WOODY ENCROACHMENT ON PASTURES IN WESTERN CANADA

BY

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A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements of the degree of

MASTER OF ENVIRONMENT

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Winnipeg

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Acknowledgements

Financial support for this research was provided by: Prairie Farm Rehabilitation Administration (PFRA), Saskatchewan Agriculture and Foods Lands Branch, Manitoba Forage Council – Native Pasture Improvement Program and Manitoba Conservation (Sustainable Development Innovations Fund). Funding to present at various international conferences was provided by the Faculty of Graduate Studies, University of Manitoba Graduate Students Association, University of Manitoba Students Association and the Clayton H. Riddell Faculty of Environment, Earth and Resources.

I would like to thank my advisor, Dr. David Walker, as well as my committee Dr. Rick Baydack and Dr. Amy Ganguli for all their support. Thank you to all my field assistants especially Melissa Sutherland for spending a whole summer on the road with me. Much thanks to Rod Lastra for the endless hours spent keying out unknown plant specimens and digitizing photographs.

I would like to thank all the staff from PFRA, particularly Ron Moss, Saskatchewan Agriculture, Manitoba Agriculture, Food and Rural Initiatives and Alberta public lands for all their in-kind support. Thank you to all the private landowners for their time and allowing us access to their land, loaned us ATVs, took us horseback riding, fed us lunch and offered us places to camp overnight; this project would have not been possible without you all!

Thank you to all my friends and family for always being there when needed, especially Josh, who always listened to all my troubles and triumphs over the years!

Lastly, but most importantly, many thanks and appreciation to my parents for all their support, from being my field assistants to always believing I can do anything.

Abstract

Grasslands are rapidly disappearing from the landscape across western Canada, resulting in a loss of biodiversity and habitat for wildlife. Pastures can provide habitat along with grazing lands for livestock. Woody encroachment is a serious problem on pastures in western Canada. The increase in woody cover results in a decrease in forage production and available wildlife habitat. Sixty seven pastures, primarily in the Aspen Parkland, were selected as study sites. To assess the extent of encroachment on pastures aerial photos from three time periods were obtained. Six cover classes were digitized and the resulting theme layer was analyzed using the Patch Analyst extension for ArcGIS. Current environmental pasture conditions were also assessed. Two fields in each pasture were randomly chosen and stratified into grass, shrub, forest edge and forest core. In each stratum vegetation cover was noted and soil and biomass samples were taken. Management history was obtained from the public agencies and a survey for private lands. Encroachment has been occurring, to a greater extent on pastures without management, private lands and in Manitoba, overall grass cover increased. Differences in soil properties were significant across the provinces, but not between sites with or without encroachment. Vegetation differed between strata and trended east to west. Management on public lands was found to be dominated by herbicides while on private lands mechanical methods were most common. Management increase greatly after the 1970s and this corresponded with a greater increase in grass cover during this time period. As there were no similar trends between environmental factors and encroachment, it was concluded that management practices probably had the most influence on the extent of encroachment.

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Chapter 1

Literature Review

1.1 Introduction

Woody plants are plants whose secondary growth is in the form of wood. The wood provides them with mechanical support to grow tall and compete more effectively for sunlight. They are perennial and the wood is produced during the plants lifetime (Bovey 2001). They can have both positive and negative effects on the landscape. They provide cover and browse for wildlife and livestock, wood products, medicinal extracts, food, aesthetics and many other benefits for people. However, extensive woody plant growth in grassland ecosystems can become an important management issue as they out compete more desirable forage plant species and many can be unpalatable to both wildlife and livestock, resulting in less available feed. These undesirable woody plants are of little value and when they begin to dominate the landscape and decrease the economic value of the grassland landscape (Bovey 2001).

Woody encroachment (Figure 1.1) is an increase in the density of woody plants suppressing the growth of grasses and herbs (Wiegand et al. 2006). The encroachment of undesirable woody plant species is not limited to forests and rangelands, but occurs along railways, roads, under power lines, airports etc. (Bovey 2001). The suggested causes of woody encroachment vary depending on location and species, but changes in management, such as grazing regimes and reduction of fire, are examples (Vallentine 1989). On the Canadian prairies the native tree and shrub species are well adapted to their environment resulting in significant challenges in management. Historically, bison and fire kept woody species from encroaching on the grasslands, but with the arrival of

Europeans, the natural disturbance regime was eliminated from the landscape (Campbell et al. 1994, Bailey 2008).

Woody encroachment is the most common and difficult issue with respect to pasture management, particularly in the Aspen Parkland, because woody species provide positive benefits such as browse as well as habitat and shelter for wildlife and livestock on the prairies (Bailey 2008). Pasture managers have to determine how much brush should be removed from the pastures, A selection of management options are commonly used on pastures in the Canadian prairies. These range from chemical, mechanical, fire, timber harvesting and prescription burning (Manitoba Forage Council 2008).

1.2 Grasslands/Aspen Ecology – Historical range, ecology and disturbance

In Canada, the Aspen Parkland ecoregion is found in the prairie provinces (Alberta, Saskatchewan and Manitoba) between the grasslands of the plains and the boreal forest (Ecological Stratification Working Group 1996). The soils of the aspen parkland are Chernozemic soils in drier areas and Gleysolic in poorly drained areas (Ecological Stratification Working Group 1996). These soils are formed under a cover of grass and herbaceous plants, which suggest that the aspen parkland represents an area that was grass covered for a significant amount of time and has been recently invaded by aspen (Bird 1961). The aspen parkland can be divided into three broad vegetation conditions based on vertical structure and environmental conditions, these are: forests (and shrublands), grasslands, and wetlands. Together these form an irregular mosaic of patches on the landscape (Bird 1961). The extent and distribution of theses vegetation patches varies over time as a function of environmental gradients and disturbance, both natural and anthropogenic (Bird 1961). Historical accounts state that major fluctuations in the extent of the grasslands and aspen forests occurred before the land was broke for agriculture (Bird 1961). Over time variability in climatic conditions has changed the vegetative landscape of the aspen parkland. Wet periods would keep fires down and result in the forest advancing while extensive wildfires would maintain grassland in dry periods (Bird 1961). In addition to fire, reoccurring droughts throughout the prairies favor the establishment of grasslands as well as extended periods of cold. Wind can also play a role, as grasses are less damaged by wind than trees (Carder 1970).

The relative cover and dominance of forest and grassland varies throughout the Aspen Parkland Ecozone, principally on a north-south direction. In the more northern areas of the aspen parkland, aspen forest dominates and is broken up by infrequent grassland patches. Southward, and as one approaches the grassland ecozones (Ecological Stratification Working Group 1996), grassland patches become dominant with infrequent aspen groves (Bird 1961). This trend is reflected east to west as the Aspen Parkland Ecozone shifts northward from Manitoba to Alberta following climatological and soil gradients. Numerous sloughs are found throughout the parkland, and there is often a spatial succession from grassland to aspen to willow and eventually to emergent and aquatic plants as moisture increases. Aspen may also dominate these wetlands as they dry either through natural drought or by increased drainage for farming (Bird 1961).

In the Aspen Parkland Ecoregion the most common species associated with brush encroachment are trembling aspen (*Populus tremuloides*), western snowberry (*Symphoricarpos occidentalis)*, wolf willow (*Elaeagnus commutate)* balsam popular (*Populus balsamifera)* and willows (*Salix spp.*) in moister areas. Aspen and western snowberry are the most common encroaching species found on pastures. Both species reproduce mainly by suckering rather than seeds (Bowes 1991).

Trembling aspen (hereafter aspen) is the most widely distributed native tree species in North America. It grows in a variety of environments and conditions. It can occur as extensive pure stands or in mixed wood conditions (Jones 1985). Most stands are evenly aged. Aspen is typically a small to medium size deciduous tree in the Salicaceae (willow family) with a straight trunk and irregular short branches. They range from 6-18m tall and 8-46cm in diameter. The bark is smooth and ranges in color from shades of green, yellow, white and grey and can become rough and fissured with age. The leaves are triangular in shape with a flattened petiole acting as a pivot that results in trembling in the wind. It is a dioecious tree and flowers in the spring before the leaves appear. The flowers are in the form of catkins (Jones & DeByle 1985) and are wind pollinated. Seeds are produced in large quantities and are covered in a wooly pappus. Although they do produce a large number of seeds, in many areas aspen spreads and regenerates vegetatively by adventitious roots or suckers. Regeneration commonly occurs from stumps and root collars and even from broken branches if they fall such that the lower stem is embedded in the ground. The regenerative capacity of aspen creates a major challenge for brush management. Aspen also frequently spread laterally through suckering expanding in such a way that many stands may consist of one large ore several large clonal patches. Several factors have been suggested to explain the encroachment of aspen onto grasslands. Soil temperature has been found to be an important environmental factor with respect to suckering and could be related to the encroachment onto grasslands from bordering aspen stand (Schier 1976). Schier, et al (1985) found that full sunlight and mesic soil conditions (neither too dry nor wet) are ideal for aspen suckering.

Western snowberry (hereafter snowberry) is a shrub that is widely distributed across North America. It is abundant in the northern Great Plains and the edges of forested areas almost from coast to coast. It found often in colonies in forest -prairie ecotones, pastures and disturbed areas throughout the region. Snowberry is an erect shrub that can be 30 – 100cm in height. It is capable of invading grasslands, shading out the grass species and allowing for further encroachment by forest species. It is limited primarily to a continental climate, but to no specific soil type (Pelton 1953). Propagation of snowberry may occur by seeds or suckering. The fruit is a berry containing two seeds and distributed often by wildlife, resulting in the wide distribution. However, suckers arising from rhizomes are far more common than seedlings. Within a year suckers may reach the full height of a mature stem and bear fruit (Pelton 1953).

The mechanisms slowing down the expansion of aspen were different in the past than they are today. Before the parkland region was settled it was home to many large herbivores such as elk or wapiti (*Cervus elaphus)* and bison (*Bison bison*). These herbivores often impeded the expansion of aspen in to the grasslands. The large herds of bison would overgraze sections of the prairie and rub and trample on small groves of trees (England and DeVos 1968) and elk would browse on young growth destroying it (Bird 1961). Small mammals (rabbits, hares, mice, voles etc.) also impact aspen at a small scale by removal of bark, girdling, and browsing on leaves. Along wetlands beavers (*Castor Canadensis*) can have significant impact on aspen, by cutting down trees or by flooding (DeByle 1970).

Fire is another important natural mechanism impeding aspen encroachment. Fires help maintain the grassland landscape by damaging forested areas, which leads to the maintenance or extension of the grasslands (Nelson and England 1971). Rural development and urban sprawl have virtually eliminated fire, which used to impede woody encroachment onto these natural grasslands (Agriculture and Agri-Food Canada 2007). In the southern mixed prairie, fires occurring every 15 to 30 years would significantly reduce the presence of shrubs and trees, although other environmental factors, such as drought, play a role (Wright and Bailey 1982).

The arrival of intensive agriculture in the past century led to significant changes to the Aspen Parkland. Land was cleared for agricultural uses, which removed native vegetation and increased wind and water erosion. Native vegetation remained mainly in marginal areas that were not suitable for agriculture (Bird 1961). Through an agreement between the provincial and federal governments pastures were created in these agriculturally sub-marginal areas to protect them from further deterioration (McCartney 1993). Some of these pastures now represent the largest contiguous blocks of grasslands in Canada and are examples of functional prairie ecosystems. Many of the pastures in the Aspen Parkland have been created by clearing aspen and then seeding with a mixture of grasses and legumes. The aspen parkland now contains 86% of the forage production and 66% of the cattle of Manitoba, Saskatchewan and Alberta (McCartney 1993). The encroachment of aspen on bush pastures is therefore a major concern for pasture managers (AAFC-PFRA 2000).

1.3 Woody Encroachment

There has been a trend of increasing abundance of woody plants worldwide (Brown and Archer 1999). Evidence of woody encroachment has been found on many continents and involving a wide range of tree and shrub species. In Litchfield National Park, Australia forest cover increased by 9.91% between 1941 and 1994 (Bowman et al. 2001); in the East Pyrenees of France, between 1953 and 2000 there was a decrease of 73% cover of grasslands (Roura-Pascual 2005) and on the African savanna shrub cover, primarily sicklebush (*Dichrostachys cinerea*), increased from 2% to 31% between 1947 and 1990 (Roques et al. 2001). In the Aspen Parkland of Alberta from 1907 to 1966 there was an increase in aspen from 4.8 to 8% (Bailey and Wroe 1974).

The implications and potential effects of an increase in woody plant cover are numerous. Woody cover impacts the biodiversity of grasslands and affects the sustainability of livestock production (Archer et al. 2001). Stocking rates have decreased in Texas due to increased woody cover (Rappole et al. 1986). Total productivity and species diversity can also decrease in areas affected by woody encroachment (Briggs et al. 2005).

In western Canada it has been found that forage production decreases when under shrub cover rather then in grass dominated areas (Johnston and Smoliak 1968, Bailey and Wroe 1974). Competition between woody and grass species result in a decreased yields overall compared to either grown alone (Bailey and Gupta 1973). The degree and extent of the woody encroachment is often dependent on many factors, both natural and anthropogenic. A change in the intensity and frequency of fires, livestock grazing and periodic drought have been suggested to have an impact on the encroachment of red berry juniper(*Juniperus coahuilensis*) in Texas, where there was an increase of 61% in juniper cover over 34 years (Ansley et al. 1995). Encroaching Coyotebrush (*Baccharis pilularis)* on grasslands in California has been linked to wildfires and grazing being eliminated in the parks (McBride and Heady 1968) and changes in rainfall amounts (Williams et. al. 1987). Archer et al. (1995) suggests that the mechanisms of woody encroachment are impacted by the interaction of various elements, such as climate, CO_2, fire and grazing; noting that soil properties and disturbances play the greatest role and CO_2 and climate facilitate the changes. Time also plays a role because the mechanisms behind the woody encroachment may differ between long and short-term changes in vegetation cover. In southeastern Arizona short term changes in vegetation have been related to climate variations, while long term variation is attributed to human activities (Bahre et al. 1993). A study in Colorado, looking at the ecotone between ponderosa pine (*Pinus ponderosa*) and grasslands found that fire played the most important role in the change in vegetation patterns, with changes in grazing regimes and favorable climate conditions also having an impact (Mast et. al. 1997).

The mechanisms behind vegetation pattern changes, such was woody encroachment vary depending on many natural (i.e. soil, topography etc.) as well as anthropogenic factors (i.e. land management). In Kansas, Bragg and Hulbert (1976) found that the rate and overall degree of woody encroachment was affected by management as well as soil type and topography. Brush increased by 34% from 1937-1969 in non burned areas, while there was a 1% increase in brush cover in areas that were burned and treated with herbicides. In the tall grass prairie of Kansas the number of trees increased by 60% over five years in areas without burning and with adequate moisture while in areas that were burned annually the number of trees decreased (Briggs and Gibson 1992).

It is difficult to determine the cause of woody encroachment; different mechanisms are at work in different areas of the world (Van Auken 2009). It would be very difficult and expensive to try and reverse the encroachment that has occurred, but sustaining the current ecosystems as they are would be an appropriate goal (Van Auken 2009).

1.4 Historical Reconstructions

The classification of the earth's features has been done for centuries, using for example, political divisions, physical features and other groupings. All these classifications have one thing in common; they have an intended purpose designed for specific users (Demers 2009). More advanced technologies such as Geographic Information Systems (GIS) allow for the collection and analysis of vast amounts of spatial data and the development of new and improved methods of classification (Demers 2009). For dynamic features, land use classification repeated over time can assist in historical reconstruction and in change detection. Identifying areas with significant changes can lead to a better understanding of the mechanism responsible and provide land managers with invaluable information.

Studies assessing changes in vegetation cover over extended time periods have been conducted on many different landscapes, comparing historical cover to present day cover. Indeed, many of the studies in previous sections of this review conducted historical reconstructions using aerial photography as a way to assess changes in vegetation over time (e.g. Bowman et al. 2001, Briggs et al. 2005, Roques et al. 2001). Aerial photos are very useful when creating a historical reconstruction because they are available from as far back at the 1930s and are easily interpretable. They cover large areas, including areas that are remote or even inaccessible and provide repeated views of these areas (Rango and Havstad 2003). Specific to studies looking at changes to rangelands, aerial photos are ideal as the establishment and management of such areas started in the 1930s when some of the first aerial photographs were being taken (Rango and Havstad 2003).

In addition to aerial photography, historical data can be obtained by using previous studies that evaluate percent cover of vegetation in permanent plots and comparing those data to current conditions. Using that approach, Anderson and Holte (1981) discovered shrub cover was 154% greater in 1975 than in 1950 in south east Idaho. Ansley et al. (1995) used survey maps from 1948 and 1982 to compare the distribution of redberry juniper (*Juniperus coahuilensis*) in northwest Texas and found a 61% increase in Juniper cover.

Of the various methods available, photographic techniques provide some of the best data for historical reconstruction, Imagery can be broadly classified based on the angle of the lens to the surface. Vertical photographs are taken at nadir and normal (perpendicular) to the surface and oblique photographs are taken at an angle other than perpendicular. In the latter case, photographs may be taken from a plane (the earliest areal photographs are of this type) or as ground-based photography for a given site. Vertical aerial photography is superior to repeat ground photography or oblique aerial imagery because the images are taken at a right angle to the earth's surface and have a large instantaneous field of view making them more useful for planimetric measurements over large areas (Bahre et al. 1993). Ground photography is still helpful in assessing long-term dynamics in vegetation cover as they often date farther back than aerial photography (Clark and Hardegree 2005). Bahre et al (1993) used aerial photography to look at changes in mesquite cover in Arizona and found that it has increased in cover most likely due to livestock grazing and/or lack of fire, rather then precipitation trends.

There are a variety of ways to obtain information from aerial photos on vegetation cover. One method is to delineate the cover classes manually. Delineating cover classes by hand on historical aerial photographs was done in studies on grasslands in British Columbia, Kansas and California (Bai et al, 2004; Knight et al. 1994; Williams et al. 1987). Bai et al. (2004) studied grasslands British Columbia, looking at the effects slope aspect, slope degree and elevation had on woody encroachment. Vegetation maps were created from historical photos and overlaid with GIS layers. The results showed shifts from grassland to treed areas occurred on southern aspects and in more level areas. Knight et al. (1994) used aerial photographs to look at changes in forest cover on the Konza Prairie Research Natural Area in Kansas over a 46 year period. Total forest area increased over the 46 years, and was potentially attributed to changes in management practices and temporal constraints. Williams et al (1987) studied the encroachment of shrubs on California grasslands. Aerial photographs showed a period of rapid increase in shrub cover in the late 1970s and early 1980s. This was correlated with annual and spring rainfall amounts.

Another method to determine percent cover of differing cover classes using aerial photography is to overlay a grid on the photograph and assess total woody plant cover in various ways such as, estimating the cover of woody species per square, counting the number of squares containing trees and looking a what ground cover existed at grid intersections. (Bragg and Hulbert 1976, Brown and Carter 1998, Johnson 1994). This method was used by Bragg and Hulbert (1976) to assess changed in tree and shrub cover in Kansas from 1856 to 1969. They found an increase of 8% through out the county. On unburned sites it was as high as 34% and herbicides only slowed down the rate of encroachment. Soil type and topography were also found to affect the rate of encroachment. Brown and Carter (1998) also used this method to determine change in cover of shrubs in northern Australia, relating the increase to changes in livestock grazing. Johnson (1994) assessed changes in *Populus-Salix* woodlands of the Platte River and it major tributaries and found there was an increase of up to 10% a year and related the increase to June flows, summer drought and ice.

