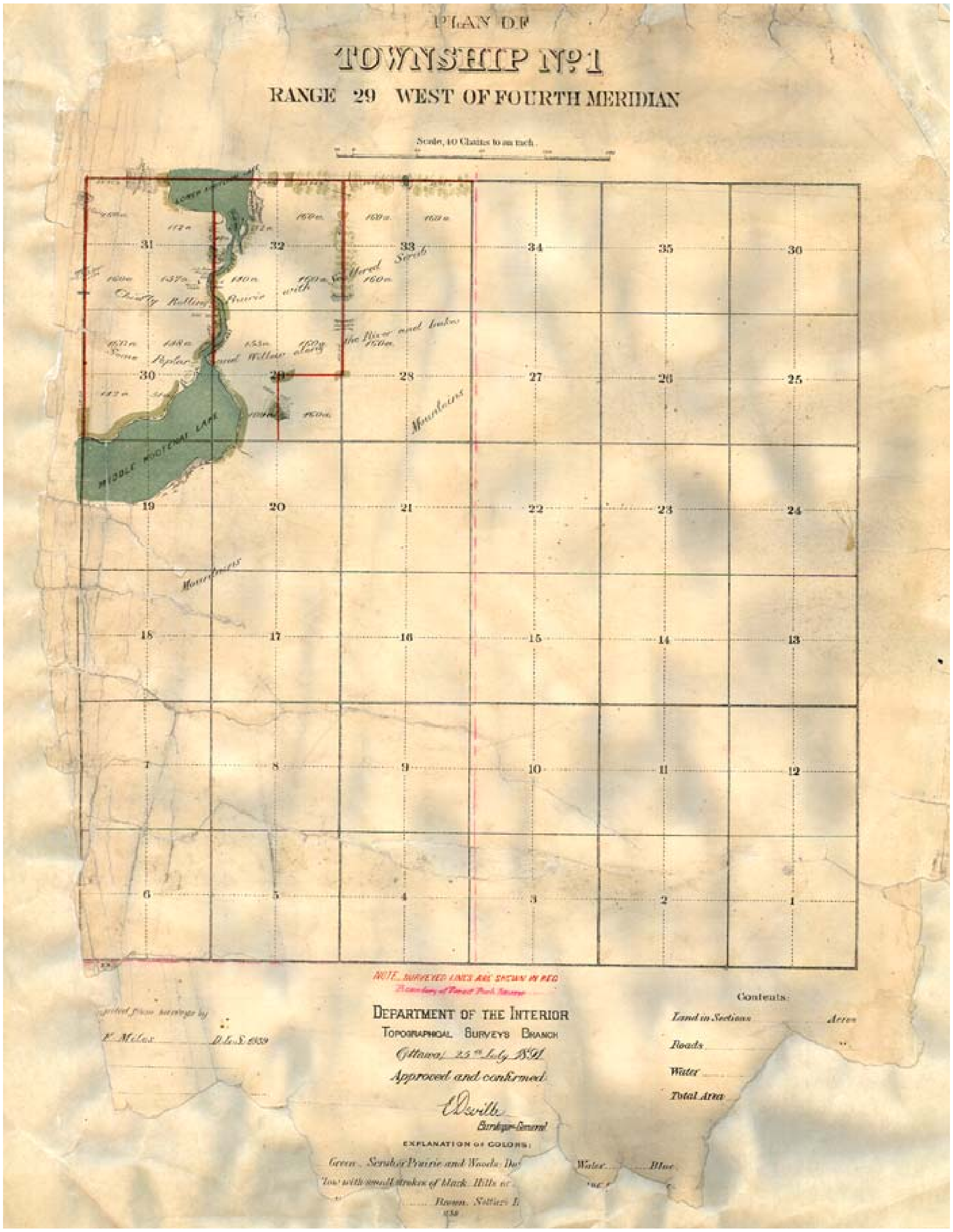