Transparent dot overlay grids have also been used to determine percent aerial coverage. This is done by counting the numbers of dots that cover woody species to estimate overall coverage (Knapp et al. 1990, Soulé and Knapp 1998, Roques et al. 2001, Briggs et al. 2002). Soulé and Knapp (1998) used this method to assess changes in western juniper cover in Oregon. Western juniper cover increased on all study sites from 1951 to 1994 and it was concluded that all potential causes, (fire, climate, grazing etc.) should be considered. In Swaziland, Roques et al. (2001) looked at changes in shrub cover over a fifty year period, using transparent dot overlay grids on aerial photographs. Shrub cover increased from 2% to 31% during this time. Grazing, fire frequency and drought were all factors in the shrub dynamics. Briggs et al. (2002) also used this method to determine changes in shrub cover in the tallgrass prairie watersheds in Kansas. Over the 15 year period, tree density increased by two to ten fold except in areas that were burned annually. Also grazing was shown to increase the percentage shrub cover in these areas.

Historical vegetation data is often from different sources and of differing quality than those collected, for example historical surveys and current aerial photography. Branscomb (1958) used reconnaissance surveys and aerial photography to assess changes in vegetation cover in the Jornada Experimental Range, discovering an increase in shrub cover, primarily mesquite. McBride and Heady (1968) used vegetation maps from 1927 and 1942 of *Baccharis spp.* and compared it to aerial photographs from 1961 in California, finding that the increase in shrub cover was due to the decrease in fires and grazing in parks. Bailey and Wroe (1974) used brush cover data from land surveys conducted in 1907 and compared them with aerial photographs taken in 1966 to determine if woody encroachment by aspen and willow species had occurred. The increase in woody vegetation led to a decrease in herbage production and was linked to climate variables. More recently Kettle et al. (2000) used public land surveys, ownership records, agricultural censuses, interviews, unpublished data and aerial photographs to assess vegetation cover and historical land use. They found that restoration management and landscape positions (i.e. near forest, along water course etc.) greatly affected forest development.

Remote sensing data such as satellite imagery has also been used in combination with aerial photographs to create land cover maps (Afinowicz et al. 2005, Asner et al. 2003). Asner et al. (2003) used both satellite imagery and aerial photographs along with field observations to study changes in woody vegetation in northern Texas. Areas without management had increases of woody cover of up to 500%. Areas with management varied in the degree of change in woody cover depending on soil type and timing of most recent management. Although these studies provide valuable information, there are both advantages and disadvantages in using satellite imagery compared to aerial photographs. Satellite imagery often does not date as far back as aerial photos and can be expensive and often requires more sophisticated analytical expertise and techniques (Asner et al. 2003), but analysis of satellite imagery is less labour intensive than developing mosaics from aerial photos when studying large areas (Asner et al. 2003).

With GIS software delineating cover classes on aerial photographs can be done digitally (Bowman et al. 2001). To assess the expansion of western juniper in central Oregon, Knapp and Soulé (1998) used aerial photographs from several time periods and with GIS software determined juniper cover by analyzing and manipulating color contrasts. They found significant changes in vegetation cover, including an increase in juniper and suggested both anthropogenic and natural means behind the increase. Mast et al. (1997) used a gray tone density slicing to determine areas with or without tree cover in Colorado, showing an over increase in woody cover. Using GIS modeling this information was linked to topographic orientation and it was found that the increase in woody cover was greater on north facing slopes. Using digital data means more extensive analysis of patterning can be conducted. Coppedge et al. (2001) and Goslee et al. (2003) both used FRAGSTATS (McGarigal et al. 2002) to obtain spatial statistics on vegetative cover. This included patch sizes and number, as well as shape index and fractal dimensions. Coppedge et al. (2001) found a substantial increase in juniper cover between 1965 and 1995. Greater number of patches, smaller patch sizes, more total edge and higher patch diversity were found in areas dominated by juniper. They found the fragmentation of woodland areas by human activity has increased the threat woody plant encroachment in grasslands. Goslee et al. (2003) looked at changes in cover of honey mesquite (*Prosopis glandulosa)* in the Chihuahuan desert of New Mexico. Shrub cover increased from 1936 to the 1970s, stabilizing at 43%. Individual patches were persistent on the landscape and patch shape complexity increased from 1936 to 1983. Di Orio et al. (2005) used aerial photographs from two time periods to assess the decline and fragmentation of aspen in California. The photos were scanned and georectified and aspen stands were manually delineated to create a polygon GIS layer. The GIS layers were then analyzed using Patch Analyst (Rempel 2008) for ArcView. Aspen cover declined by 24% over 48 years and the number of stands increased while stand size decreased resulting in a more fragmented landscape.

1.5 Pasture Management with a focus on woody encroachment

Based on a study by Chorney and Josephson (2000) the primary reasons for applying pasture management in Canada are to improve the pasture conditions and maintain long-term sustainability of land resources. Secondary reasons are to increase stocking rates and income. Although wildlife habitat wasn't of major importance, it was noticed that with better management practices it was improved.

The encroachment of aspen and associated shrub species (i.e. western snowberry) is a major management concern on pastures in the Aspen Parkland. Herbage yields can be decreased by as much as 10% when under the cover of aspen or western snowberry (Bailey and Wroe 1974). Many management strategies have been evaluated for their effectiveness. Some methods of brush control commonly used are prescribed burning, intensive grazing, mechanical methods, such as mowing and chaining, as well as chemical control with herbicides (Zentner and Bowes 1991). In some areas, to create pastures, aspen and associated shrub species were bulldozed, piled and then burned. Cereal crops would be planted for a year or two to control brush followed by seeding with a legume grass mix (Johnston and Smoliak 1968).

Many studies have been conducted on woody plant control, with the greatest focus being on chemical methods (Bovey 2001). Herbicide use was the greatest method studied followed by fire, mechanical and biological controls. Although reseeding and revegatation are not control methods they are important for creating desirable grazing conditions and in hampering woody encroachment (Bovey 2001). Often combining management methods to control woody encroachment is the most efficient and economical choice. Control methods may be applied in the same year or used on consecutive years (i.e. prescribed burning followed by herbicides; Bovey 2001).

Fire has been used as a method of control for woody encroachment for centuries. Fires were set by aboriginals for a variety of reasons that ranged from improved berry production to weed and brush control (Bovey 2001). In Texas there are large areas now covered by mesquite that at one time were kept as open prairie through fires set by aboriginals (Stewart 1951). The effects fire can have on the landscape vary greatly by the type of vegetation, fire frequency, topography, soil type and climate (Bovey 2001). On the prairies it is difficult to assess the historical fire frequency because there is a lack of preserved evidence (e.g. tree ring scars as used in forestry), but it has been estimate to be 5 to 10 years in the drier prairies and in some areas up to 30 years (Wright and Bailey 1982).

Fire suppression started around the turn of the ninetieth century. Fires were considered bad because they killed trees; this train of thought stemmed from European trained foresters who were used to growing and protecting trees until harvest time. The lack of fires resulted in fuel buildups, dense under stories of shrubs and trees leading to catastrophic fires, increase presence of shrubs and trees in grasslands and monocultures of trees that are more susceptible to insects and disease (Wright and Bailey 1982). This philosophy started to change when it was realized that fires are beneficial in reducing dry fuel load (organic debris not yet fully decomposed), disease control, thinning of trees, removal of above ground woody material, and in increasing herbage and availability of forage (Wright and Bailey 1982).

It was in the 1960s that fires were reintroduced as a form of management because alternative methods such as herbicides and mechanical and biological methods were either environmentally unacceptable or ineffective (Wright and Bailey 1982). On the prairies, the benefits of prescribed burning include increase herbage yields, improved wildlife habitat as well as control of undesirable trees and shrubs (Wright and Bailey 1980). Bailey et al. (1990) looked at the effect the combination of short term heavy grazing and fire would have on aspen. Regardless of the degree of grazing, the density of woody species decreased 6 years after burning compared to 3 years after burning (Bailey et al. 1990). Aspen and wild raspberry densities both decreased with early and late season grazing, but late season grazing resulted in a higher density of western snowberry. Burning combined with seeding and short duration heavy grazing is effective in improving pasture quality (Bailey et. al. 1990).

Biological control of woody plants is another method that has been used for centuries. Most plants have natural enemies that cause damage either by consuming the plant or injuring them (Bovey 2001). Some plant species may be unpalatable to livestock and wildlife resulting in those undesirable plants dominating the landscape and becoming weed problems. This is often the case with exotic species because there are no natural species of pathogen or insect to attack them (Bovey 2001). The goal of biological control is not to eradicate a species but to maintain it at a lower density (Huffaker 1964). Selective grazing by livestock is used as a means of biological control on pastures (Bovey 2001). Goats were found to most effective in reducing brush and increasing grass. They are better for brush control because they destroy small trees and saplings by girdling. Goats are not deterred by thorny vegetation and browse higher by standing on their hind legs therefore browse on a larger variety of woody plant species (Wood 1987). Using goats as a management strategy for woody encroachment is not simple though, special fences are required, along with shelters as predation can be a problem and in areas without year round foliage, they have to be sold or fed throughout the winter months (Bovey 2001). In Alberta, Fitzgerald and Bailey (1984) studied the effects of cattle grazing on aspen. An aspen forest was burned, seeded and then grazed heavily by cattle for two seasons either after the emergence of suckers (early) or just before the leaves fall (late). They found that a single heavy late grazing almost eliminated the aspen regrowth.

Mechanical and manual control of woody plants has been practiced for millennia starting with hand clearing, which is slow, costly and labour intensive. Some examples of manual methods include cutting or girdling (Bovey 2001). More recently new technologies have been developed to create larger more powerful machinery to control unwanted woody species. These include bulldozing, grubbing, chaining, railing, chopping, mowing and shredding, root plowing and disking (Bovey 2001). Bulldozing is a widely used method of brush control. It is most often used on stands of large trees in areas where other methods are not possible. Often other methods of control will be necessary a few years after bulldozing to kill seedlings (Vallentine 1989). Chaining is an inexpensive but temporary method of brush control (Rechenthin et al. 1964). It is most effective on sandy, shallow and moist soils with large single stemmed trees (Bovey 2001). Roller chopping consists of knocking down and crushing brush; it is also a temporary measure as resprouting occurs soon after use (Rechenthin et al. 1964). Mowing is temporary as well as should be done in the spring to minimize impacts on grasses (Rechenthin et al. 1964). Root plowing and disking both destroy the roots of unwanted woody species and results in a good seedbed for planting (Bovey 2001). The cost of mechanical control depends on size and total area of woody plants to be removed and the degree of soil disturbance. Some of the most effective methods; bulldozing, disking; are the most expensive. Roller chopping and mowing are less expensive (Bovey 2001) but temporary.

The use of herbicides on pastures has expanded rapidly since the 1950s and tends to be more effective and less costly then other methods of brush control (Klingman 1961). Common herbicides used on pastures, industrial sites, rights-of-ways include 2, 4-D, which is one of the oldest used (Bovey 2001). Hilton and Bailey (1974) found that a single application of 2, 4-D increased the annual herbage production three fold, two years after treatment. Dicamba is another herbicide used for weed and brush control and often combined with 2, 4-D (Bovey 2001). On a recently cleared pasture in Saskatchewan, Bowes (1991) found that one application of the herbicide 2, 4-D combined with Dicamba is effective in the control of aspen for up to nine years. In one experiment two applications of herbicide were necessary to control western snowberry, while one was sufficient in another experiment. Glyphosate, commercially known as Round-up, is a foliar applied herbicide that is used on pastures, but has limited uses because it kills many other desirable plants, such as grasses (Bovey 2001). Herbicides can be applied in a various ways depending on the particular compound chosen and its bioactivity (Bovey 2001). They can be sprayed on foliage (typically 2, 4-D), wiped onto stems and/or foliage (Round-up), basal bark spraying and injection (Round-up) or soil application (Glyphosates).

When two or more methods of brush management are used to maximize the control of undesirable woody species it is referred to as an integrated brush management system. The methods are selected to have the lowest cost and minimal impact on the environment while maximizing reduction of woody material. Bailey and Anderson (1979) compared the effects of spring prescribed burning, herbicide and a combination of spring burning and herbicide on aspen, balsam poplar and willow in central Alberta. They found that after 5 years, the combination of burning and herbicide was most effective in reducing brush. Re-encroachment of brush did occur in all areas, but repeated burning and spraying reduced the density.

A major factor when considering what type of brush management to implement is cost. There have been a few studies looking at the economics of brush control in the Aspen Parkland. Zentner and Bowes (1991) found when using herbicides for brush control the results vary widely depending on the value assigned to the useable forage gained and the length of the forage benefits. When herbicides were applied to younger stands it was generally more profitable and that repeat herbicide applications were not justifiable in any economic circumstance (Zentner and Bowes 1991). Novak and Lerohl (1986) compared the economic costs of various methods of brush control and found a combination of spraying and burning is potentially a profitable means of brush control when compared to clear and break. Although it should be noted that this result could be due to the large input cost of clear and break and the delay in improved forage production.

While pasture management in Canada often involves removing aspen and other woody species, it should be noted that aspen groves are an important part of the aspen parklands ecology and their maintenance should also be considered (Ripley and Archibold 1999).

Figure 1.1 Woody encroachment – Montrose Community Pasture, Saskatchewan

1.6 Objective

The goal of this thesis is to quantify the loss of grassland cover on pastures that has resulted from, but is not limited to, increased cover of woody vegetation and relate these changes to land management, climate and other environmental factors (e.g. soils) that may affect or inhibit encroachment. There are three major components to this study:

- Creating a historical construction using aerial photographs and analyzing patterns of landscape change over time.
- An assessment of current ecosystem conditions and how they relate to woody encroachment.
- Examine different pasture management strategies specific to woody encroachment.

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Chapter 2

Study Area

2.1 Introduction

This study was conducted in pastureland sites found on the Canadian Prairies roughly within the region: 49°N-55°N Latitude, 97°W-115°W, Longitude (Figure 2.1). In total 67 sites were visited, 32 publicly owned and 35 privately owned. Sites were specifically located based on three criteria: 1) to be in or near to the Aspen Parkland Ecoregion; 2) to ensure broad dispersion within the region (east-west and north-south), and; 3) to cover six of the most common soil types in the area. Using these criteria, the sites retained in this study are found within two Ecozones (Prairies and Boreal Plains) and seven ecoregions (Figure 2.1).

2.2 Ecozones

Prairies

The Prairies Ecozone spans the southern portion of Manitoba, Saskatchewan and Alberta. Study sites are located in four ecoregions found in the Prairies Ecozone: Aspen Parkland, Moist Mixed Prairie, Lake Manitoba Plain and Southwest Manitoba Uplands. The Aspen Parkland is found in all three Prairie Provinces. It is the transitional zone between the boreal forest to the north and the grasslands to the south. The Moist Mixed Prairie is the northern portion of the Interior Plains of Canada. The Lake Manitoba Plain extends from the U.S.A border to Dauphin Lake in Manitoba. The Southwest Manitoba Uplands consists of two uplands areas; the

Pembina Hills and the Turtle Mountain area in southern Manitoba (Ecological Stratification Working Group 1996).

Boreal Plain

The Boreal Plain Ecozone stretches from northwest British Columbia to southeast Manitoba. Study sites are found in three ecoregions found in the Boreal Plains Ecozone: the Mid Boreal Uplands, Western Alberta Uplands and Boreal Transition Ecoregions. The Mid Boreal Uplands is found from Manitoba to Alberta in various upland areas; for example the Duck Mountain region in Manitoba and the Alberta Plateau in Alberta. The Western Alberta Uplands are found in west central Alberta. It is a transitional area between boreal and cordilleran vegetation. The Boreal Transition Ecoregion stretches from southern Manitoba into central Alberta. It is marks the southern extension of closed boreal forest and is the northern limit of arable agriculture land (Ecological Stratification Working Group 1996).

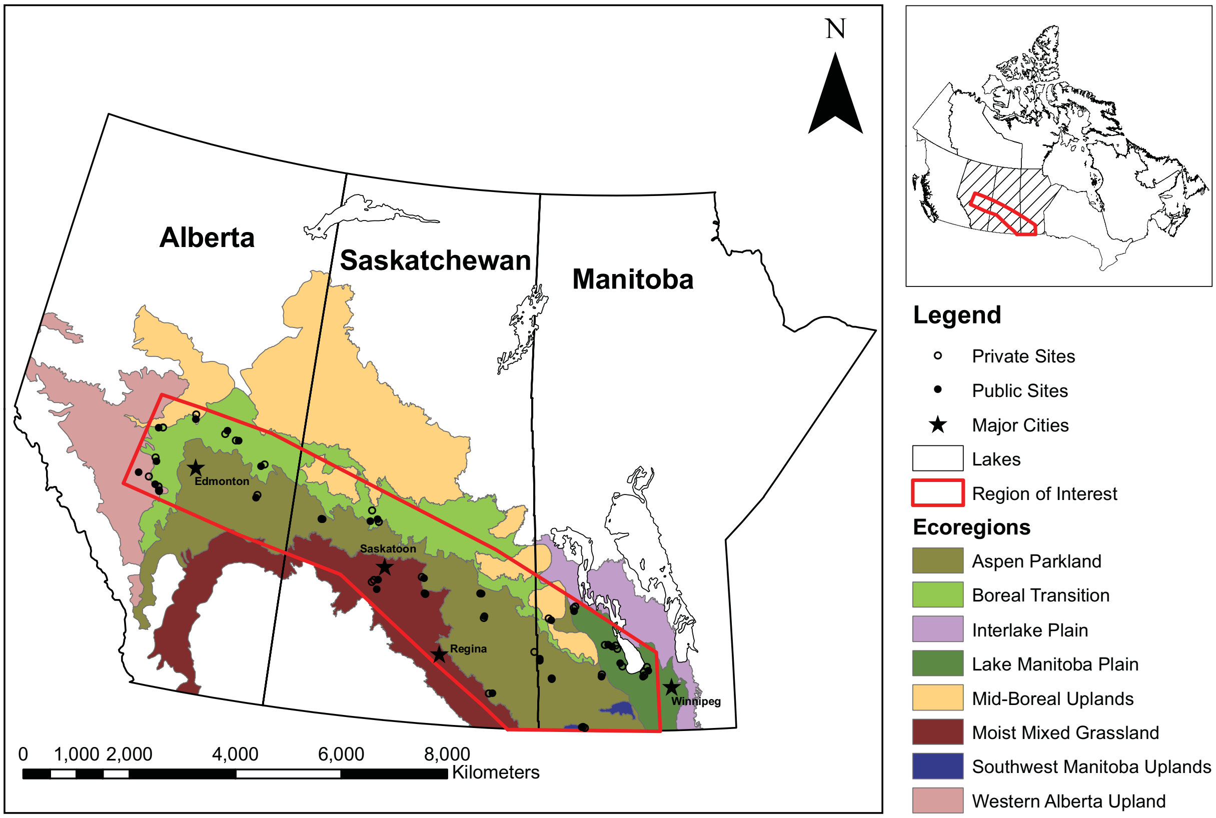

Figure 2.1 Ecoregions of Manitoba, Saskatchewan and Alberta

2.3 Climate

The average temperature and precipitation in three major urban centers found in the study area (Winnipeg, Saskatoon, Edmonton) show that there is little variability across the region (Figures 2.2, 2.3, 2.4; Environment Canada 2006).

Prairies

The Prairies Ecozone has a continental climate because of the influence of the Rocky Mountains in the west preventing moisture-bearing winds from the Pacific. It is typified by short hot summers and long cold winters with little precipitation and high evaporation rates. The winter temperatures range from -12.5°C to -8°C and summer temperatures range from 14°C to 16°C (Ecological Stratification Working Group 1996).

Boreal Plains

The climate in the Boreal Plains Ecozone is typified by cold winters and moderately warm summers. Average winter temperatures range from -17.5°C to -11°C and summer temperatures range from 13°C to 15.5°C. Precipitation in this ecozone increases from west to east (Ecological Stratification Working Group 1996).