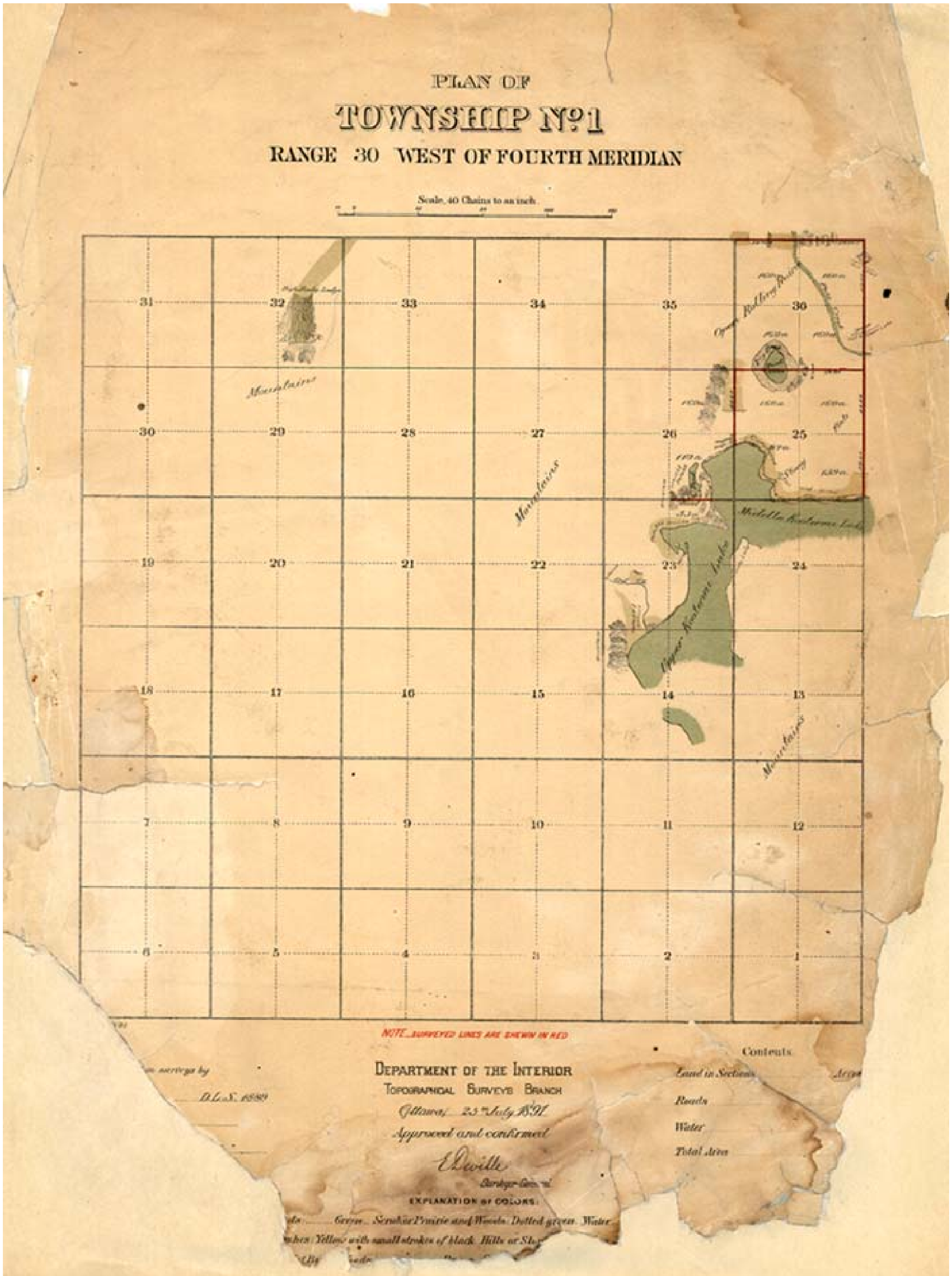
APPENDIX 1

Township Plans for Waterton Lakes National Park

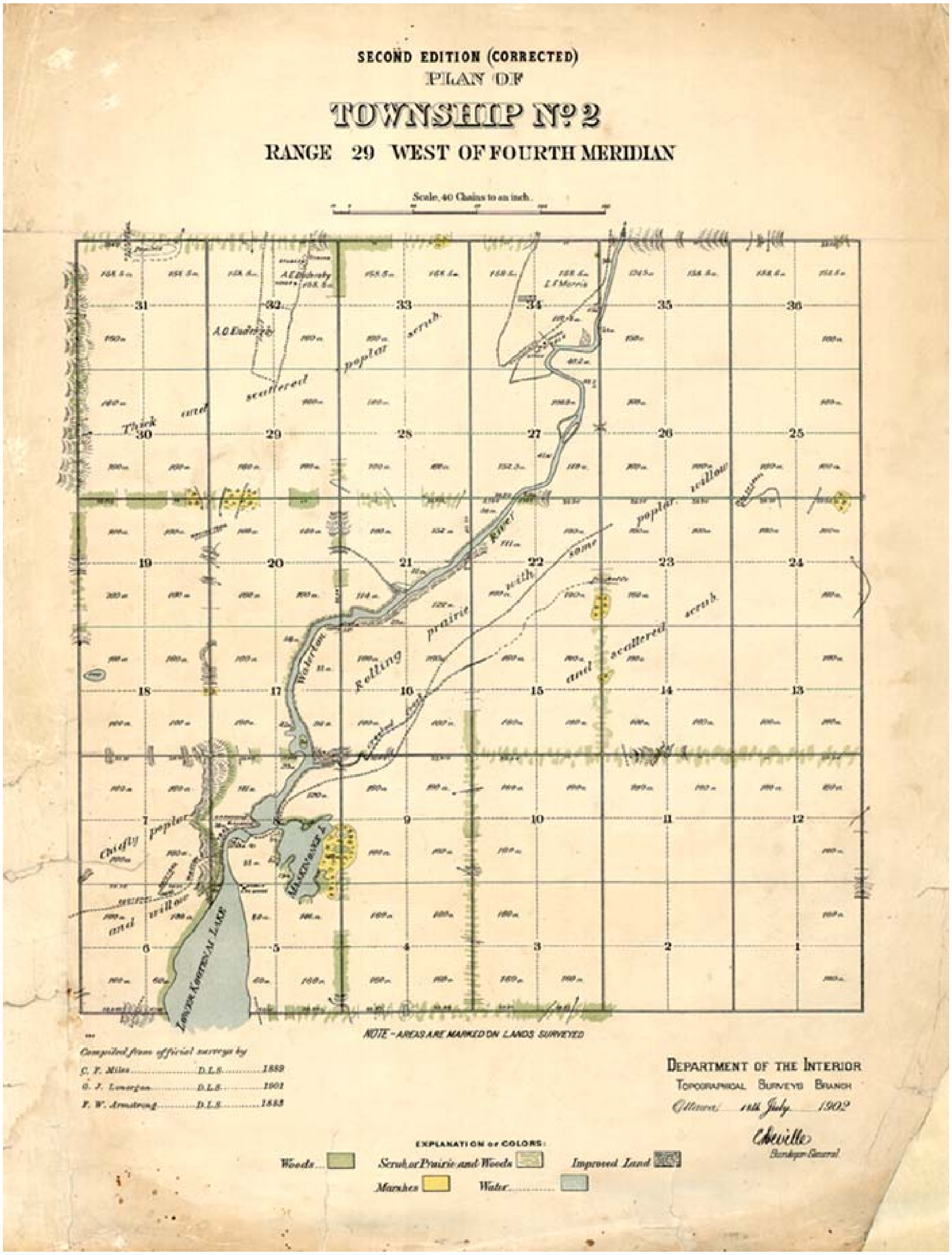
(a) Township 1, Range 29



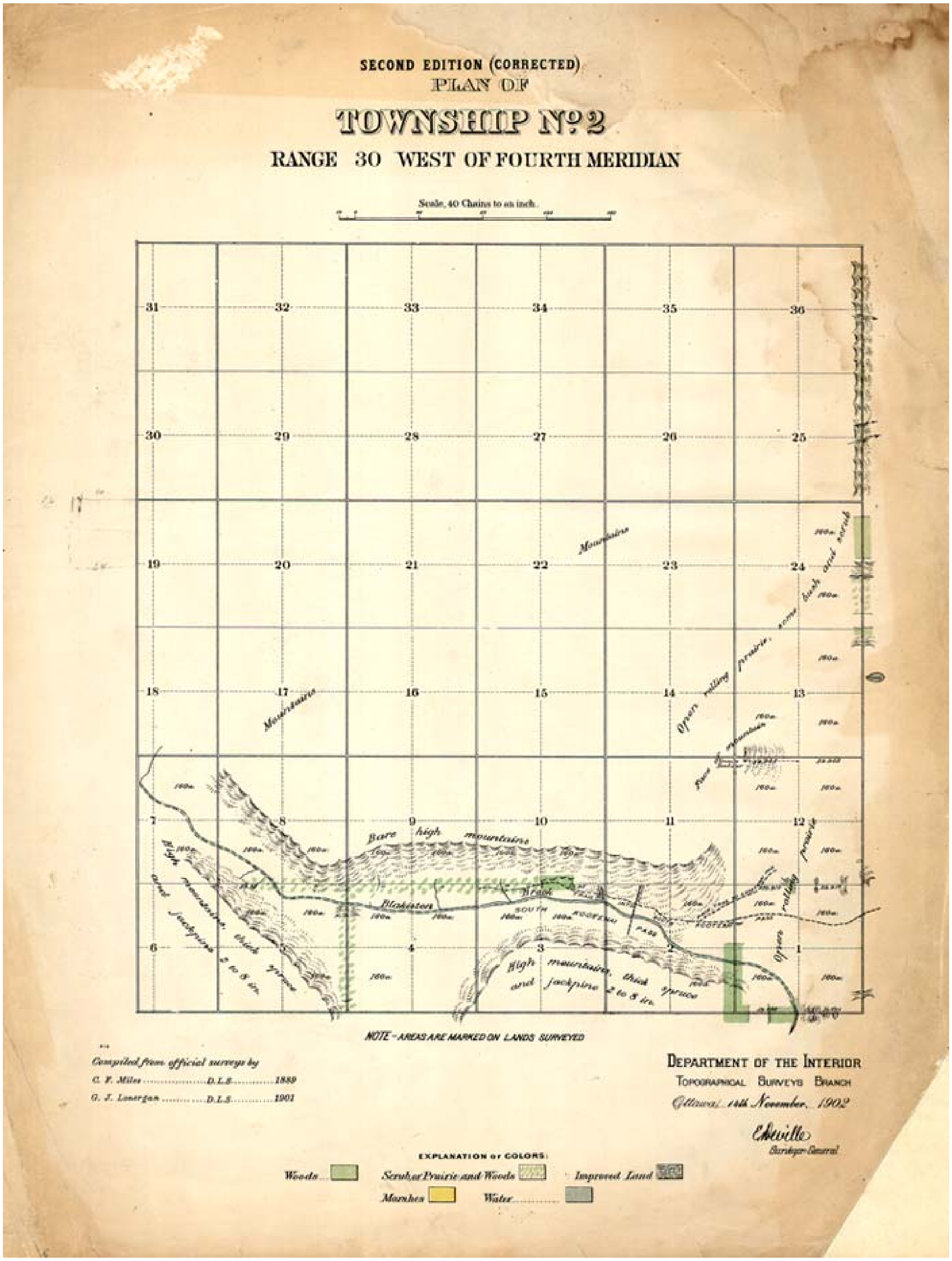
(b) Township 1, Range 30



(c) Township 2, Range 29



(d) Township 2, Range 30



APPENDIX 2

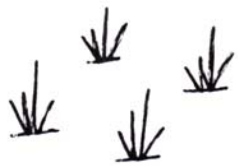
1889 Land Cover Classification

Both written and pictorial descriptions were used by C.F. Miles in his Dominion Land Survey records completed in 1889. The descriptions were reclassified to be compatible with the land cover classification used for aerial photograph interpretation (Appendix 3).

Written Descriptions

Historical Description (Miles 1889)	Contemporary Land Cover Description
Non-Vegetated	
"stony flat", "stony flats with boulders", "stony bottom", "rocky sterile flats"	Rock/sand/gravel
"dry water course", "dry bed", "dry beach", "dry slough"	Rock/sand/gravel
"river", "shallow pond", "pond", "lake", "small stream"	Water
Vegetated	
"open rolling prairie", "open undulating prairie", "level prairie"	Grassland
"poplar", "poplar timber"	Aspen Forest
"cottonwood"	Cottonwood Forest
"dense spruce"	Conifer forest
"2nd growth poplar"	Shrubland
"scrubby poplar with willows"	Mixed aspen/willow shrubland
"undulating prairie with willow scrub", "rolling prairie with willow brush", "open rolling prairie with scattered willow scrub", "dense willow"	Willow Shrubland

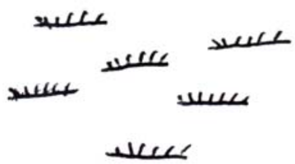
Pictorial Descriptions



willow shrubland

mixed poplar and willow shrubland

poplar forest



wetland

conifer forest

(a) creek bed

(b) trail

rock/sand/gravel

APPENDIX 3

Land Cover Classification for Air Photo Analysis