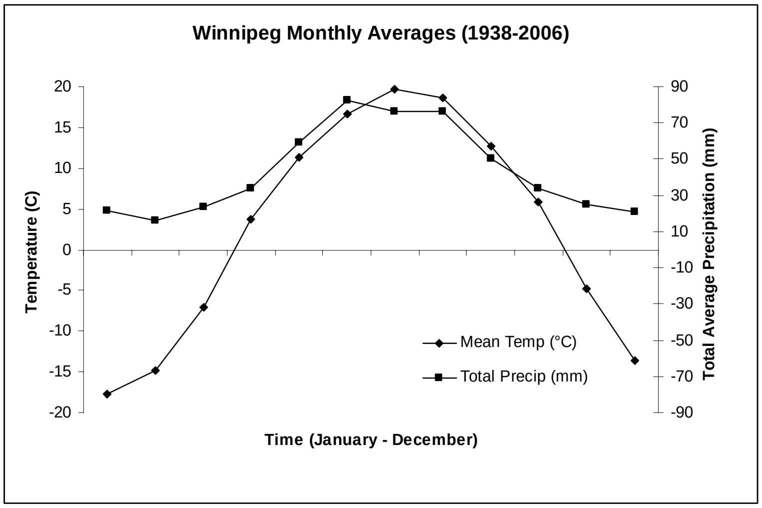

Figure 2.2 Monthly average temperature and precipitation for Winnipeg (1938-2006)

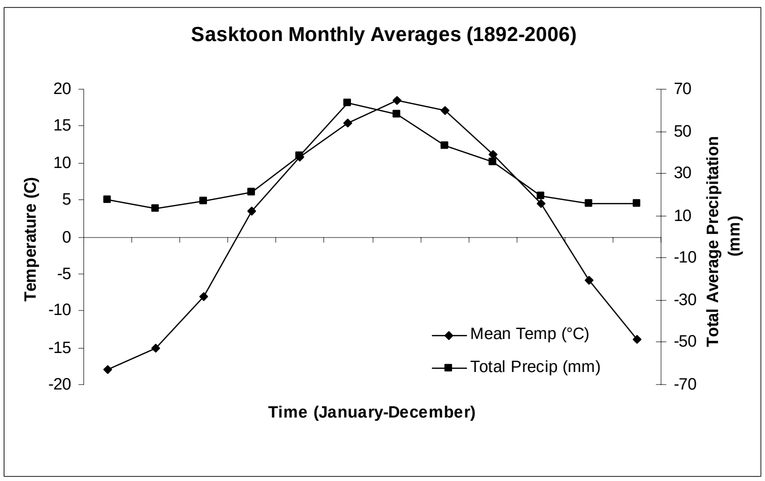

Figure 2.3 Monthly average temperature and precipitation for Saskatoon (1882-2006)

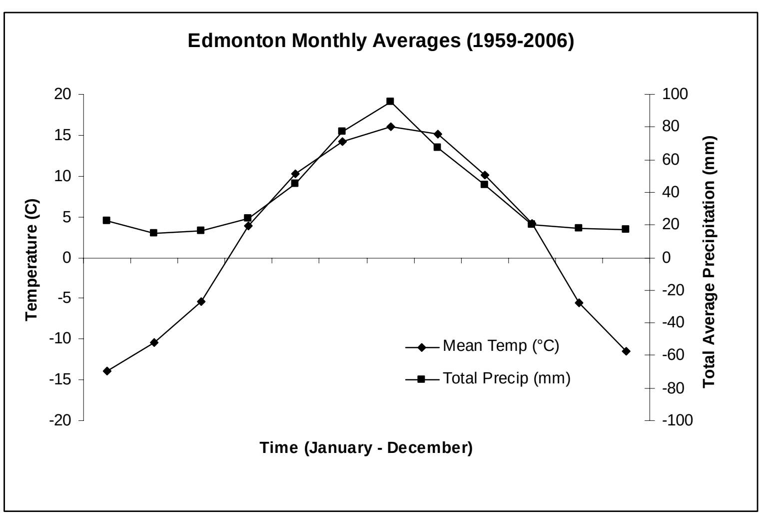

Figure 2.4 Monthly average temperature and precipitation for Edmonton (1959-2006)

2.4 Soils

The soils in the area are primarily derived from glacial till of modified bedrock and there are large surficial deposits of sand throughout the area (Looman 1979). Eight soil orders are represented within the study area and include Brunisolic, Chernozemic, Gleysolic, Luvisolic, Organic, Regosolic, Solonetzic and Vertisolic (Figure 2.5).

Chernozemic soils are the most common soils found within the study area. They are formed under grassland areas, but many transitional areas between grasses and forests are found on this soil type. They are well to imperfectly drained soils with darker surface horizons due to the accumulation of organic matter from the decomposition of grasses forbs and shrubs (Agriculture Canada Expert Committee on Soil Survey 1987). The next most common soil order is Gleysolic. These are soils that have been saturated with water for extended periods of time. They are often found with other soil orders and in low lying areas (Agriculture Canada Expert Committee on Soil Survey 1987). The remaining soils orders are not widely found in the region. Regosolic soils are soils that are not well developed. They are usually rapidly to imperfectly drained and often consist of young parent material. Brunsolic soils are slightly more developed than Regosolic soils, but still do not have sufficient horizontal development to be classed with other soils. Luvisolic soils develop in well to imperfectly drained areas often under forest vegetation (Agriculture Canada Expert Committee on Soil Survey 1987). Luvisolic soils are found within the study area primarily in Alberta. Organic soils are primarily composed to organic materials and have been saturated for extended periods of time. They are often peat and/or bog soils. They are most commonly found in poorly drained depressions (Agriculture Canada Expert Committee on Soil Survey 1987).

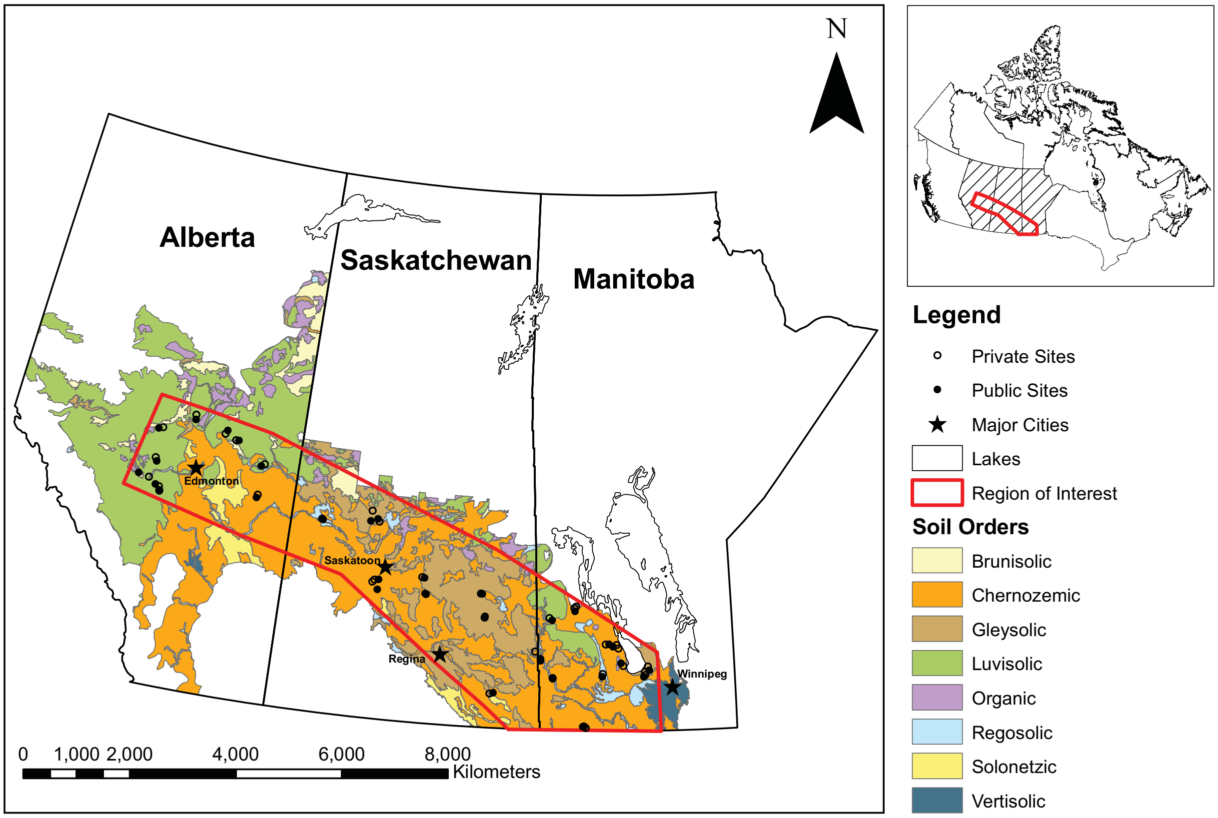

Figure 2.5 Soil orders of Manitoba, Saskatchewan and Alberta

2.5 Landform

Prairies

The Prairies Ecozone is underlain by Cretaceous shale and Paleozoic limestone in southeastern Manitoba. The surface is nearly level to rolling plain and consists of hummocky to kettled glacial moraine and lacustrine deposits (Ecological Stratification Working Group 1996).

Boreal Plains

The Boreal Plains ecozone is underlain by Cretaceous shales and consists of hummocky to kettled glacial moraine and lacustrine deposits. The elevation in this ecozone varies from nearly level to gently rolling (Ecological Stratification Working Group 1996).

2.6 Post glacial history

After the retreat of large glaciers during last glacial period, several glacier lakes were formed. Lake Souris in southwestern Manitoba, Lake Regina in Saskatchewan and the largest was Lake Agassiz in Manitoba. As the ice continued to melt these lakes drained resulting in several large lakes found throughout the prairies. In other drained areas, marshes and sloughs are now found (Bird 1961). The vegetation that established immediately after glacial retreat was a combination of marsh areas and grassland (Bird 1961). As the climate warmed broadleaved forest species began to move northward into the grassland areas and pine and oak species moved in to drier areas. As the lakes continued to recede, grasslands grew in and spruce forest moved into the more northern areas beyond the limit of the broadleaf forests. The border between prairie and parkland has moved back and forth through the centuries with changes in climate. In the past two millennia, the range of spruce forest has expanded and aspen forests have been encroaching on prairie areas (Löve 1959, Ritchie 1976).

2.7 Vegetation

Prairies

Along the northern edge of the ecozone *Populus tremuloides* and *Populus balsamifera* are found in groves within grassland areas. In the southern region the natural grassland vegetation is composed primarily of spear, wheat and blue grama grasses (Ecological Stratification Working Group 1996). With respect to non grass herbaceous species, *Artemesia fridgida, Artemesia ludoviciana, Achillea millefolium, Antennaria spp., Aster spp.* and *Solidago spp.* are all found in open grassland areas. Two shrubs, *Symphoricarpos occidentalis* and *Elaeagnus commutata* are found commonly throughout the prairie region (Bird 1961).

Boreal Plains

Broadleaf tree species such as, *Betula papyrifera, Populus tremuloides* and *Populus balsamifera* are most dominant in the transitional area along the southern edge of the ecozone. Coniferous species such as, *Picea mariana, Picea glauca, Pinus banksiana* and *Larix laricina* are more dominant along the northern edge of the ecozone (Ecological Stratification Working Group 1996). In the understory of aspen groves various shrub species are found such as, *Corylus Americana, Corylus cornuta, Cornus stolonifera, Prunus virginiana, Rosa spp., Amelanchier alnifolia Rubus idaeus* and *Symphoricarpos occidentalis.* In terms of ground cover commonly found species are *Aralia nudicalis, Actaea rubra, Galium boreale, Cornus canadensis* and *Fragaria virginiana* (Bird 1961).

Invasive Species

Invasive species can be found in many areas on the prairies, such as, cultivated fields, disturbed and waste areas (Looman 1979, Masters 2001). Many invasive plants were brought to North America for food, fiber or ornamental use and are now found throughout the continent (Pimentel et al. 2000). Invasive species arrived in the region before 1883, by fur traders bringing seed mixtures containing these species as contaminants (Bird 1961). The three most common invasive species are quackgrass (*Bromus inermis)*, *Poa pratensis (introduced as forage species)*,and *Circium arvense*, (common thistle), which is a costly invasive species (Pimentel et al. 2000; Wilson and Belcher 1989). The plant species found on pasturelands have changed significantly since domestic grazing began over 100 years ago, in part because of invasive species (DiTomaso 2000). Invasive species have negative effects on pasturelands, by replacing more palatable native species and some species such as *Euphoria esula,* which is commonly found across the prairies, is toxic to cattle and wild ungulates (Pimentel et al. 2000, DiTomaso 2000). Invasive species decrease the yield and quality of forage costing producers and decrease plant and animal diversity (DiTomaso 2000). Various methods of invasive species have been used on pastures over the decades; chemical, mechanical, biological and cultural (Masters 2001). Some invasive species were seeded onto pasturelands to increase productivity, for example, *Medicago sativa, Trifolium hybridum, T. repens* and *Agropyron cristatum* (McCartney 1993).

2.8 Ecosystem Disturbance

Fire

Fire had a great influence in this area historically. They were started either by lightning or man and occurred most often in the spring and fall. Depending on the environmental conditions some fires could extend for thousands of square miles, even crossing large river valleys. Fires had an impact on both flora and fauna; for example fires would often damage trees helping maintain the open grassland areas (Nelson and England, 1971).

Agriculture

Agriculture started in this area as early as 1680, with the Hudson's Bay Company wanting gardens and grains planted and livestock established near their forts. Major settlements focusing on agriculture did not occur until the late 1800s after most of the big game was gone along with important fur bearing animals, which had provided food and income for the settlers. Settlement continued throughout the area, increasing with the establishment of railways (Bird 1961). As technology improved more land was cleared for crops; aspen forests were cleared, piled and burned. Pastures were broken up and reseeded into *Bromus inermis* and *Medicago sativa*, therefore native pastures only remain in areas that were difficult to plow under; either to hilly, stony or sandy. Overgrazing was evident resulting in a decrease in more nutritious species and an increase in *Artemesia frigida* and *Symphoricarpos occidentalis* (Bird 1961). There has been significant water and wind erosion because of the intensification of agriculture. Chemicals for weed and brush control began in the late 1940s. It is hard to find areas of the parkland region that have not been disturbed (Bird 1961). The establishment of agriculture in the region has had a huge impact on the fauna and flora of the region. Currently 60% of Canada's cropland and 80% of its rangelands and pastures are found in the Prairie Ecozone. Some common crops are spring wheat, other cereals, oilseeds, forage crops and numerous specialty crops (Ecological Stratification Working Group 1996).

Grazing

Bison grazing had an impact on the vegetative landscape of the area. Bison hinder the expansion of aspen by eating and trampling on new stems (Wright, 1982). It has been suggested by Campbell et al. (1994), that the beginning of aspen expansion occurred with the extinction of bison and before European settlement and fire suppression. Livestock are the principal grazers in the region now, primarily cattle. Two thirds of cattle all the cattle in Canada graze in this region (McCartney 1993).

Natural Resource Development

In some of the more northern forested regions of the study area, natural resource development had a more significant impact than agriculture (Ecological Stratification Working Group 1996). Forestry has been taking place in the aspen parkland since the late 1800s, first for lumber and more recently for pulp (Rowe and Coupland 1984). Mining (i.e. coal and potash), oil and gas production activities are commonly found in the area as well (Ecological Stratification Working Group 1996).

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Chapter 3

Woody encroachment on pastures in Western Canada

Abstract

The loss of grasslands to woody encroachment has been occurring around the globe for decades. This results in a loss of productivity for livestock producers as well as a decrease in habitat for wildlife. Trembling Aspen (*Populus tremuloides)* is the dominant tree species encroaching on grasslands and on pastures in western Canada. Assessing the long-term trends and underlying causes of woody encroachment is important to determine the effects (i.e. decrease in productivity) and what can be done to mitigate them in the future. Historical and current aerial photography were used to determine changes in vegetation cover. Over 27,000 hectares of pastureland were classified into six different cover classes (Grass, shrub, forest, water, marsh and other) for three different time periods: early (1945-1955), middle (1970s) and recent (1991-2001). Overall cover and patch statistics were calculated and compared between various logical groupings (i.e. public versus private). Patch dynamics differed significantly between classes; grass patches were most diverse and most irregular and forest patches were more numerous. Early time period grassed sites had greater rates of encroachment, while early forested sites had an increase in grassland cover. Publicly owned sites increased in grass cover and privately owned sites decreased. Unmanaged sites suffered from woody encroachment while managed sites did not. Alberta, Saskatchewan and Manitoba differed in their trends. Manitoba is losing grasslands and Alberta and Saskatchewan are slightly gaining. Changes in grassland cover were least severe in the recent time period, coinciding with an increase in management since the 1970s.

3.1 Introduction

The loss of grasslands because of encroachment of woody vegetation has been occurring around the world for decades (Brown and Archer 1999). The change of vegetation cover from grasslands to bush has consequences for livestock producers and wildlife. Grasslands are more productive for cattle feed than forested areas and pasturelands represent some of the last remaining areas of grasslands available to wildlife as habitat (PFRA, 2001). Woody pastures can have up to a 70% lower carrying capacity with respect to livestock than grasslands and therefore are much less productive. Prairie Farm Rehabilitation Administration (PFRA) pastures are estimated to have more than 50 species at risk and maintaining their habitat to ensure viable populations is a benefit to all (PFRA, 2001).

Many investigations of encroachment examine short-term trends in what are often geographically restricted areas (Bailey and Wroe 1974, Briggs et al. 2002). While these studies have made important contributions to information regarding encroachment, fundamental questions regarding the historical range of variability within western Canada and the factors most contributing to loss of perennial grassland remain unanswered. Management requires that we develop a means to assess areas most threatened and strategies to best target problem sites.

Geographic Information Systems (GIS) are a useful tool in environmental monitoring (Burrough and McDonnell 1998). GIS layers can be used to measure both the extent of land cover (i.e. total area) and to assess the spatial pattern of patches on the landscape. Following this approach Coppedge *et al*. (2001) examined woody invasion of grasslands by juniper in the southern Great Plains using historical aerial photographs (ca. 1965-

1995). They found that the spatial patterns of encroaching vegetation and the total extent of vegetation were equally critical in determining impacts of invasion. The complexity of patches also plays a role in increasing species diversity (Gustafson and Gardner 1996; Hamazaki 1996) and several measures of spatial pattern are available to assess landscape change (Elkie et al. 1998).

Historically in the Aspen Parkland, woody vegetation (primarily aspen) covered approximately 10-30% of the landscape, while the remaining cover was grass. A study by Bowes (1996) stated that currently woody vegetation is expanding by 2.2%/year and is worse in areas where brush has previously been cleared compared to areas that have never been cleared. Potential causes of encroachment could be the loss of natural vegetative controls such as: fire and grazing bison herds, land use change and, atmospheric CO_2 enrichment (Polley et al. 2003; Briggs et al. 2002; Archer et al. 2000; Bird 1961). Many species require a mixture of cover types and a recent study on farm wildlife habitat and biodiversity showed that the largest diversity existed in the transition area between aspen stands and grasslands (Godwin et al. 1998). It is important to maintain the historical level of the woody and grassland cover types to continue to provide grazing areas and habitat for wildlife. Quantifying the change of vegetation cover is a critical issue because agriculture is an important aspect of life in the prairies and the encroachment of woody species is problematic for livestock producers.

3.2 Objective

The objective of this paper is to examine the extent and patterning of woody encroachment on private and public pastures in Western Canada.

- Determine the degree of change in vegetation cover on pastures.
- Examine patterns of vegetation change on pastures.
- Compare the degree and patterning of woody encroachment between different land categories (i.e. owner, original cover, management etc.)

3.3 Study Area – See Chapter 2

3.4 Materials and Methods

Private and publicly owned pasturelands in western Canada were chosen as study sites using a stratified random sampling approach. The pastures were stratified such that they were: 1) near or within the Aspen parkland ecoregion; 2) representative of the major soil types found on the prairies and 3) distributed along an east-west and north-south gradient to ensure that placement was well dispersed. For each pasture two fields were chosen at random (and corresponding to fields that were sampled as part of a ground survey, see Chapter 4) for digital pattern analysis (as described below). In some instances (often small private pastures) the entire pasture was evaluated.