In the interest of consistency, map classification codes from the ongoing WLNP Vegetation Mapping Project were utilized for this study. Some map codes were generalized (i.e. grouped together) to better reflect the lower level of detail distinguishable in the 1939 black and white photography, and to more directly address the goals of this study.

MAP CODE	DESCRIPTION
VEGETATED (>10% vegetated cover)	
Forested (> 10% forest cover): trees usually taller than 5m with a well-developed understory of shrubs and/or herbs	
CON	**Coniferous forest:** >25% conifer composition
FEP	**Mixed forest:** when deciduous/coniferous components each >25% relative canopy cover; both canopy types should be evenly distributed throughout the stand
FAP	**Aspen forest:** <25% coniferous; will be designated as aspen forest if trees are >2m in height
FCW	**Cottonwood forest:** <25% coniferous; stands occur along streams and lakeshores
Non-Forested (<10% forest cover)	
SDS	**Shrubland**: mixed deciduous shrub species; includes young aspen/conifer saplings >2m in height
SWL	**Willow Shrubland**: where shrub cover appear along rivers, wetlands, and in wet depressions
HGL	**Grassland:** includes all herbaceous species of forbs and grasses
WET	**Wetland**
HES	**Vegetated Shoreline:** exposed shoreline along rivers and streams with 10-20% vegetation cover of herbs and/or shrubs
NON-VEGETATED (<10% vegetation cover)	
NLP	**Water**: includes lakes, rivers and streams
RSG	**Rock/Sand/Gravel**: rocky outcroppings, stream embankments, exposed shoreline
ANTHRO	**Anthropogenic**: roads, buildings, waste disposal sites
SMR	**Burned:** burned areas with no significant revegetation

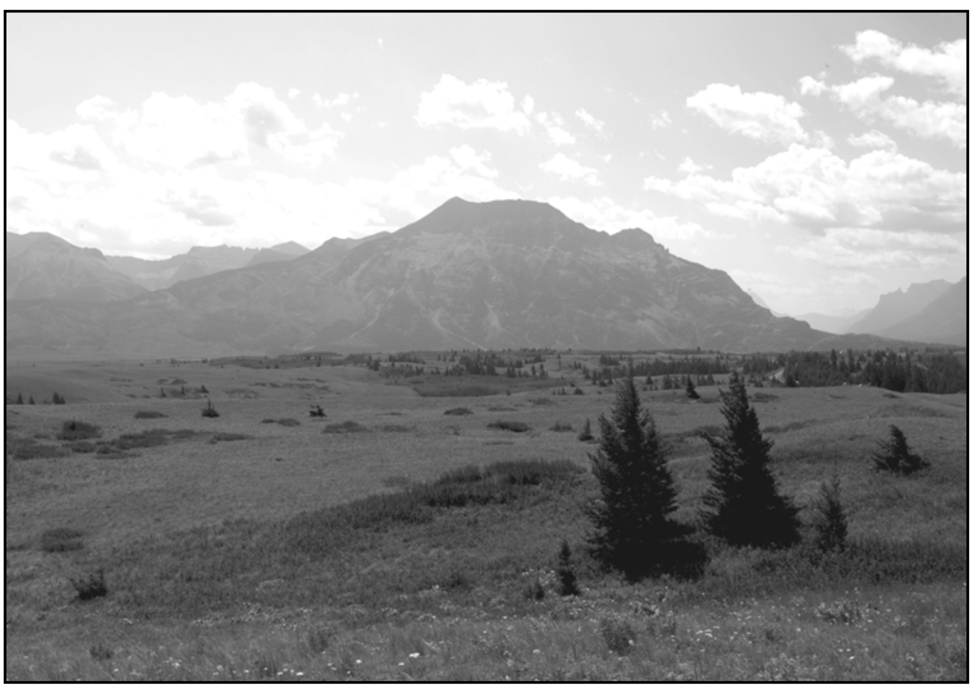
Appendix 4a: Blakiston Mouth
Image #: 655

There has been a dramatic increase in conifer cover with over 10 new woodland and denser forest patches, mostly Douglas-fir, establishing mostly from the right of the photograph. It is possible that these stands were also burned in the fire that affected the North side of Crandell Mountain. Many new aspen and conifer patches have established along the road. Three very large aspen stands have established from what appear to have been small scrub patches in 1914, with scattered conifers among the aspen clone.

APPENDIX 4

Comparison of Historical (1914) and Repeat (2003-2004) Photographs

1914



2004

Appendix 4b: Bison Paddocks
Image # 539

In the image foreground, little land cover change is apparent between 1914 and 2003. In this image pair. Aspen forest appears to be spreading down-slope into the grasslands at higher elevations in the image background, but increase from this perspective is not remarkable. One scrubby aspen patch at the image right has increased slightly in height, but height has remained less than 5 m. There has been significant conifer establishment along the base of the mountain range with dense stands appearing on steeper, high elevation slopes, and scattered trees establishing at lower elevations in the grasslands and in the middle of aspen forest stands. Conifers seem to have established more readily in cleared slide areas obvious in the 1914 photos.