A time series database was created for each pasture (or sampled field) in order to determine changes in woody vegetation cover. To accomplish this, a series of aerial photographs were obtained for three time periods: 1945 – 1955, 1970 – 1978, and 1990 – 2001. Only those pastures that had photos available for all three time periods were used in the final analysis. Approximately half of the photos were in already in digital format, although at varying resolutions. Analog photographs (i.e. prints) were scanned at 1200dpi on a flatbed scanner to generate raw digital imagery. All photos were black and white except for a selection of photos from Alberta in the most recent time period. Image contrast, resolution and overall quality varied. In total over 400 photos were collected ranging in scale from 1:15000 to 1:82000.

For each photo six cover classes were identified (grass, shrub, forest, water, marsh and “other”) and manually digitized (**Figure 3.1)**. These cover classes were chosen because they could be readily identified and are the major cover types found on pastures. Ocular classification is greatly influenced by image contrast and sharpness, and thus the accuracy of the vegetation cover classification can vary depending on the individual technician. To avoid differences related to individuals the same technician digitized all photos in a series and to determine if there were differences, some pastures were double classified. No significant differences were observed between technicians. A final raster thematic layer was produced for each image at the same resolution and extent as the source layer.

Following image classfication, all images were standardized to an identical 1 m resolution by georectification and image resampling in ArcMap 9.2. Ground control points were identified on source photos from each time period for each sampled pasture or field to create unique a Ground Control Point (GCP) models for each image. Points were typically located at road intersections, fence lines and stable natural features (i.e. rock outcrops). The GCP models were then applied to thematic layer and georectified and resampled using the nearest neighbor algorithm. All images were projected to the appropriate Universal Transverse Mercator (UTM) coordinates (Zones 11-14). The resultant data layers were incorporated into a multitemporal GIS database. To test the accuracy of the aerial photo interpretation GPS locations of the sample sites were overlaid onto the theme layers and compared to see if the sample plots matched the classified vegetation. This was done on the most recent photos as they are most likely to have the same vegetation cover as the current conditions. Changes in total cover and landscape spatial pattern were determined (see next section). These were also related to environmental and/or management factors in subsequent analyses (see Chapters 4 and 5).

GIS Spatial Analysis

Woody encroachment and changes in the spatial pattern of forest, shrub and grassland patches were determine for each of the aerial photo series using the ArcGIS extension Patch Analyst (Rempel 2008). Spatial statistics such as mean patch size (MPS), edge density (ED), mean shape index (MSI) and others can all be calculated using Patch Analysis (**Table 3.1**). Selections of these statistics were exported and further analyzed using CRAN-R (R Development Core Team 2010).

Data Analysis

Samples were stratified by ownership, management, historical cover and Provincial jurisdiction to compare changes in overall and mean grass cover. Ownership was based on public and private pastures while management was simply divided into those sites where one or more management prescription had taken place versus those with no management. Historical cover was divided into pastures that were originally dominated by forests (i.e. major clearing was required to create open grassland areas) versus pastures that were dominated by grassland areas before becoming pasture were also compared. Lastly, differences between the three Prairie Provinces (Manitoba, Saskatchewan and Alberta) were assessed.

Discriminant Analysis (DA)

DA is used when there are observations from pre-determined groupings with two or more response variables. A DA generates a linear combination of variables, maximizing the probability of accurately assigning observations to their groups (Quinn and Keough 2002). In this study it was used to assess the difference between the above groupings and to test for significant differences with respect to encroachment for all cover class patches and specifically grassland patches. Wilks lambda was calculated to evaluate the significance of differences between the provincial groupings and to see if significant differences in patch dynamics existed between classes and pastures with and without encroachment. This value is a measure of the amount of total variance is due to the residual, smaller values indicate larger group differences (Quinn and Keough 2002).

Principal Components Analysis (PCA)

To provide an overall assessment of the observed differences amoung the sudy sites, a Principal Component Analysis (PCA) was performed. A detailed description of the PCA method is available in Legendre and Legendre (1998). In summary, Principal component analysis (PCA) obtains an optimized set of linear axes that best describes the overall trend in a multivariate dataset (note: prior to optimization the data are summarized using covariance or correlation). The first axis maximizes linear variance (i.e. summarizes the single strongest trend in the dataset), the second maximizes the residual variance not accounted for by the first axis (i.e. strongest secondary trend), and subsequent axes account for remaining residual information. The method is analogous to linear regression (except all input variables are considered to have variation – thus there is no ‘independent-dependent’ relationship).

The first step in PCA is the calculation of a *p* x *p* covariance (or correlation) matrix **S**, from a *p* x *n* data matrix **X**. The Covariance-correlation matrix **S** summarizes only linear relationships and given **S**, eigenvalues are sought that satisfy the equation:

$$\det |\mathbf{S} - \lambda\mathbf{I}| = 0$$

Where λ is a vector of *p* eigenvalues:

$$\lambda = [\lambda_1 \quad \lambda_2 \quad \dots \quad \lambda_p]$$

The sum of all eigenvalues is equal to the sum of the diagonal elements of **S.** When **S** based on a covariance matrix the sum of eigenvalues is equal to the sum of all of the variances for each of the *p* variables, and when **S** is a correlation matrix, the sum is equal to *p*. For datasets containing mixed variables a correlation matrix is required, but if the data are already standardized (e.g. percentage habitat) a covariance matrix is preferable.

Each $[b_{1i} \quad b_{2i} \quad \dots \quad b_{pi}]$ eigenvalue (λ_i) is the variance of the i^{th} component axis. Associated with each eigenvalue λ_i is an eigenvector:

Where each eigenvector element b provides an objective weight and collectively all eigenvectors form an eigenvector matrix **B**.

PCA repartitions the total variance into linearly uncorrelated components to satisfy the equation:

$$\mathbf{S} = \mathbf{B}'\lambda\mathbf{B}$$

Collectively, this analysis provides vital statistics for evaluating the common trends in multivariate data. In PCA each variable (in this case each patch statistics) receives a final "weight" (the elements of **B**) on a given ordination axis based on the extent to which it ‘contributes’ to the overall linear trend summarized by that axis. In data that have a ‘strong’ multivariate structure – that is the variables share a common trend – the first axis would be expected to summarize the majority of the overall variation (i.e. have a high eigenvalue as a proportion of the total) and each species (cover class patches) with a high ‘weight’ is important in determining the direction of that main trend. Coordinate positions of the sampling units (in this case route segments) on the ordination axes are obtained by combining the species weights. This provides an order for the sites from positive to negative along the first axis – in this case reflecting the importance of a particular site in providing habitat to a species. It is standard procedure to display PCA results as a scatter plot (called a biplot), showing the coordinate positions of the sampling units on the first two (i.e. most important) ordination axes (the scores are treated as coordinates) with the variables overlaid as vectors. The variance explained for each axis is usually indicated as a percentage of the total (here we provide it as part of the axis label) and typically no units are provided along the X or Y axis as all relationships are contained in the relative distances between sites (route segments) on the graph. All values were log transformed (log(x+1)).

Table 3.1: Spatial Statistics Definitions (following Elkie et al. 1998).

Spatial Statistic	Description
Mean Patch Fractal Dimension (MPFD)	Mean patch fractal dimension is a measure of shape complexity. Mean fractal dimension approaches one for shapes with simple perimeters and approaches two when shapes are more complex.
Area Weighted Mean Patch Fractal Dimension (AWMPFD)	Area weighted mean patch fractal dimension is the same as mean patch fractal dimension with the addition of individual patch area weighting applied to each patch.
Class area (CA)	Sum of areas of all patches belonging to a given class in hectares.
Number of patches (NUMP)	Total number of patches in each class (shrub, forest, grassland) or total number of all patches (all).
Mean patch size (MPS)	The mean size of patches of each class (shrub, forest, grassland) or mean of all patches (all) in hectares.
Patch size standard deviation (PSSD)	Standard deviation of each class of patches or of all patches.
Patch size coefficient of variance (PSCOV)	Coefficient of variation of each class of patches or all patches. The coefficient of variance is the ratio of the standard deviation and the mean.
Total edge (TE)	Perimeter of patches for each class or all classes in meters.
Edge density (ED)	Amount of edge relative to the landscape area for each class or for all classes.
Mean patch edge (MPE)	Average amount of edge per patch for each class or for all classes.
Mean shape index (MSI)	An index of patch shape complexity, a value of 1 indicates a perfect circle (a simple shape), values greater than one indicate more complex shapes.
Area weighted mean shape index (AWMSI)	Mean shape index adjusted by the area of each class or of all classes.
Mean perimeter area ratio (MPAR)	A measure of shape complexity.
Shannon's diversity index (SDI)	A measure of the diversity of patches. Only available when all classes are considered. The index is zero when only one patch exists on the landscape.
Shannon's evenness index (SEI)	An index of the equitability of patch types. Ranges from 0 (when one patch-type dominates) to 1 (when all patches are equally present).

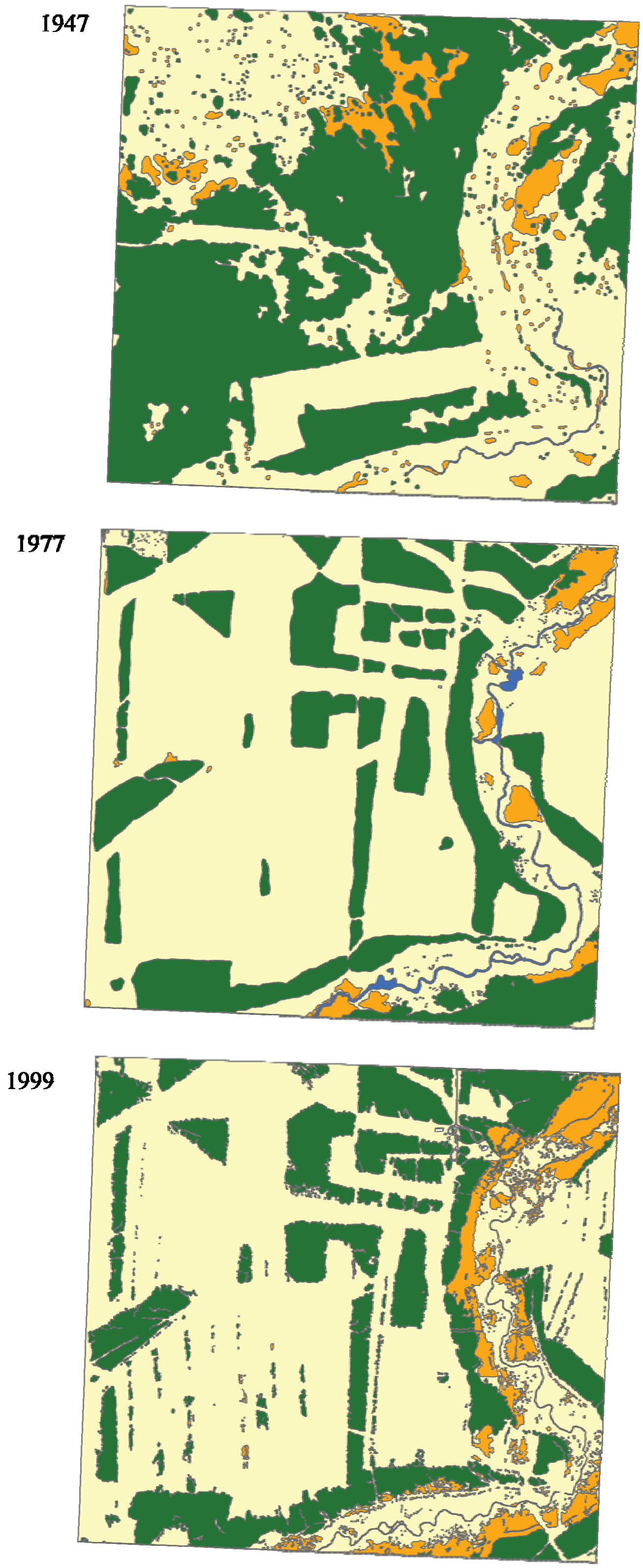

Figure 3.1 Example of digitization – Privately owned pasture associated with Black Bear Grazing Reserve, Alberta (Yellow → Grass; Orange → Shrub; Green → Forest, Blue → Water)

3.5 Results

More than 400 aerial photos were obtained for over 27000 hectares of pastureland, resulting in the classification of over 81000 hectares for the three time periods. There were 524 points checked with 92% accuracy. Most of the error occurred in the shrub class as it was the most difficult to assess. Another explanation for error may be the delay between when the photo was taken and when the field sampling occurred; this difference ranged from a maximum of 15 years to a minimum of 4 years.

The PCA analysis of the patch statistics data for all cover classes indicates that each of the different cover classes shared common patch characteristics, with the strongest trends along the first axis being mean percent cover, average weighted mean shape index (AWMSI) and patch size standard deviation (PSSD). The strongest trends along the second axis were mean patch size (MPS) and mean perimeter area ratio (MPAR) (**Figure 3.2)**. Grassland pastures were more spatially dispersed with a greater range in overall patch statistics. Forest and shrub areas show a high degree of overlap in patch statistics suggesting similar patch dynamics. Marsh and water areas were less variable than the other cover classes and quite similar to each other.

The Wilks Lambda values derived from a MDA of all classes grouped by cover class and presence of encroachment show a significant difference in patch statistics between cover classes (**Wilks = 0.10**), but not when comparing pastures with or without encroachment (**Wilks = 0.96**).

Patch statistics for grassland patches only were analyzed also using a PCA **(Figure 3.3a-e)** and the various groupings were compared using a MDA. Differences between groupings based on the MDA for grassland patch statistics were not significant**,** although some slight differences could be observed. Pastures that were originally grassed tend to have, larger mean grass patch sizes, than those originally forested and cleared areas. Patch dynamics ranged widely between managed and unmanaged pastures, as well as private and public pastures. Manitoba and Saskatchewan patch dynamics are both more diverse than Alberta's but similar to each other. No differences were noted between grassland patch dynamics on pastures with or without woody encroachment.

Overall grass cover was calculated for each time period, along with changes in mean grassland over. There was an increase in total grass cover from the earliest photos (1945 – 1955) to the most recent (1990 –2001) (**Figure 3.4e)**. The mean patch size of grassland areas has decreased **(Figure 3.5e).** Comparisons by groupings show that changes in both total grass cover and mean percent grass cover vary depending on the owner of the pasture, the original condition, management and location **(Figures 3.4 a-d) & Figure 3.5 a-d)**.

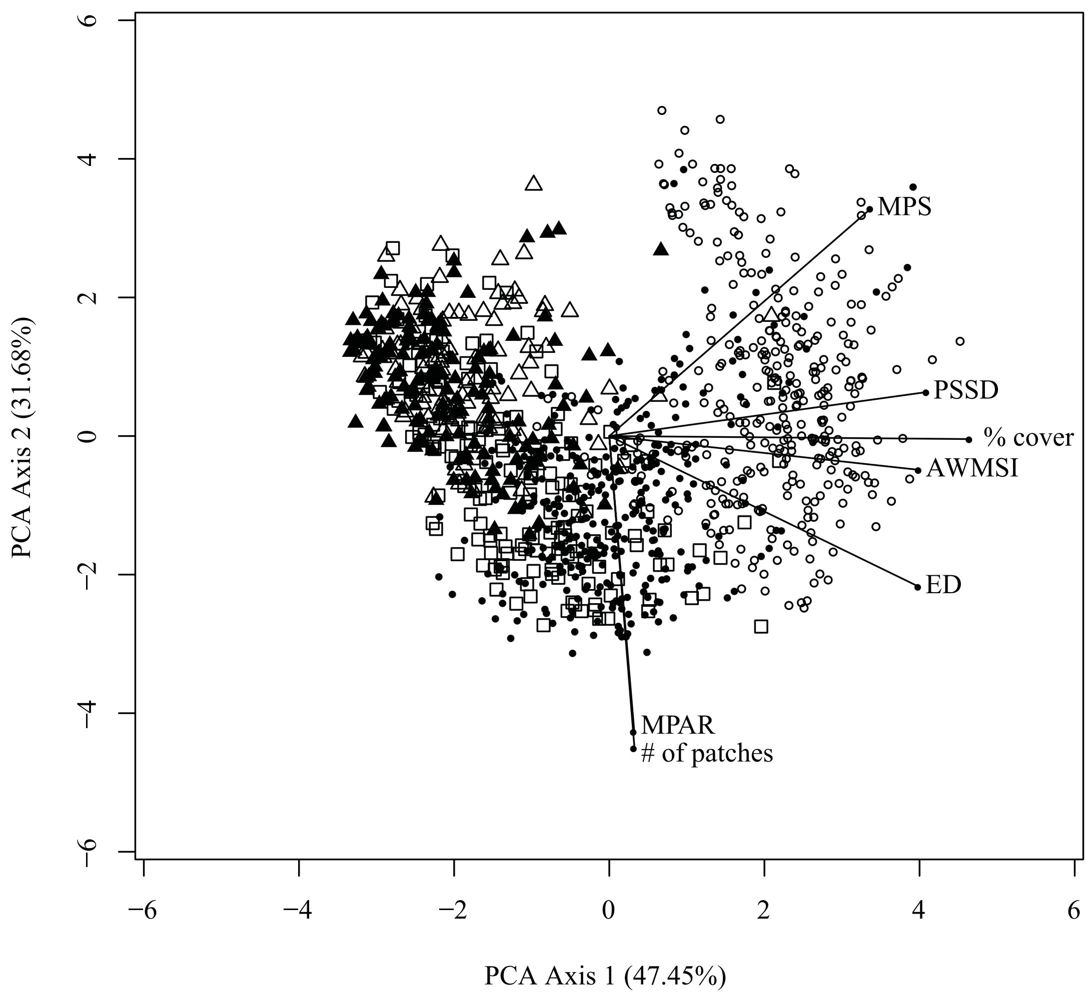

Figure 3.2 PCA of patch statistics – Points represent patches at various study sites (forest =●, grass=○, marsh=Δ, shrub = □, water=▲) and vectors represent the various patch statistics measured.