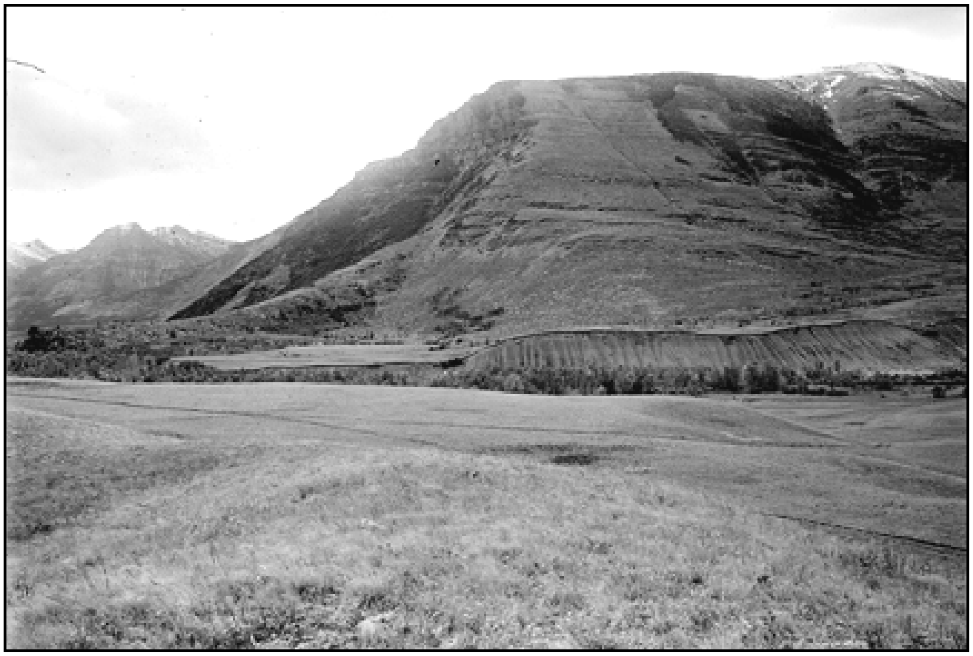
1914

2003

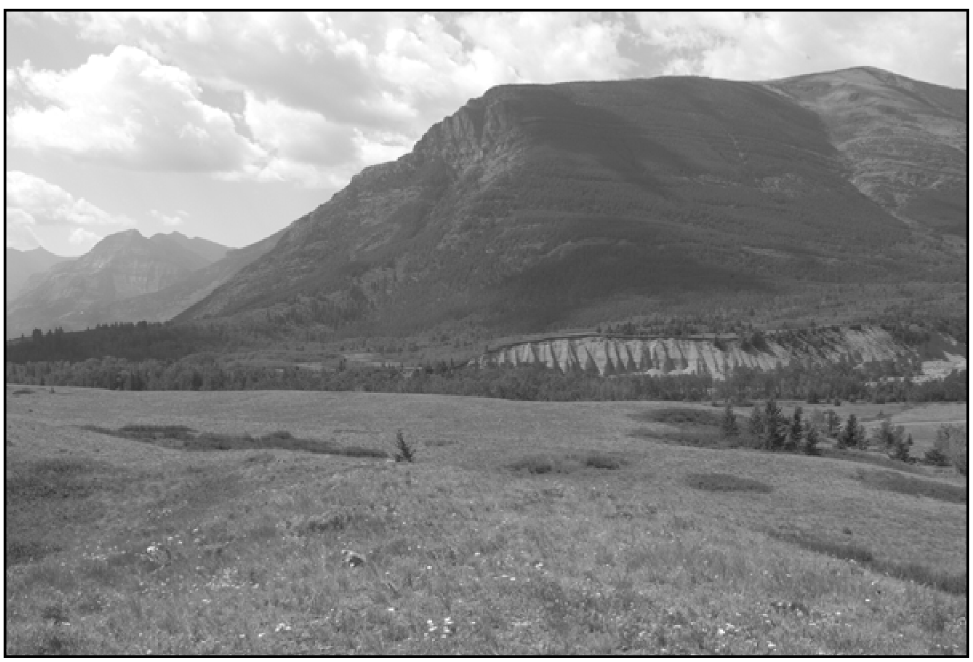
Appendix 4c: Blakiston Mouth
Image #656

A few shrub patches have established in the grasslands in the image center, mostly appearing in pockets on west-facing hillsides and in small gulleys and depressions. There is a large shrub patch surrounding the lone conifer woodland in the image foreground, and some conifer seedlings are visible in closer shrub patches. Many existing conifers are visible at the toe of Crandell in the 1914 image, and dense aspen stands have established around them with the conifer forests becoming denser and noticeably taller, especially on plateau on the south side of the river.

There has been considerable conifer establishment at the base of Crandell Mountain where a burn was apparent on the north facing slope in 1914. Riparian stands have increased considerably in height, particularly several Douglas-fir trees at the base of the cliff, and on the north side of the river. Some new small shrub patches have appeared among the conifer woodlands, but overall shrub cover has declined since most shrub patches visible in 1914 have converted to large contiguous aspen stands, especially on the south side of the river above the cliff.



1914



2004

Appendix 4d: Crandell Mountain
Image #681

Along the Blakiston River, the riparian forest has matured and contains a much higher percentage of conifer trees within the mixed riparian forest. Several aspen patches that were confined to small depressions in 1914 have expanded and merged to form one large aspen patch in image foreground. There has been considerable conifer establishment on the toe of Blakiston Mountain. The few small wetlands have expanded indicating potentially wetter conditions. Numerous small patches (likely aspen) have appeared in open grassland area. At the base of Crandell itself and along the south bank of the Blakiston River, there has been a major increase in pine cover.

1914

2004

APPENDIX 5

Results of Statistical Tests for Differences in Mean Patch Size

1. Entire Study Area

ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	53.261	24	2.219	5.573	0.000
Intercept	0.658	1	0.658	1.652	0.199
YEAR	3.528	1	3.528	8.86	0.003*
PTCH.TYP	40.649	12	3.387	8.506	0.000*
YEAR x PTCH.TYP	1.274	11	0.116	0.291	0.988
Error	581.831	1461	0.398		
Total	640.838	1486			
Corrected Total	635.092	1485			

Independent Samples Test

T-test for Equality of Means

Patch Type	T	df	Sig. (2-tailed)
Anthropogenic	-0.454	14	0.657
Conifer Forest	-0.784	34	0.439
Aspen Forest	-2.080	327	0.038*
Cottonwood Forest	-1.025	73	0.309
Mixed Forest	0.049	25	0.961
Exposed Shoreline	-1.623	37	0.113
Grassland	-2.728	297	0.007*
Water	-0.343	14	0.736
Rock/Sand/Gravel	-1.679	53	0.099
Shrubland	-3.600	396	0.000*
Willow Shrubland	-0.564	100	0.574
Wetland	-1.378	90	0.172

*** indicates significant result at the 95% confidence level (P < 0.05)**

2. Area A

ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	37.427	22	1.701	4.682	0.000
Intercept	0.131	1	0.131	0.362	0.548
YEAR	0.357	1	0.357	0.984	0.322
PTCH.TYP	29.988	11	2.726	7.503	0.000*
YEAR x PTCH.TYP	2.743	10	0.274	0.755	0.673
Error	310.641	855	0.363		
Total	356.989	878			
Corrected Total	348.068	877			

Independent Samples Test T-test for Equality of Means			
Patch Type	**t**	**df**	**Sig. (2-tailed)**
Anthropogenic	0.155	5	0.883
Conifer Forest	-2.433	15	0.028*
Aspen Forest	-2.577	253	0.011*
Cottonwood Forest	0.243	38	0.809
Mixed Forest	1.212	9	0.256
Grassland	-0.918	124	0.360
Water	0.243	6	0.816
Rock/Sand/Gravel	-0.367	25	0.717
Shrubland	-4.238	297	0.000*
Willow Shrubland	-0.280	40	0.781
Wetland	-0.746	36	0.460

*** indicates significant result at the 95% confidence level (P < 0.05)**

3. Area C

ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	42.052	21	2.002	6.927	0.000
Intercept	0.111	1	0.111	0.384	0.536
YEAR	0.441	1	0.441	1.527	0.218
PTCH.TYP	36.471	11	3.316	11.468	0.000
YEAR*PTCH.TYP	5.005	9	0.556	1.923	0.050
Error	67.651	234	0.289		
Total	121.441	256			
Corrected Total	109.703	255			

Independent Samples Test T-test for Equality of Means			
Patch Type	**t**	**df**	**Sig. (2-tailed)**
Anthropogenic	-	0	-
Aspen Forest	-1.864	17	0.080
Cottonwood Forest	-0.210	7	0.840
Mixed Forest	-	0	-
Grassland	-1.539	120	0.127
Water	-2.298	3	0.105
Rock/Sand/Gravel	-	0	-
Shrubland	0.999	13	0.336
Willow Shrubland	1.223	41	0.228
Wetland	0.596	32	0.555

*** indicates significant result at the 95% confidence level (P < 0.05)**

APPENDIX 6

Detailed Notes on Repeat Photographs

		Forest Cover				Shrub Cover		
Photo Number	**Image Area**	**Stand Height**	**Stand Density**	**# of patches**	**Patch size**	**# of patches**	**patch size**	**Description**
Blakiston Mouth								
658	Foreground	increase	increase	increase (x 4)	increase	increase (x 9)	increase	Most forest expansion is by conifers, concentrated along ridgetops and on east side of small glacial features (i.e. drumlins). All new conifer patches have distinct shrub establishment around or among the trees. Some isolated aspen patches appearing, although pattern appears random.
	Background	increase	no change	increase (x 3)	increase	increase	IND	Aspen establishing in depressions. Heavy conifer establishment along toe of Lakeview mountain, and many scattered individual trees appear among new shrub patches in lower-lying areas. Numerous isolated scrub patches have merged in depressions or around glacial landscape features.
657	Foreground	increase	slight increase	increase (x 2)	increase	increase (x 1)	increase	Forest is mostly establishing in depressions, with aspen spreading from existing patches laterally as well as up the side of several glacial features. Two large stands in image center have spread towards each other and will likely merge. Two new conifer woodlands appear where shrub patches existed in 1914.

657	Background	increase	increase	increase	increase	decrease	increase	Forest height and density has increased markedly along Blakiston Creek. Mixed deciduous scrub cover has converted to mature cottonwood forest with the occasional large conifer. Also a dramatic increase in forest cover along the toe of Blakiston mountain - in the 1914 photograph there appears to be a large fire scar covered either in burned or extremely young scrub. Open conifer woodlands have freely established along the toe of Lakeview mountain also. One large, distinct aspen patch in the back center of photo appears to have established on a former shrub patch. Several shrub patches appear to have merged together in the image background, and several others have been replaced by aspen stands. One notable conifer seedling patch on image back-right.
656	Foreground	increase	increase	increase	increase	increase (x 5)	no change	Only one distinguishable conifer woodland at image right on west-facing hillside on which to base observations. A few shrub patches have established in center grasslands, appearing in pockets on west-facing hillsides and in small gulleys and depressions. Large shrub patch surrounding conifer woodland, and some conifer seedlings visible in closer shrub patches.

656	Background	increase	IND	increase	increase (++)	decrease	decrease	Many existing conifers are visible at the toe of Crandell in 1915, and dense aspen stands have established around them with the conifer forests becoming denser and noticeably taller, especially on plateau on the south side of the river. Considerable conifer establishment at the toe of Crandell, and across burn on north facing slope. Riparian stands have increased considerably in height, particularly several Douglas fir at base of cliff and on north side of the river. Riparian community still obviously of mixed composition. Most visible shrub patches have converted to large contiguous aspen stands, especially on south side of river above cliff. Some new small shrub patches have appeared among conifer woodlands, but overall shrub cover has declined, apparently due to forest succession.
655	Foreground	increase	no change	increase (x 1)	increase	increase (>15)	increase	One small conifer patch establishing at image right.
	Background	increase (++)	increase (++)	increase (++)	increase	increase (>20)	increase	A dramatic increase in conifer cover with over 10 new woodland and denser forest patches, mostly Douglas fir, establishing mostly from the right of photograph. It is possible that these stands were also burned in the fire that affected the north side of Crandell. Many new aspen/conifer patches have established along road. 3 very large aspen stands have established from what appear to have been small scrub patches in 1915, with scattered conifers among the aspen clone.
654	Foreground	increase	increase	increase (+1)	increase	increase (++)	increase	One young conifer woodland has established in image center (previously none) on west side of small hillock. Dense shrub establishment in low-lying depression in between dry raised glacial features in image foreground.