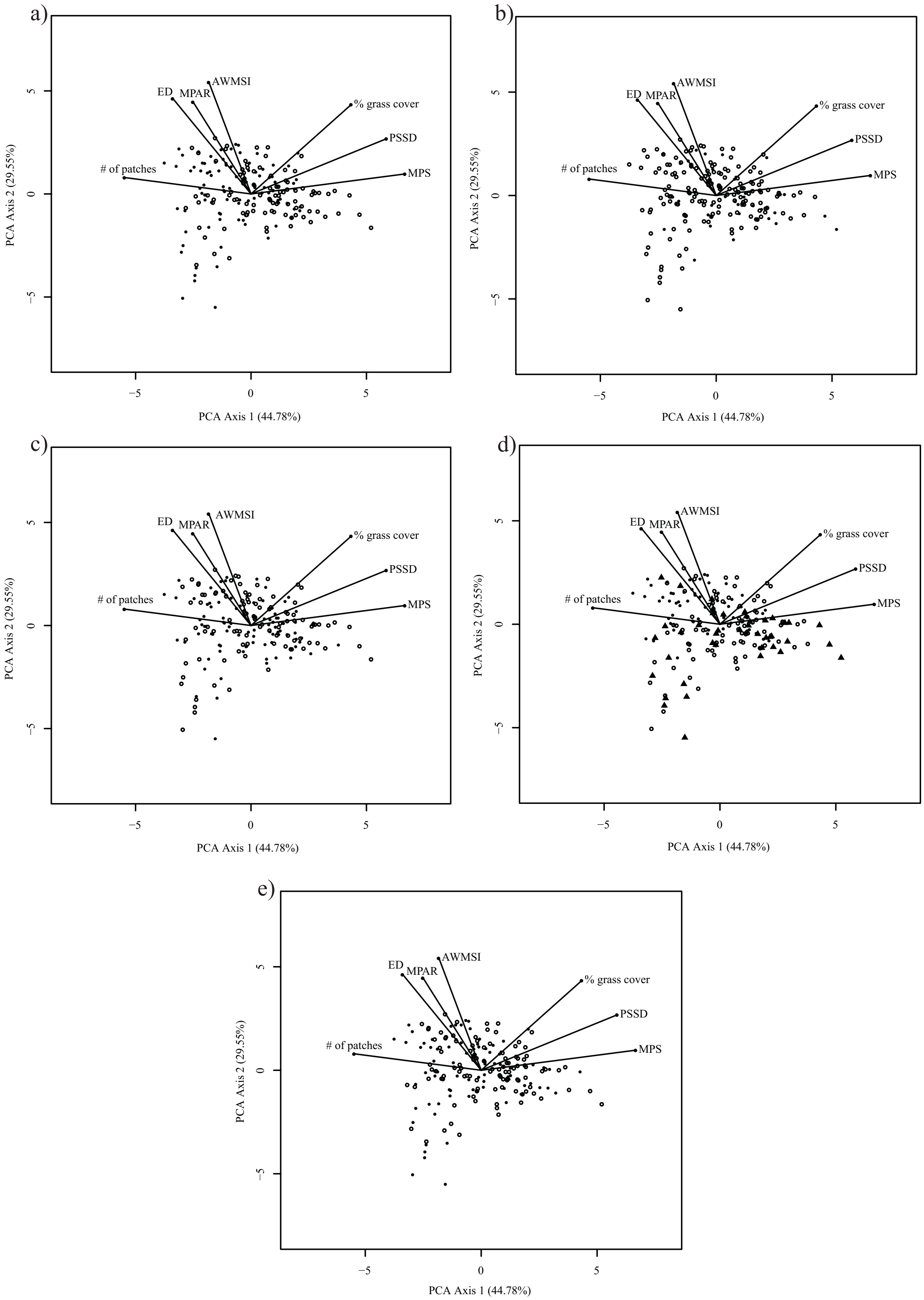

Figure 3.3 PCA of spatial statistics for grassland patches only a) Originally grass (●) vs. originally forested (○) b) Managed (●) vs. not managed (○) c) Public (●) vs. Private (○), d) Alberta (●) Manitoba (○) & Saskatchewan (▲) , e) No encroachment (●) vs. Encroachment (○)

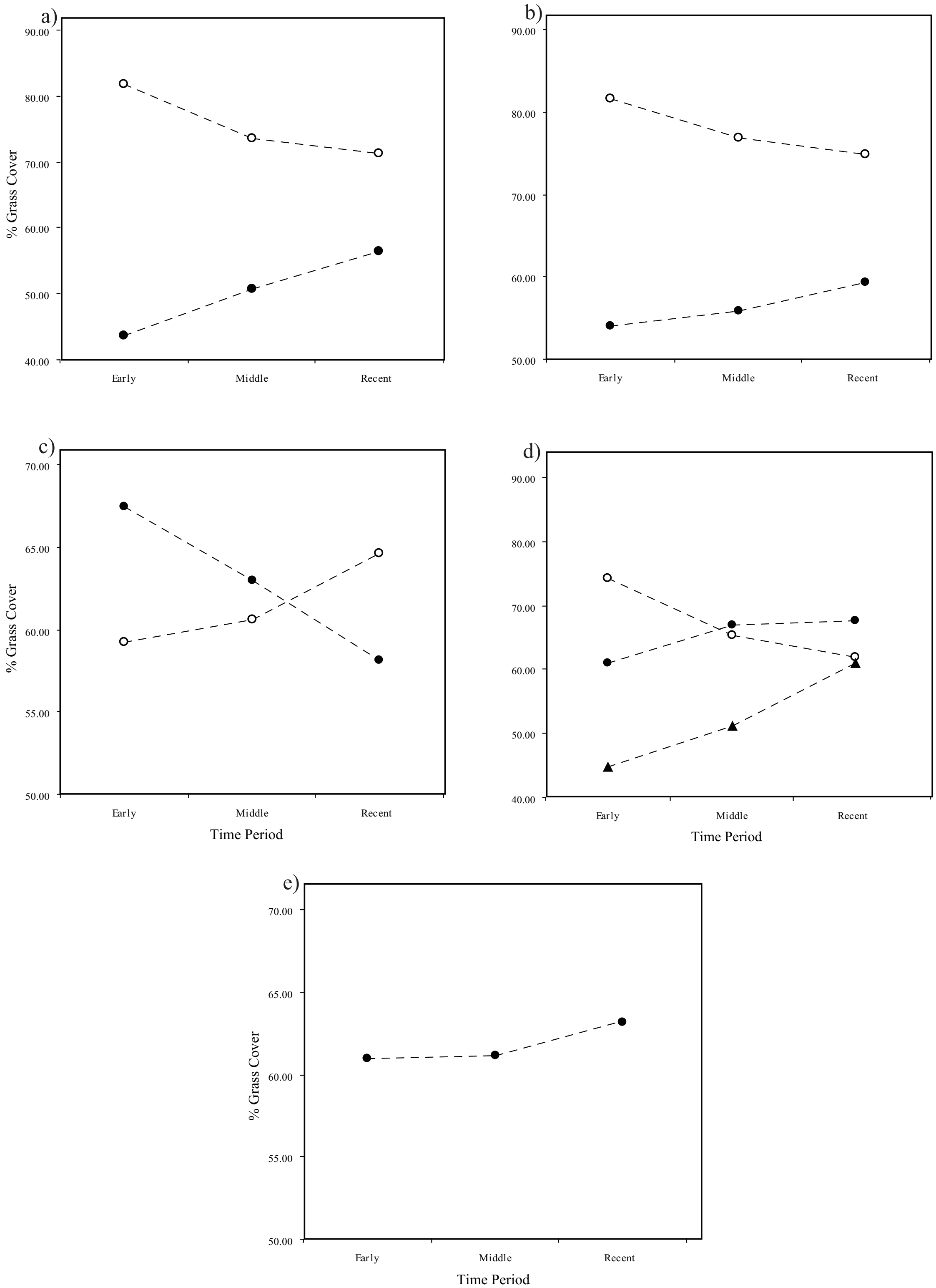

Figure 3.4 Means values of total percent grass cover a) Originally forested (●) vs. originally grass (○) b) Managed (●) vs. not managed (○) c) Private (●) vs. public (○), d) Alberta (●) Manitoba (○) & Saskatchewan (▲) , e) All pastures

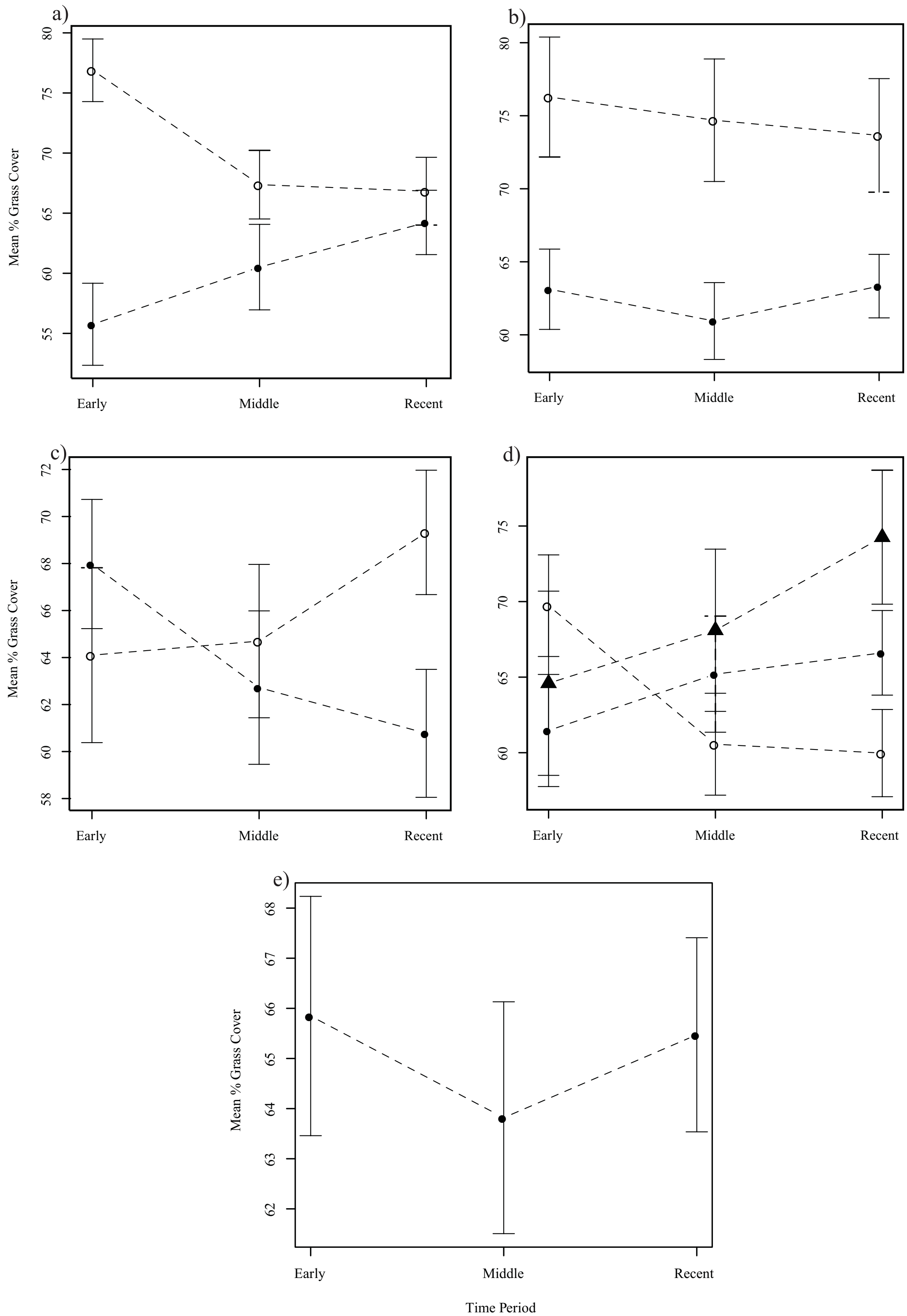

Figure 3.5 Means values of percent grass cover a) Originally forested (●) vs. originally grass (○) b) Managed (●) vs. not managed (○) c) Private (●) vs. public (○), d) Alberta (●) Manitoba (○) & Saskatchewan (▲) , e) All pastures

3.6 Discussion

The Wilks Lambda statistic shows a significant difference in patch dynamics between cover classes, but no significant differences in pastures with and without encroachment. The significance of the differences in patch statistics by cover class is likely due to certain patch statistics being dependent on common edges, if two patches border each other then the related statistics would be opposing. Grassland patches are larger in area overall and the most irregular (increased AWMSI) out of all the cover classes. Grassland patches were more likely to have a larger mean patch size; ranging between less than 5 ha to more than 1500ha. The number of grassland patches was highly variable ranging from one to over a three hundred patches on one pasture. Larger grassland patches are expected as pastures are defined as areas where grasses are the dominant life form with respect to vegetative cover (Meyers and Turner 1992).

Forest patches range from less than one hectare to greater than 2500ha in size, but tend to be smaller overall. The number of forest patches tends to be higher, over 2000 on one pasture, and more complex in shape than the other cover classes. There are several potential explanations for the higher number of forest patches. For example it is recommended to maintain wooded areas throughout pastures to provide shelter for livestock from the sun, wind and rain (Bovey 2001). Another benefit of leaving some forested areas on pastures is the ecotone area between forest and grasslands tend to be the most diverse with respect to wildlife (The Expert Committee on Forage Crops 2003).

Shrub patches were relatively small in size, less complex and covered less area than grass and forest vegetation classes. This could be because shrubs were primarily found along edges of forest patches and did not dominant the landscape.

Marsh areas and areas classified as water (ponds, stream, lakes etc.) had the lowest percent cover and a smaller patch size with fewer patches overall. This was highly variable depending on the year photos were taken as the amount of wet areas varies from year to year depending on precipitation. Small water bodies can be dry in a drought year and twice as large in an extremely wet year. Some wetlands also may have been drained to create more grassland areas, as it is a common agricultural practice to drain wetlands for fields (Martin and Hartman 1987).

Grassland patch statistics were highly variable, but no significant differences were found when comparing groupings (i.e. Owner, Management history, historical cover or provincial jurisdiction). Pastures with larger patch sizes tend to have fewer patches and those with greater edge density were more complex. Alberta grazing reserves are less diverse in terms of patch statistics; this could be because the majority of them are bush pastures and created in the late 1970s and early 1980s through clearing (Government of Alberta 2010).

Greater differences existed between groupings which are with respect to overall grass cover and mean grass cover. Pastures classified as originally grassed had a decrease in overall grass cover while those classified as originally forested had an increase in grass cover. This is probably due to the clearing of brush pastures that has occurred since mid 19th century, creating more grassland areas (Agriculture and Agri-Food Canada 2007). Woody encroachment occurs to a greater extent between the early and middle time periods than the middle to recent time periods. The woody encroachment increase coincides with the implementation of different management regimes in the 1970s (Land Management Service 1995). Mean grassland patch size followed the same trends, decreasing on originally grassland pastures and increasing on originally forested pastures and at present mean patch size is quite similar on all pastures.

Managed pastures have lower overall grass cover, although it has steadily increased with time. Managed pastures are defined as pastures with any form of management, including initial bush clearing to create the pasture, this was done on many of the studied pastures and could explain the lower initial grass cover. Unmanaged pastures had an overall decrease in grass cover; as expected. Without any form of management woody species could continually encroach into the grasslands. Grassland patch size also decreased on non-managed pastures and increased slightly overall on managed pastures, decreasing in the early time period before increasing to the present level. Again the increase in the second time period is probably due to the increase of management during the 1970s (See Chapter 5).

Currently, public lands tend to have larger grassland patches than private lands. Private pastures had a steady decrease in grass cover while publicly managed pastures had an increase in grass cover, to a greater extent in the second time period. A potential reason for this disparity would be differences in management. Environmental variables, such as soil properties and climate variables (i.e. temperature and precipitation), are less likely to be a factor as the public and private pastures were paired to be within proximity these variables would vary minimally. Public lands are managed by government agencies over time and costs are less. For example equipment is shared over many pastures. Private lands often have a variety of managers over the years with differing management strategies and would have to justify the costs of management for smaller areas. Mean grassland patch sizes between public and private pastures; follow the same trend as overall grass cover.

The degree of encroachment varied greatly between provinces. Alberta had an overall increase in grass cover and to a greater extent in the earlier time period. The increase in the earlier time period is probably due to the creation of many pastures at this time by brush clearing in primarily forested areas. Saskatchewan has increased temporally in grassland cover. There are several very large PFRA pastures in west-central Saskatchewan that were cleared during this time leading to the large overall increase in grass cover (The Expert Committee on Forage Crops 2003). Grassland cover in Manitoba decreased, slowing in the trend in the most recent time period. This could be due to an increase in management since the 1970s.

Overall, mean grassland patch size is decreasing, but overall grass cover is increasing on pastures since the late 1940s and early 1950s and to a greater extent since the 1970s, most likely due to the increase in management since the 1970s.

3.7 Conclusions

Patch statistics varied by cover class and grassland patch statistics did not differ significantly by owner, original cover, management, province or presence of encroachment. Overall there has been an increase in grass cover on pastures. This result is likely due to the significant amount of bush clearing done to create pastures in the past. So, while encroachment was been occurring on non managed pastures, areas that were originally grass cover, private lands and in Manitoba, total percent grass cover has actually increased. The main cause of a decrease in encroachment is the increase in management in the later time period.

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Chapter 4

The impact of environmental conditions on woody encroachment in Western Canadian pastures.

Abstract

Much of the native grasslands on the prairies have disappeared, converted to urban areas or agriculture lands. Pastures are large continuous blocks of land that represent some of the last remaining parcels of grasslands on the prairies. They provide habitat for wildlife along with grazing lands for livestock. One threat to these grasslands is woody encroachment by trembling aspen and associated shrub species. In this study, 67 pastures were visited and the current vegetation and soil conditions were assessed. Of these 35 were privately owned and 32 were government owned. At each sample site vegetative cover was recorded and biomass and soil samples were taken for four defined vegetation strata (grass, shrub, forest edge and core). Height and circumference at breast height (CBH) of all trees were assessed in large forest plots. pH, electric conductivity, organic matter and texture were assessed in each stratum. Overall soils differed along an east west gradient. Organic matter and electrical conductivity increased from grass to forest and pH decreased. Total biomass increased from grass to forest plots, primarily because of litter associated with shrub and forest plant residues. Species diversity was greater on private lands and in areas that were originally forested and subsequently cleared to create pastureland. Locally species turnover occurs along the grassland to forest gradient and climate variables, such as temperature and precipitation influence regional species occurrences. Soil properties and biomass did not have any significant impact on encroachment. Larger, but fewer trees were found in the forest core, the more numerous and smaller stems in the forest edge are the primary source of encroachment.

4.1 Introduction

Agricultural development has destroyed most native grasslands on the prairies, resulting in only marginal areas unsuitable for agriculture being left as native grasslands. As a result native prairie is rare on the landscape and one of the most endangered ecosystems in Canada. Some current threats to this landscape are: industrial development, urban development, poor land management, invasive non-native species and encroachment by native woody species (e.g. aspen and willow; PFRA 2001). Pastures represent some of the last remaining areas of grasslands on the prairies and provide excellent habitat for wildlife because they are large unfragmented blocks of native grassland (PFRA 2001).

Many factors, both natural and anthropogenic, can influence the occurrence and degree of encroachment (Archer et al. 2001). Climatic conditions are one natural influence studied in this thesis. Branscomb (1958) found that cyclical climatic patterns favored the invasion of shrubs on grasslands in New Mexico. In Arizona, Brown et al. (1997) found that a change in regional climate, higher than average winter precipitation since 1977, resulted in an increase in shrub density. Tews and Jeltsch (2004) found that an increase in precipitation could possible facilitate shrub encroachment in South African savannas threatening rangeland conditions and biodiversity. In Queensland, Australia the opposite was found, a decrease in precipitation resulted in an increase of woody cover (Fensham 2005). It is often a combination of natural and anthropogenic factors influencing encroachment. Grover and Musick (1990) found that a combination over grazing and unfavorable rainfall regimes in the American southeast may have caused the expansion of shrubs in the area. Soule et al. (2003) came to the same conclusion when studying western juniper in Oregon in the past century.

Aspen is the most common tree species found on pastures on the prairies and continues to encroach onto the grasslands because the historical natural controls (e.g. fire, bison grazing) no longer exist (Bowes 1996). The encroaching aspen displaces grassland species and replaces them with forest species changing the vegetation affecting both the ecology and productivity of the rangelands. Aspen is widely adapted to may climatic conditions; this is evident by its broad distribution across North America. Aspen prefers cool continental climates and boreal forests over coastal or humid environments (Peterson and Peterson 1992). At lower latitudes it is more common at higher elevations and at higher latitudes it can be found primarily on south facing slopes (Peterson and Peterson 1992). Clones for different areas of the distribution do adapt to their location (Brissette and Barnes 1984). Holdaway (1988) found high precipitation and low temperature in June to be the most influential climatic factor relating to cold weather hardwood growth. *Populus* species have been present for many geological time periods where climatic conditions have varied greatly suggesting that they are adaptable to long term climate changes as well as localized climates (Peterson and Peterson 1992). Landhausser et al (2010) found that aspen has expanded up the slopes of the Canadian Rocky Mountains because of the exposure of mineral soil substrates caused by forest management practices and the warming climate.

Soil type another environmental factor can influence encroachment. Bragg and Hulbert (1976) found the along with burning and topography, soil type influenced the rate of woody encroachment on prairies in Kansas. Aspen can grow on a wide variety of sites, but is mainly found on well-drained uplands sites. It grows best on well-drained porous, loamy soils (Haeussler and Coates 1986). The degree of productivity of aspen varies based on soil condition though, particularly moisture. High organic matter and silt and clay content of 55-65% and a water table that is optimum for the parent material (i.e. shallow water table with coarse soils) leads to the ideal moisture conditions for maximum growth (Sucoff 1982). Soil compaction makes it difficult for aspen to regenerate because suckers have a hard time breaking the surface (Peterson and Peterson 1992)

Assessing the current conditions of these pastures and others privately managed allowed us to determine if environmental factors, such as soil type and climate, impact woody encroachment on pastures in western Canada.

4.2 Objective

Examine the biotic and environmental conditions present on pastures in Western Canada and their impact on woody encroachment.

- Determine soil conditions and trends on the pastures and the impact on woody encroachment.
- Determine climatic conditions and trends on the pastures and the impact on woody encroachment
- Determine plant composition and trends on the pastures and the impact on woody encroachment
-

4.3 Study Area – See Chapter 2

4.4 Materials and Methods

Both public and privately owned pasturelands in western Canada were selected as study sites. The public pastures sampled were chosen at the regional scale using a stratified approach that firstly considered that they be near or within the Aspen parkland ecoregion (Ecological Stratification Working Group 1996), secondly that they occurred across the major soil types found in the study area (Chernozemic, Gleysolic, and Luvisolic) and; lastly to ensure that they were maximally dispersed east-west and north-south. Privately owned pastures were selected by pairing them with the nearest sampled public pasture. Typically these were either directly adjacent or within a few 100 m from a sampled public pasture site.

<u>Ground Survey</u>

Two fields within each pasture were selected randomly as sample sites and a stratified random sampling procedure was used in the placement of sample units.. Each sample site was stratified into four strata based on dominant vegetation: grass, shrub, forest edge and forest core (**Figure 4.1**).

- Grass: Forb and graminoid dominated with generally less than 25% woody vegetation
- Shrub: Shrub, forb and graminoid dominated. This zone was defined based on shrub cover (≥ 25%).
- Forest: Tree dominated vegetation (e.g., aspen stands). The forest zone was further subdivided into two additional forest habitat classes:
    - Forest edge: This edge habitat formed a transition between shrub or open field/grassland communities and had different structural

and compositional properties (e.g., stem age, diameter, species composition) compared to core forest habitats.

- Forest core: Core habitat was characterized as the mature canopy based on the size and age class distribution of trees.

In the grass and shrub strata, three randomly located sampling units (1m x 1m quadrats) were used to measure percent cover of vegetation. In the forest strata two 5m x 5m quadrats were randomly placed and within each of these two nested 1m x 1m quadrats were located at opposite corners of the larger quadrat. In the 5x5 quadrat, circumference at breast height (CBH) and tree height and overall cover was measured for all trees greater than 2m tall. The 1 x 1 m quadrat was used to assess cover of herbaceous and small shrub species (as was done for the grassland and shrub strata).

Species Nomenclature

Samples of all unknown species were collected and later identified at the University of Manitoba. All species nomenclature follows Scoggan (1957).

Soil

To examine the role of soil condition on encroachment, soil cores were collected from the top 25cm of the soil horizon once in each of the four strata at all sites. Soil samples were randomly chosen to be within one of the randomly placed 1x1 m sample unit in each stratum. The soil samples were dried in an oven and large clumps of soil particles were broken up using a mortar and pestle (Carter 1993). To separate out the sand, silt and clay particles from coarser fractions, the dried soil was sieved using a 2mm mesh. The final processed samples were kept in cold storage at the University of Manitoba. Organic matter content, pH electrical conductivity and a texture analyses were conducted.

Organic matter was measured using the loss on ignition method (Storer 1984). Approximately 10g of soil was measured into a crucible and put in a muffle furnace for 2hrs a 550°C. Total organic matter was determined based on the difference between the initial weight and final weight.

Soil pH and conductivity were determined using an Accumet AP85 meter. A slurry was created using a 1:2 soil water ratio (i.e. approximately ~50g of dried soil and mixed with 100ml of distilled water).

Soil texture analysis was determined using the Bouyoucos hydrometer method. Methods were modified from those outlined in Bouyoucos (1962). A 5% sodium hexametaphosphate solution (50ml) was added to 50g of dried soil and agitated for 5 minutes. The soil solutions were transferred to 1000ml cylinders and topped up to exactly 1000ml with distilled water. The samples were stirred and the first hydrometer measurement was taken at 40seconds (sand content) and after six hours the second measurement was taken (silt content). These two readings were used to determine the sand, silt and clay content of the soil following formulae published in Ashworth et al. 2001.

$$\text{Sand (\%)} = 100 - (100/w)(R_{40s} - R_L)$$
$$\text{Clay (\%)} = (100/w)(R_{6hrs} - R_L)$$
$$\text{Silt (\%)} = 100 - (\text{\%sand} + \text{\%clay})$$

(Where *w* is the weight of dry soil)

Biomass

Biomass samples were taken from 25cm x 25cm quadrats in the grass, shrub and forest edge strata. These quadrats were randomly chosen to be within one of the randomly placed 1x1 m sample unit in each stratum. All the above ground vegetation was clipped to the soil surface and divided into four categories; litter, grass, herb and shrub. The samples were dried in an oven at 40°C for 24 hours and total dry biomass for each category was recorded.

Data Analysis

The species cover in the three 1m x 1m plots in the grass and shrub strata of each field within a pasture were combined to obtain the average percent cover. These values along with the soil texture, electric conductivity and organic matter were combined into a master database with 536 rows, 140 species, 6 soil, and 8 climate variables. Most of the subsequent analyses proceeded on combinations of variables from this master database file, although in most instances the values in the database were log transformed. Two analyses proceeded on a modified version of this master file. To create the Renyi Diversity Profiles (described below) the percent cover of the plants species was averaged into broad groups depending on the analysis (e.g. all species averaged for public versus private pastures). To compare/examine the influence of climate the species data were averaged by ecodistrict because the source data for climate used these units.

Ordination Methods

Multivariate methods were used to conduct statistical analyses on soil, biomass and species data. The methods used are outlined in the following sections.

Principal Components Analysis (PCA)

To examine trends in the biomass and soil variables used in this study Principal Components Analysis (PCA) was performed. In PCA, linear trends in a dataset are extracted in order of 'importance' (variance explained). A principal components analysis extracts the principal found in the dataset. The second strongest trend is extracted next and subsequently the third and so forth until all the variability in the dataset is accounted for (Legendre and Legendre 1998). A PCA was conducted on the soil variables (6 variables and 536 sites) and biomass (4 variables and 402 sites) components of the environmental data. All values were log transformed log(x+1) except for pH.

Correspondence Analysis (CA)

Correspondence analysis looks at the chi-squared contingency between rows (species assemblages) and columns (site characteristics) of a dataset. A detrended correspondence analysis was used on the vegetation data (536 sites and 140 species). This is a variation of a CA that accounts for an underlying trend and optimizes the spread along the primary ordination axis (Legendre and Legendre 1998).

Canonical Correlation Analysis (CCA)

A canonical correlation analysis is used to examine the relationship between two sets of variables (e.g. vegetation data and environmental data). CCA uses multiple regression analysis to find an environmental variable that is a linear combination of the environmental variables and minimizes the within species to total species variance (Ter Braak 1987). In this study the soil variables (pH, Organic matter (OM), Electrical Conductivity (EC), and texture) were related to the species percent cover data. Both data sets were log transformed with the exception of the pH values.

Discriminant Analysis (DA)

A discriminant analysis is used when there are observations from pre-determined groupings with two or more response variables. It generates a linear combination of variables, maximizing the probability of accurately assigning observations to their groups (Quinn and Keough 2002). In this study multiple discriminant analyses was used to determine if there were statistical differences in environmental conditions and biomass accumulation based on several different combinations of factors: Provincial jurisdiction (MB, etc.), and areas with or without encroachment (treated as a binary variable). The Wilks' λ (lambda) test statistic measures the extent a group differs from its centroid, it is an approximate statistic and smaller values indicate larger group differences. This statistic was calculated for all MDA analyses (Legendre and Legendre 1998).

Diversity Indices

Renyi's entropy function was used to assess the diversity of species between various known groupings (Renyi). The Renyi function is an extension of Shannon's entropy to a 'family of information statistics' based on moments of a qualitative distribution (Renyi, 1961).

$$H.a = 1/(1-a) \log \mathrm{sum}(p^a)$$

By varying q continuously, a diversity profile is generated and can be interpreted as a diversity curve. If a curve of a community is greater than another it indicates that the first community is more diverse than the second. The shape of the curve is also important, if it drops rapidly it indicates that there are rare species present or low equitability (Walker et al. 2003).

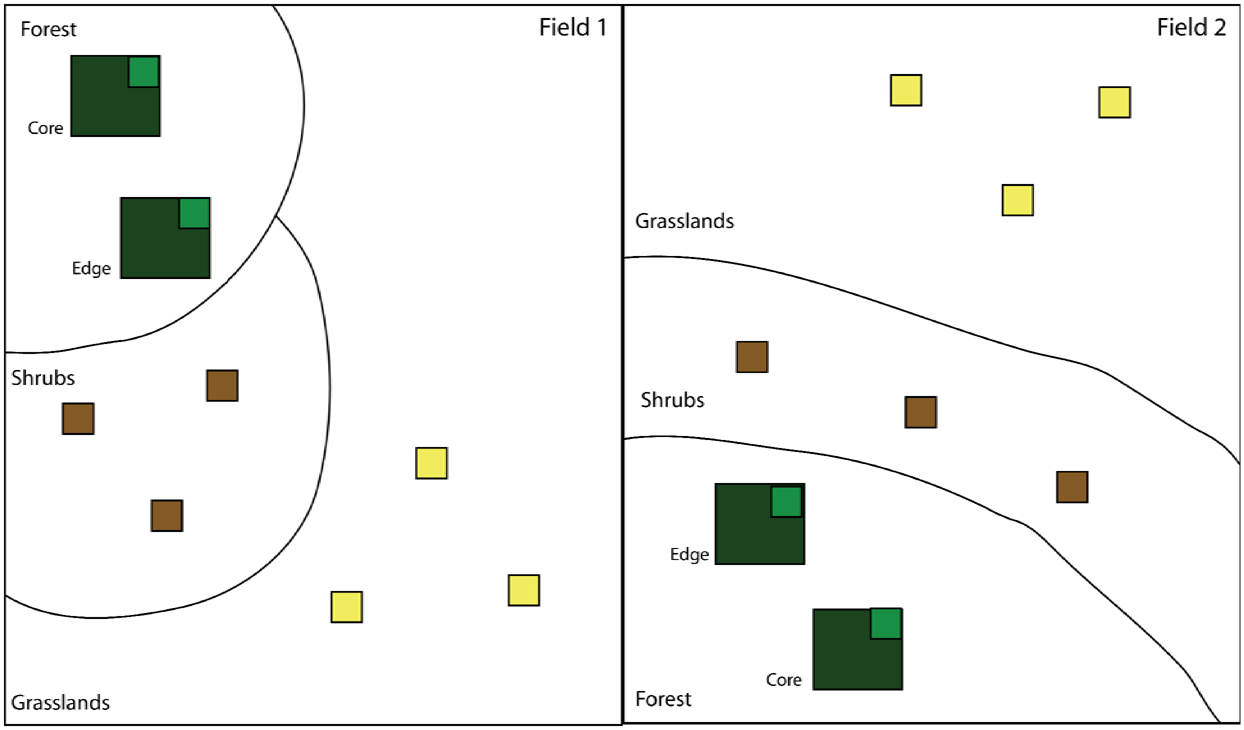

Figure 4.1 Potential locations of sample sites in shown in the four define strata

4.5 Results

Field seasons were conducted from June to August in 2005 and 2006. In total 67 sites were visited across western Canada. There were 32 public pastures and 35 private pastures as study sites. The privately owned pastures were located as close as sharing a fence line to within a few kilometers of the public pasture.

Soils and encroachment

It was found that soil properties trended regionally among the three Prairie Provinces. The strongest trend was that higher pH values were found in Manitoba soils. Soils in Manitoba tend to have more clay and sand than soils in Alberta (Figure 4.2). Within pastures locally, organic matter and electrical conductivity both tended to increase from grass to forest plots, while pH decreased (Figure 4.3a, b, c). Wilks Lambda values (Table 4.1) show that the most significant trend with respect to the measured soil properties were interprovincial differences. There were no significant differences between soils properties when comparing sites with encroachment and those with no encroachment.

Biomass

Total biomass increases from grass plots into forest plots (Figure 4.4). Accumulation of litter and woody material are primarily associated with the forest and to a lesser degree the shrub strata (Figure 4.5). Wilks Lambda values indicate that there is a significant difference in biomass fractions between the different sampled strata (an expected result) but no significant difference between sites with or without encroachment (Table 4.2).

Vegetation

Renyi Diversity profiles show that private pastures tend to be more diverse overall all (Figure 4.6a), but the profiles vary throughout the three provinces (Figures 4.6b).

Diversity profiles are also different for sites with and without encroachment (Figure 4.6c). When comparing the diversity in sites that were originally forested versus those that were originally grass cover, it was found that forested sites were more diverse than grass sites (Figure 4.6d).

The first DCA axis scores by strata shows a species turnover from the grass plots to the forest core plots (Figure 4.7). The stratum order from grass to forest core plots meaning shrub plots share species with both grassland and forest plots. A CCA using precipitation and temperature data as the constraining variables suggest that climate has an effect on species occurrences and that these differ among the provinces. The primary CCA axis scores plotted against centroid easting values each pasture illustrates this trend along an east to west gradient (Figure 4.8).

Stand Structure

Structures of forest plots were characterized and compared using differences in the distribution of tree circumference at breast height (CBH). Twenty-one, CBH size-class units were determined for the two most commonly occurring tree species in the sampled forest patches: aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*). **Figure 4.10** shows the distribution of size classes. In the forest edge plots, there are a greater number of stems, but of smaller class sizes. Forest core plots tend to have fewer trees which are larger in size indicative of self thinning.

Table 4.1 Wilks and P-Values calculated on a combination of all measured soil properties assessing the level of significance of location (province) and encroachment**.**

Data	Factor	Wilks	P-Value
Soils by pasture	Province	0.1163	2.2-16
Soils by pasture	Encroachment	0.94429	0.8257

Table 4.2 Wilks and P-Values for all collected biomass divided by public and private pasture assessing the level of significance on the division of strata and encroachment**.**

Data	Factor	Wilks	P-Value
Biomass – Public	Strata	0.3562	2.2-16
Biomass – Public	Encroachment	0.85997	0.02482
Biomass – Private	Strata	0.4378	1.241-14
Biomass – Private	Encroachment	0.97487	0.7152

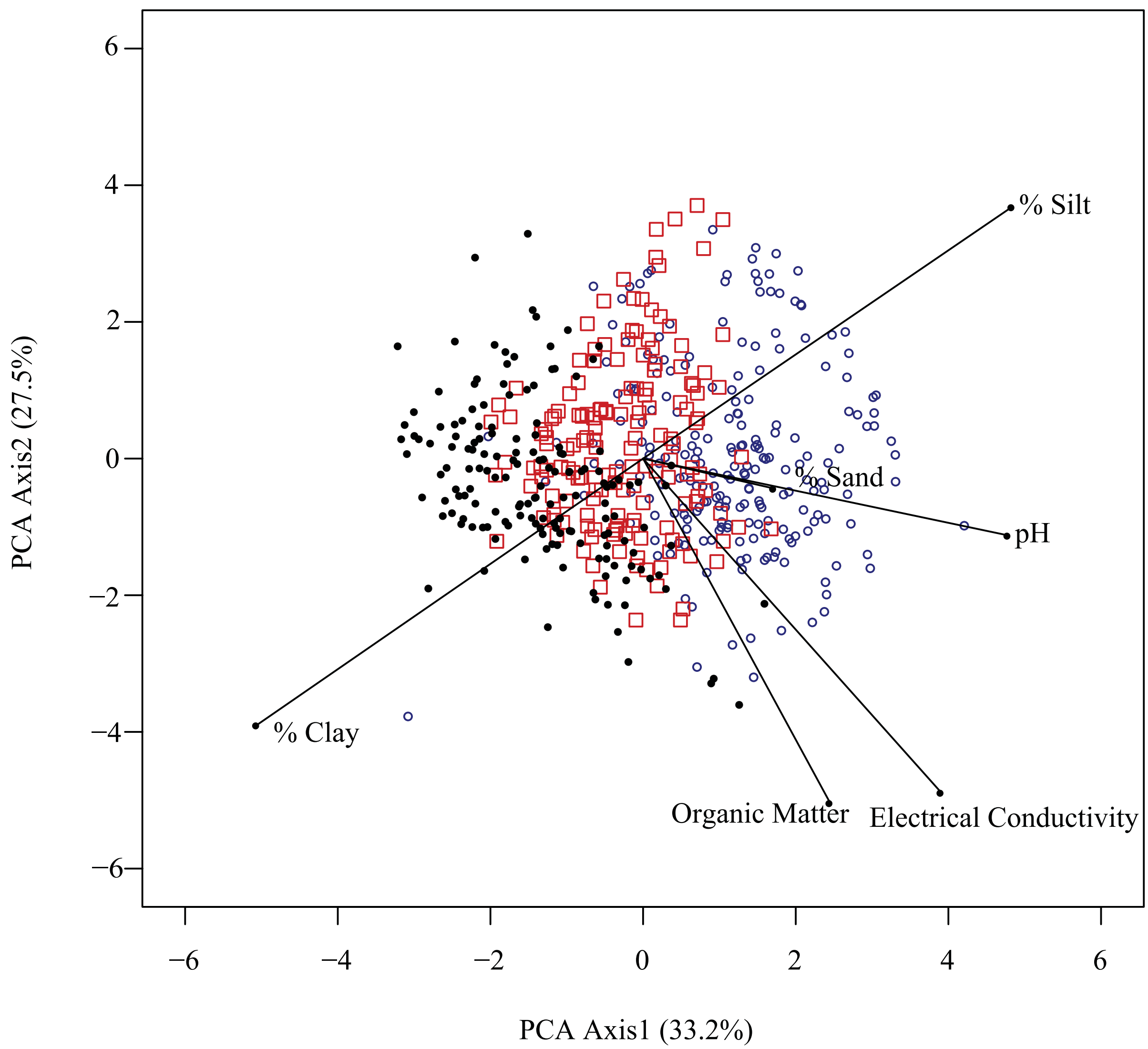

Figure 4.2 Principle component analysis of the soil properties assessed for each site (Alberta ● Saskatchewan □ Manitoba ○)

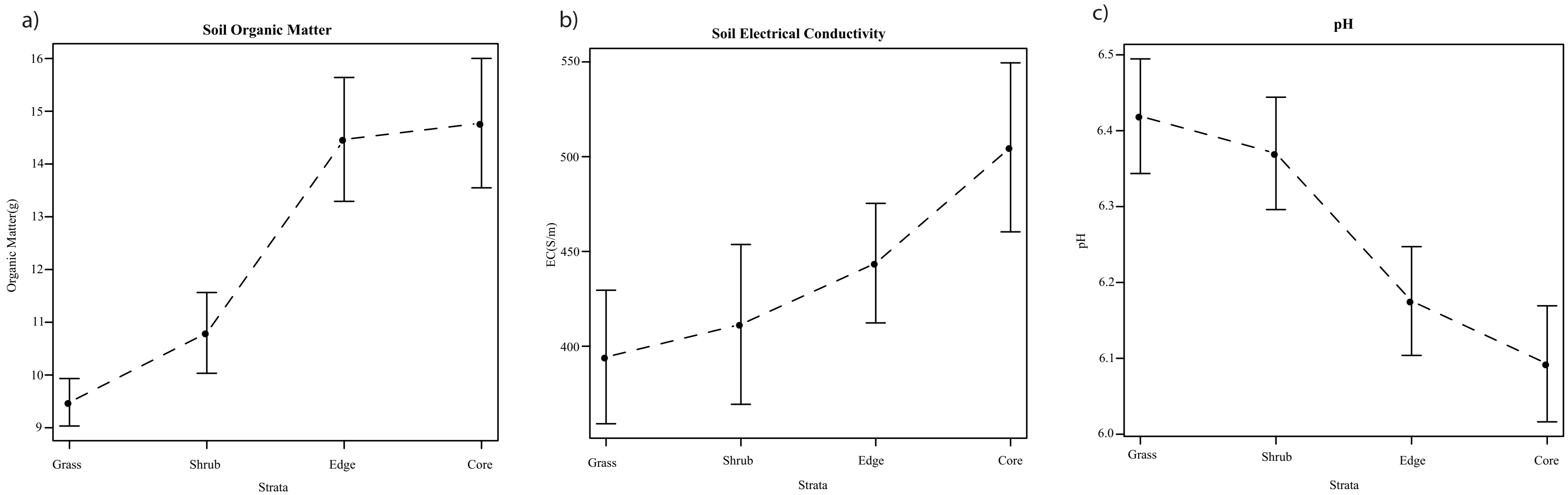

Figure 4.3 Plot of mean values for selected soil properties: a) pH, b) Electrical Conductivity and c) Organic Matter