654	Background	increase	increase	increase	increase	increase	no change	Growth and merging of large scrubby aspen stands in image background. Two open srubby patches established along ridge bottom in image background, with short, scattered conifers establishing along ridgetop. In far distance, forest cover was fairly thick in 1915 photos, but conifer cover has spread downslope. Large grassland in image background has decreased in size, and some small openings created by small rockslides have filled in with conifers. Uniform cover of undetermined species in background (grassland?) appears to have broken up a little bit and is now dotted with both scattered conifer patches and older aspen patches. Existing shrub patches in image foreground have appeared to shift somewhat, but no obvious expansion noted, although several small patches are notable in the image background.
Bison Paddock								
541	Foreground	no change	no change	no change	no change	no change	no change	
	Background	increase	increase	IND	increase	decrease	decrease	Although few new patches have established, what scruby aspen cover there was in 1915 has matured into dense aspen forest, and there seems to be a ubiquitous horizontal spreading of what patches did exist.
540	Foreground	no change	no change	none	no change	no change	no change	No forest expansion, and shrub patches shifted, but did not markedly increase.

540	Background	increase (++)	increase	IND	increase			Many small grasslands have filled in, and large grasslands covering hilltops have converted to aspen forest. Mixed forest in image background has developed into dense conifer forest, while much of the aspen forest along mountain base has converted to mixed forest with pine and fir appearing to spread downslope. Forests along riparian zones have increased markedly in height, but open grasslands have remained open. Most forest expansion occurring in the distant background on hillsides as opposed to in low-lying dryer hillock area in image foreground.
539	Foreground	no change	no change	no change	no change	decrease (x 1)	decrease	One small shrub patch disappeared.
539	Background	no change	IND	no change	increase	IND	IND	Aspen forest seems to be spreading downslope into grasslands from higher elevations, but increase from this angle is not remarkable. One scrubby patch at image right has increased slightly, but height has remained less than 10ft. Significant conifer establishment along toe of mountains with dense stands on steeper, high elevation slopes and scattered trees establishing at lower elevations in grasslands and in the middle of aspen stands. Conifers seem to have established more readily in cleared slide areas obvious in 1915 photos.
536	Foreground	no change	no change	no change	no change	no change	no change	No obvious change.
	Background	increase (+)	increase	no	increase	IND	increase	Existing aspen forest patches have extended into open grassland areas, and forested slopes in far background have closed in developing a thick, uniform cover. Forest density and height, and shrub cover have increased in low-lying wet areas.

Crandell								
681	entire image	increase - riparian zone especially	IND	increase	increase	IND	IND	Along Blakiston river, riparian forest has matured with increased % of conifer trees within the mixed riparian forest. Several aspen patches confined to small depressions in 1914 have merged to form a large aspen patch in image foreground. Considerable conifer establishment on toe of Blakiston and Crandell. Small wetlands have expanded indicating potentially wetter conditions. Numerous small patches (likely aspen) have appeared in open grassland area.
682	entire image	IND	IND	increase	increase	IND	IND	Major increase in forest cover to the west of middle Waterton Lake,especially along the w side of two prominent drumlins.Forest cover in low-lying area south of lake appears not to have changed much with forest/shrub cover uniform in 1914 photos. Aspen cover is thick and uniform to the east of the lake in 1914. Definite migration of conifer/aspen boundary downslope in image background. Some small grasslands in image background have disappeared.
Vimy								
687	entire image	IND	increase	increase	increase	IND	IND	Evidence of many new forest patches in dry grassland on west of lakes. Cottonwood/willow complex in image foreground (1914) has not changed markedly in total area, but appears to have converted from a mixed-aged mosaic to a thick cover of mature cottonwood forest. Rise of water level evident along entire river-lake system with new ponds, and widening of river channel obvious. In image distance, aspen cover appears to be fairly constant, although small, dispersed patches of grassland have either filled in, or become more symmetrical. To the east of the lakes, forest cover appears patchy and scrubby in 1914, and thick and more uniform in 2004.

688	entire image	increase	increase	no change	no change	IND	IND	Aspen forest to the right of lakes from this angle definitely appears to have increased in height and become more uniform. Some distinct new grasslands have appeared in the 2004 image, suggesting an opening up of the apparently closed 1914 cover. Very obvious migration of conifers from the east, with scattered conifers in 1914 being replaced by dense pine/fir forest. Notable new wetland on right side of photo, and apparent increase in amount of standing water in image. Increase in height and number of mature trees along alluvial fan/river flowing from image right.
693	entire image	increase	increase	no change	no change	IND	IND	Good view of maturation of lake edge Cottonwood forest, changing from low-lying scrub to mature forest. From this perspective, not much lateral expansion of riparian forest patches along Blakiston river. Some reduction in aspen patches on golf course. New Park headquarters, golf course and several new roads belie human development over the last century.