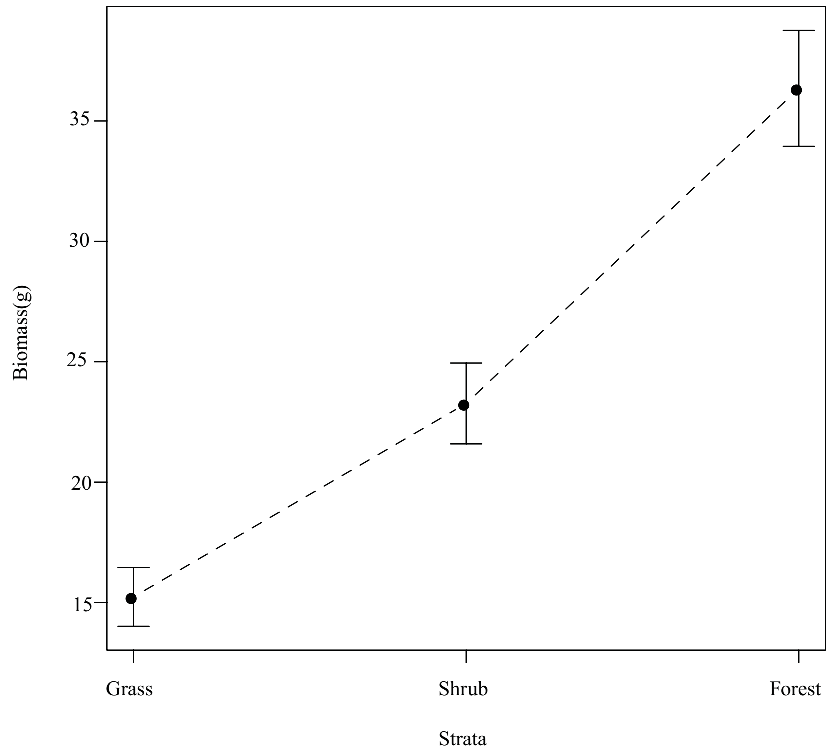

Figure 4.4 Mean values for collected biomass

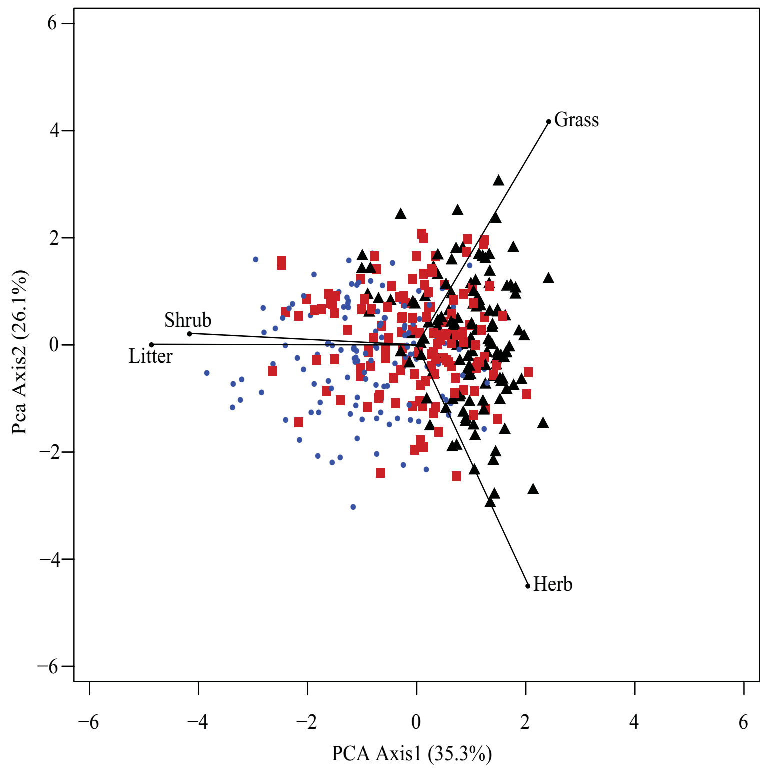

Figure 4.5 Principle Component Analysis of collected biomass (Forest Plots ● Shrub Plots ■ and Grass plots ▲)

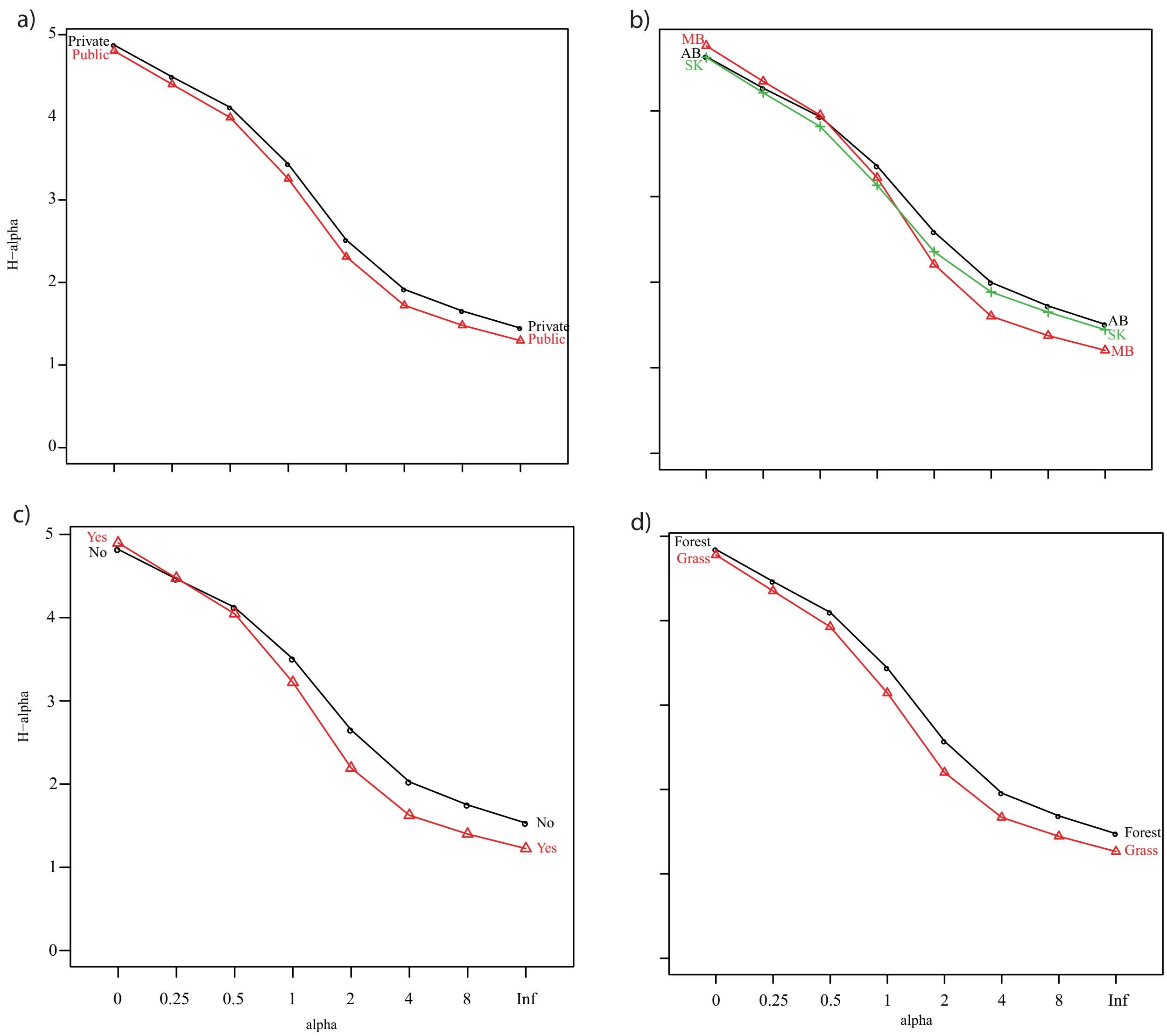

Figure 4.6 Renyi Profiles for four different paired sets of vegetation cover: a) Private and Pubic Pastures, b) Provinces, c) Encroachment & d) Original Cover

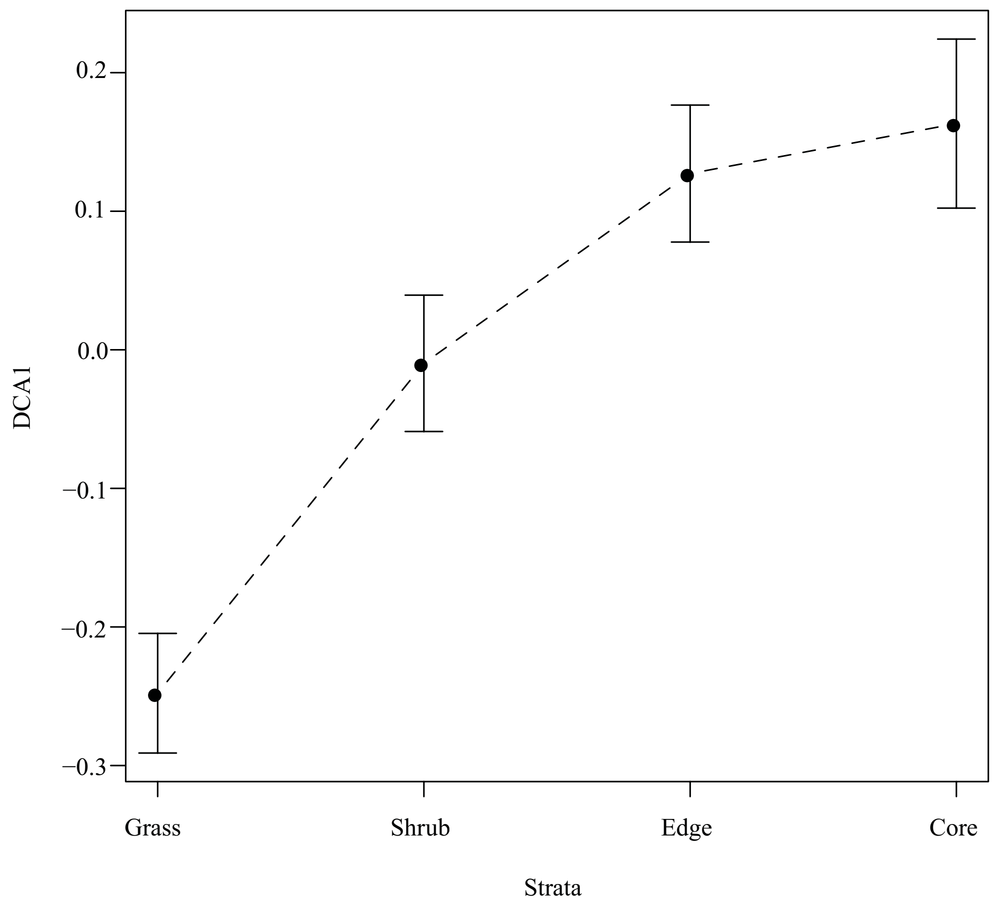

Figure 4.7 DCA Axis 1 scores from vegetation cover plotted against the four strata types

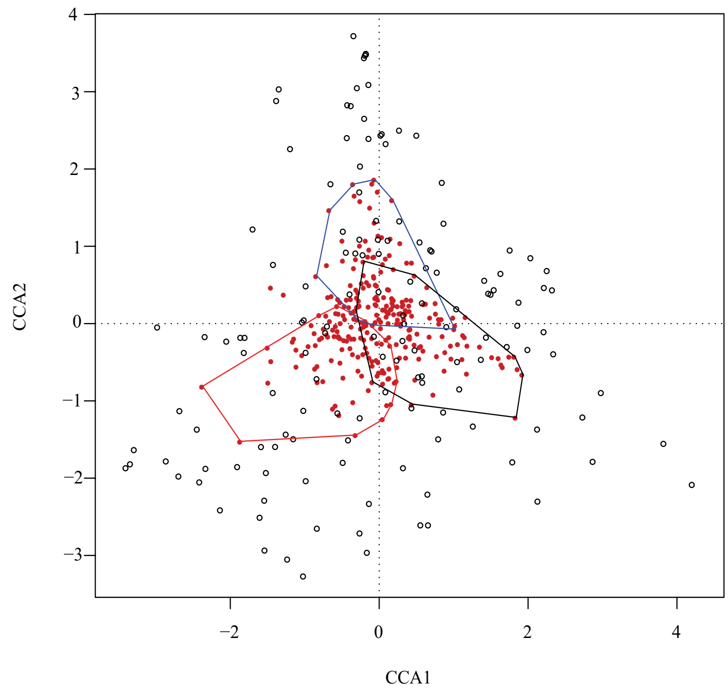

Figure 4.8 CCA of vegetation cover constrained by precipitation and temperature data (Alberta, Saskatchewan and Manitoba)

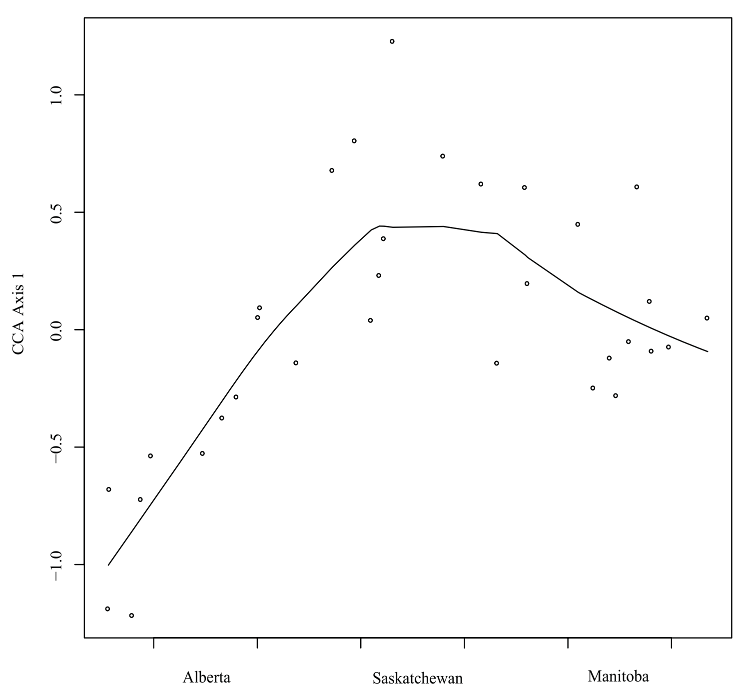

Figure 4.9 CCA Axis1 plotted against the easting centroids of each pasture

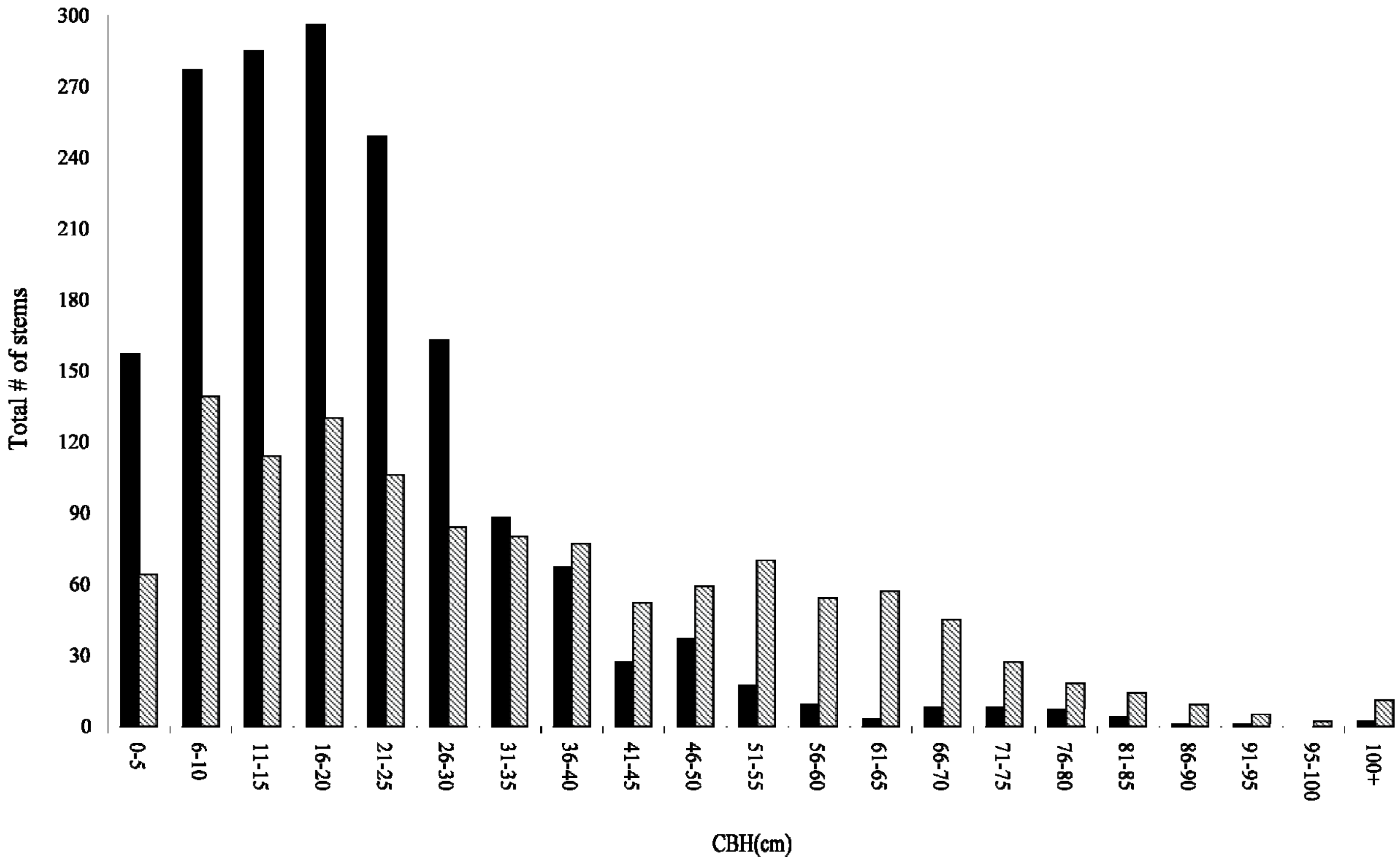

Figure 4.10 Distribution of Trembling Aspen and Balsam Poplar stems (Forest Core □ and Forest Edge ■)

4.6 Discussion

Soils and encroachment

Differences in soil properties regionally might explain some of the interprovincial trends in encroachment. Locally there is evidence that key soil parameters trend with the vegetation strata. For example we found that organic matter (OM) content in soils was higher in the forest plots (mean > 14g) compared to grassland plots (mean <11g) (**Figure 4.2a**). This is expected since forest soils (Luvisols) are often characterized as having greater organic matter compared to grassland soils (Chernozems); Fuller and Anderson 1993). The electrical conductivity (EC) also increased from the grass plots into the forest plots (**Figure 4.2b**), indicating a higher cation abundance or salinity in forest plots. Salinity often results in a decrease in yield and is affected by ground water content (AAFC-PFRA 2000). The pH is highest in the grasses and decreases into the forest core (**Figure 4.2c)**. Whether these trends are a result of encroachment or are enabling encroachment (e.g. pH may already be low in areas with active encroachment) is unknown, although this result is similar to Bekele and Hudnall's (2005) conclusion that pH in encroached prairies decreases to values found in forested areas in Louisiana.

Biomass and encroachment

Litter and shrub biomass accounts for over two thirds of the overall collected biomass. These biomass components are found primarily in forest and shrub plots resulting in greater overall biomass in those strata compared to the grassland sites (**Figure 4.4 & Figure 4.5)**. The amount of litter on pastures can have both negative and positive impacts on forage yields depending on the moisture regimes of the respective study sites (Willms et al 1986). This is also expected based on the definition of the strata themselves; shrub stratum should have more shrub biomass than grassland areas.

Long term grazing can impact litter and soil organic matter. Early season and high intensity grazing has greater negative impacts on both litter and soil organic matter than light intensity/late season grazing on grasslands in Alberta, Canada (Naeth et al. 1991). We found soil organic matter and litter were higher in forest plots, which are less impacted by grazing.

Vegetation and encroachment

Renyi profiles (**Figure 4.6**) for the private pastures have consistently greater diversity in both richness and evenness when compared to public pastures. This could potentially be due to differences in management. Public pastures in Manitoba and Saskatchewan all follow management guidelines provided by PFRA (Agriculture and Agri-Foods 2007), and in Alberta they are provided by grazing associations (Government of Alberta 2010). Private lands are all managed by individuals, sixty-five different managers, resulting in much more diversity in management strategies, for example which forage crops to seed; which would effect species diversity. Sites that were originally covered in forests also tend to have greater diversity and evenness than sites that have always been primarily grass covered. There is species turn over as the plots go from grasslands to forest cores (**Figure 4.7**). This is expected since the strata were defined on the basis of differing vegetation.

Climate is an important factor in determining where vegetation can persist on the landscapes. Some continental climate factors that impact rangelands in Canada are drought, wind and extended periods of cold (Carder 1970). Borchert (1950) states "The vegetation gradients appear to coincide with the climatic gradient changes, the vegetation pattern may be expected to tend to shift also…". This is evident when looking at variation in vegetation on pastures and where the pastures are located. Vegetation and climate differs between the provinces (**Figure 4.8)** and follows an east to west trend (**Figure 4.9**). There is not a huge variance in the climate conditions between the prairie provinces, but in the spring and summer months Alberta tends to have higher precipitation than Manitoba and Saskatchewan, with lower temperatures, which may lead to slight difference in the occurrence of plant species. Anderson and Holte (1981) found no relation between precipitation and an increase in woody vegetation in southwest Idaho. Although it has been suggested (Archer et al. 1995) that climate change and the increase in CO_2 concentration may have enabled the encroachment of woody species onto grasslands worldwide.

Stand Structure of Aspen and Encroachment

In this study we observed clear patterns of encroachment from existing aspen stands. Forest edge plots were characterized by a high density of regenerating or colonizing hardwood stems (most <25cm CBH) that are presumably young in age. Maini (1960) demonstrated a high correlation between size and age class distribution for aspen and balsam poplar. In contrast, the forest core plots are characterized by mature aspen stems (maximum CBH > 100 cm) occurring at much lower density (**Figure 4.10)** indicative of self thinning which occurs naturally in young aspen stands (Peterson and Peterson 1992). The stems on the edge plots are probably a source for encroachment into the shrub strata. Forest patches are the most numerous on pastures (See Chapter 3), resulting in many opportunities for expanding into grassland areas through suckering.

4.7 Conclusion

Vegetation and biomass both differ at a strata level, as expected, as the strata were defined based on these differences. Private lands and sites that were originally forested are more diverse than public and grasslands pastures. Vegetative composition and soil properties trend along an east west gradient, potentially due to climatic differences and neither have a significant impact on whether or not encroachment occurs on a site.

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Chapter 5

Management of woody encroachment on pastures in Western Canada

Abstract

Pastures provide many benefits for society, such as: land for livestock grazing and/or recreational use, habitat for wildlife, and increase biodiversity. Woody encroachment on pastures across western Canada threatens the quality of these ecosystem services. Management is necessary to stop woody species from encroaching onto grassland areas. There are many management techniques available to use. The most commonly used ones are chemical (herbicide application), mechanical (plowing, mowing, bulldozing etc.), prescribed fire and prescription grazing. In this study, public and privately owned pastures in the aspen parkland ecoregion of the Prairie Provinces were sampled to examine the relationship management strategies and woody encroachment. Management histories of public lands were obtained from the various managing government agencies and surveys of private landowners were undertaken to determine how they manage woody encroachment. We found that management in the broad sense decreased the rate of invasion. The methods of control used on both public and private pastures were similar; herbicide use was greater on public lands, while mechanical methods were more common on private lands. Fire was used rarely on both public and private pastures and winter feeding and herbivory was used solely on private lands. It could be suggested that since woody encroachment was more severe on private lands that mechanical techniques are not as effective as herbicides treatments, which are more commonly used on public lands. Woody encroachment management is a continual process and is most effective when several techniques are combined. It is important to have a management plan in place and to monitor the effects to be able to ensure positive results.

5.1 Introduction

Community pastures provide many benefits to Canadian society. Environmental benefits that pastures provide are habitat for wildlife, including many endangered species, increased biodiversity, soil conservation and carbon sequestration. Some social benefits pastures provide include areas for recreational use, such as hunting and land for scientific research (Kulshreshtha et al. 2008).

The most important management issue on pastures in western Canada, particularly in the Aspen Parkland, is woody encroachment. Land owners/managers have to consider the benefits of woody species; browse, shelter for livestock and wildlife; and contrast them with the negative impacts; lower productivity and loss of grassland habitat for wildlife species (PFRA 2001, Bailey 2008). In the northern grasslands of Canada, Trembling aspen (*Populus tremuloides*) is the main species of concern. Although it is native, it readily invades into grasslands on the prairies (Oliver 2008).

Different management practices have been used over time to remove aspen from pastures. When deciding which method to use there are many things to consider, soil conditions, type of vegetation and topography. In open areas that are stony, chemical treatments may be best, in more wooded areas mechanical methods of clearing and then breaking the land it to seed may be more appropriate (Friesen et al. 1965). Many of these methods can be costly and new alternatives are needed that are more economical and decrease environmental impacts. Grazing is one of the most cost effective treatments when used in combination with other management practices, such as mechanical, chemical and/or prescribed burning (Oliver 2008).

Chemical and mechanical methods using heavy equipment have made it simpler to remove trees and shrubs on agricultural land (Friesen et al. 1965). Mechanical methods of brush control are methods that cause physical damage to trees or shrubs. Often aspen is cleared by bulldozing followed by plowing and seeding (Johnston and Smoliak, 1968). There are a variety of mechanical brush control techniques commonly used on pastures in western Canada, including break and seed, mowing, timber harvesting and grazing. To determine what kind of technique to use, the size of the trees and secondary treatments need to be considered (Moss 2008).

Mechanical treatments for controlling aspen are most effective in May and June but after clearing there is usually significant suckering from the remaining roots so follow up treatments are necessary (Moss 2008). Chemical treatment is a common follow up option and is recommended for application 2-4 years after clearing. Post-clearing prescribed burning is also often done if there is sufficient fuel and is recommended a minimum of three years after clearing. Other mechanical treatments can also be used, such as mowing, which is most effective on the smaller regrowth (Moss 2008). The removal of larger trees provides more forage for wildlife as well as livestock and the remaining forest provides the animals shelter all year (Moss 2008).

Chemical treatments are another commonly used option for reducing aspen encroachment onto pastures. For herbicides to effectively kill aspen trees they must be absorbed into the plants growing tissue (Friesen et al. 1965) and are more effective when combined with other methods (Gardiner et al. 2008). Herbicide application is often done by aerial application especially for controlling woody growth over large areas that may be difficult to access. Ground applications (i.e. wiper, basal bark application and hand wands) are used on smaller areas with a lesser density of woody encroachment. When using herbicides it is important to consider the weather conditions with regards to type of application and effectiveness of the herbicides. As well, it is important to make sure the herbicide is applied only to the targeted area to avoid negative impacts on wildlife and biodiversity. Each application type and herbicide has advantages and disadvantages ranging from costs, time required and effects on other plant species. (Gardiner et al. 2008).

Prescribed burning as a primary control method can be effective in reducing aspen on pastures when combined with other management strategies, such as herbicide (Johnston and Smoliak 1968). Many factors need to be considered when planning a burn, a fire break should be created, sufficient fuel load, weather, equipment and personnel (Bailey and Kirychuk 2008). It is very important to also plan what techniques to use before and after the burn. Prescribed grazing, mechanical and/or chemical methods may be used. Fires with a high intensity will have the greatest effect on aspen although there will be suckering from the roots of any remaining trees (Bailey and Kirychuk 2008). Fires often benefit wildlife by diversifying habitat and increasing palatable browse. Grassland diversity often increases after fire, also beneficial for wildlife (Bailey and Kirychuk 2008).

Timber harvesting is another method of aspen control that was once viewed as incompatible with livestock grazing. With proper land management both timber harvesting and grazing can be successful. It is best used in areas that can support mature hardwood stands and can provide added income for the landowner. Grazing is most often used after a harvest to manage regrowth due to the regrowth of many shrubs and herbs (Gardiner 2008).

Grazing is one of the most economical methods of aspen control and works best when combined with other techniques. It can be used to manage aspen at an optimal level or to remove it all together. Heavy grazing is most effective in the spring and early summer to reduce brush cover. Deferred rotational grazing is best to maintain pastures sustainably (Bailey 2008a). When implementing a grazing strategy land managers have to decide if their goal is to reduce the presence of brush or maintain it for forage. Timing of grazing and stocking rates are also important to consider to avoid over grazing and damage to palatable species (Bailey 2008a).

Managing for woody encroachment is ongoing and monitoring its success is important. Land managers can use the information to assess what works best on their land and how they should proceed. Records of the techniques used, the location and the time of management and photographs are important tools in monitoring (Elsinger 2008).

5.2 Objective

Examine the effect of management strategies on woody encroachment on pastures in Western Canada

- Determine whether there are differences in the choice of management strategies between publicly and privately owned land and the influence these have on woody encroachment.

5.3 Study Area – See Chapter 2

5.4 Materials and Methods

Thirty-two public pastures in western Canada were sampled using a stratified random design with paired private pastures. Land owners for the selected private paired pastures were provided a survey (**ethics approval protocol number J2006:006)** to gain information about the management and historic cover of their pastures **(Figure 5.1**). For the public pastures in Manitoba and Saskatchewan, Prairie Farm Rehabilitation Administration (PFRA) provided their annual reports detailing pasture improvements and management on each site. The reports detailed the type (i.e. brush clearing, spraying etc.), date, total area and location of the management. Alberta Sustainable Resource Development – Public Lands branch provided similar information for the Alberta grazing reserves. Codes were assigned to each management practice and the frequency of management types calculated. The focus is on techniques directly related to brush management.

Management History

1. How many acres of pastureland do you have?
2. How long have you owned/managed the property? _______________
   a. How long has it been pastureland? ____________
3. How much livestock do have on the land on average?
4. Has the above amount remained constant since you have been on this property?
   If not, please make note of large changes in livestock numbers over the years.
5. Were your pastures naturally grassed or were they forest/brush covered?__________________
   a. If forest/brush covered, when were they cleared? _______________
6. Has there been any brush management undertaken? (Bulldozing, fire, spraying etc.)
   If so, when, what and where?
7. Has the pasture land ever been seeded? If so, which crops/forage plants were seeded?

Other comments/information: ____________________________

Figure 5.1 Management history questionnaire

5.5 Results

Brush management techniques on public pastures are quite similar across the provinces. Chemical control is most common followed by mechanical methods, only 13% of pastures had no form of management (**Figure 5.2a**). Some management practices such as chain clearing are used only on public lands. Prescribed burning is occasionally used by PFRA to control aspen (Bowes 1996). Management on the pastures is often focused on areas which were cleared of brush initially and along fence lines. The management techniques used and their frequency of application was found to be quite consistent across the study area.

Management techniques on private land were generally found to be similar to those used on public pastures with a few additional methods (**Figure 5.2b**). One example is winter feeding in areas with woody encroachment. Cattle are concentrated in one area where their feeds is and subsequently trample down aspen suckers. Winter feeding is not an option on public pastures as no cattle are present on these pastures in the winter. Another technique employed on private lands is grazing by goats. The landowner continually moves the goats, to areas with active encroachment to ensure it does not worsen. Mechanical techniques are the most common form of brush control on private lands. Only 10% of pastures had no form of management and overall the frequency of management was lower on private lands.

On public lands management for woody encroachment was much more frequent since the 1970s. Out of all the recorded management incidences for public lands in all three provinces 73.4% of them occurred since the 1970s. In general, management for woody encroachment was more frequent on Alberta grazing reserves compared to PFRA community pastures in Manitoba and Saskatchewan

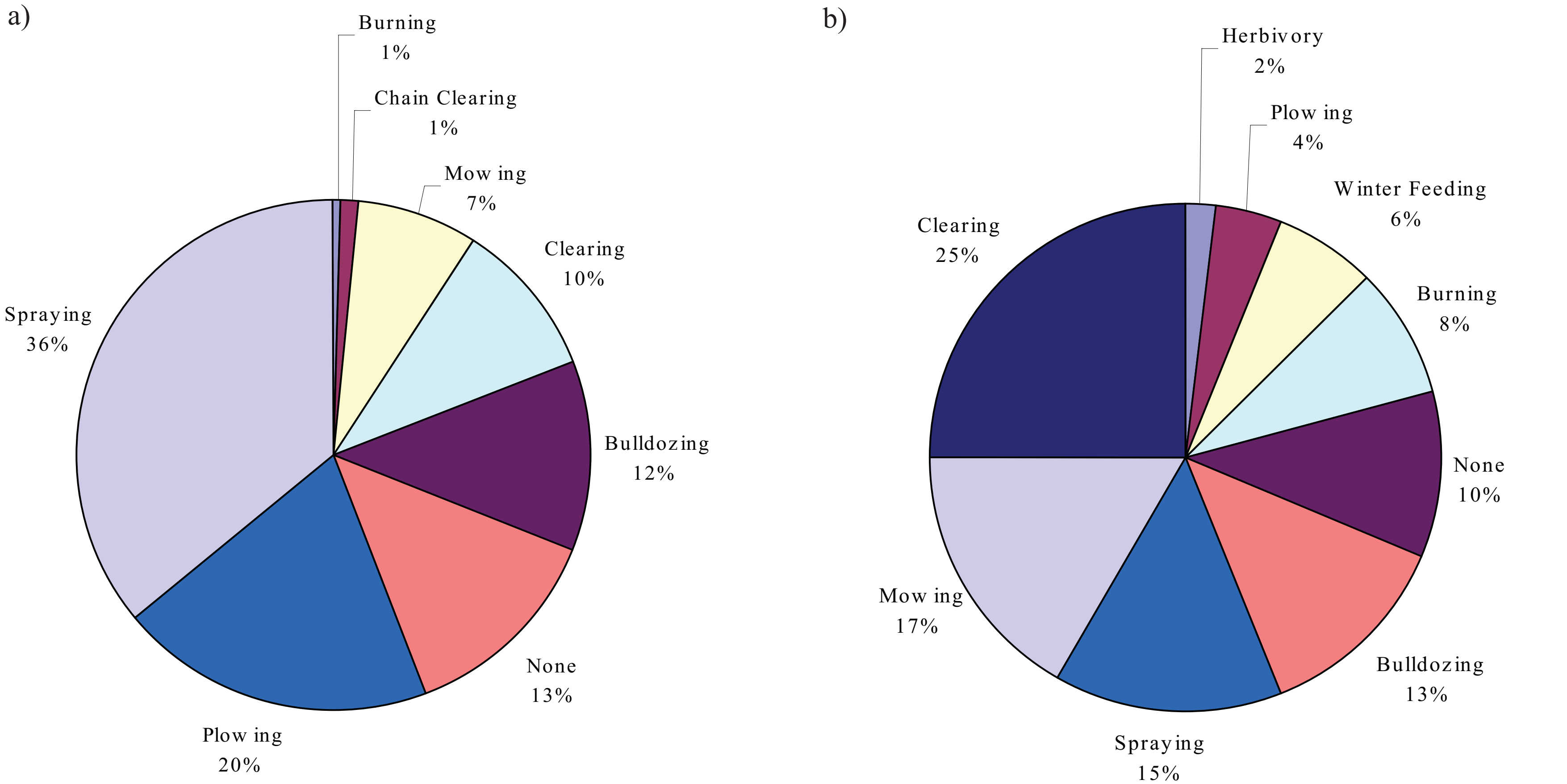

Figure 5.2 Summary of management practices specific to woody encroachment a) Public & b) Private

5.6 Discussion

Woody encroachment, primarily by trembling aspen, has been occurring on pastures across the prairies. Environmental factors, such as soils types, vegetation and climate, did not have a significant impact on the occurrence or the extent of woody encroachment. Soil properties and vegetation varied between strata but not between sites with or without encroachment (**See Chapter 4)**. Management practices have had an impact on the extent of encroachment, sites without management had increases in woody vegetation cover and sites with management had decreases (**Chapter 3 - Figure 3.4 and Figure 3.5).** The rate of increase has lessened since the 1970s, on public lands this is most likely due to an increase of management. Previous research by the Saskatoon Research Centre (1996) suggests that the control of suckers after the clearing of aspen is important to increase forage yield.

We found that the frequency of herbicide use is double on public pastures compared to private lands. The low cost per unit area associated with herbicide application might explain this trend as herbicides are effective and a financially viable option for private producers. Bowes (1991) found herbicide applications on recently cleared land controls aspen encroachment for up to 9 years. Hilton and Bailey (1974) found that herbicide applications increased annual herbage production by three times after two years of treatment and Bowes and Spurr (1996) found herbicide treatment of aspen increased forb and grass production by 50% on pastures in the aspen parkland of Saskatchewan. Zentner and Bowes (1991) looked at economics of chemical brush control in Saskatchewan and found it depends on the value of the gained forage and how long it will be available.

Specifically, they found that repeat application of herbicides was not economically beneficial and it is best to apply them on younger stands.

In this study, prescribed burning was rarely used on either public or private pastures to manage woody encroachment. Prescribed fire combined with grazing has been shown to be effective in the control of aspen encroachment (Fitzgerald and Bailey 1984, Bailey et al. 1990). Some issues with the ability to use fire as a management technique on pastures in western Canada are liability and government policies (Bailey 2006).

Mechanical methods were more common on private lands because of potentially lower annual input costs. Many landowners have the necessary equipment although it may have been purchased for other uses (e.g. crops). Herbivory by other livestock (i.e. goats and sheep) was only used on private lands and this is likely because there would be no place for these animals to be kept over the winter on public pastures. They are primarily used for cattle and horse grazing (Kulshreshtha et al. 2008). One option pasture managers have is to solicit goat/sheep farmers to bring their livestock to public pastures to graze, potentially at a lower rate to gain the benefits of woody encroachment control. Winter grazing of pastures is also a method that was not used on public lands, again as livestock are only on public pastures from May to October. Combinations of different methods, spraying and burning, were found to be more profitable compared to the mechanical methods of clearing and breaking the land (Novak and Lerohl 1986).

The results from Chapter 3 **(Figure 3.4c and Figure 3.5c)** show that private lands had a decrease in grassland cover, while public lands have an increase. This could suggest that herbicides, which are more commonly used on public lands, are more effective in the management of woody encroachment than mechanical methods, which are used more commonly on private lands.

The methods with the most positive results can often be the most costly. In areas where forests are being logged and the land then seeded has become a more economical viable option. The most cost effective method of control is intense short-term livestock grazing (Bailey 2006).

The management of woody encroachment on pastures in western Canada is very challenging due to the low return land managers receive and the variety in the land (i.e. soil and vegetations types) (Bailey 2008b). Many of the techniques are expensive to implement and do not always result in sufficient increases in productivity to be worth the effort (Bailey 2008b). Woody encroachment management has to be done on a continual basis; one-time applications often provide limited control for short periods of time. It is important to plan out a woody encroachment strategy that will result in more positive results for land managers (Bailey 2006).

In private lands the increase in woody encroachment was found to be greater on the pastures without management although an increase in woody encroachment occurs when managed. Public lands exhibit a decrease in brush on lands that have had management and a large increase on lands without management. The increase in woody cover is greater on the private lands. The reasoning for this may be that while management was done on the private lands it often was not as frequent as on the public lands. On the public lands often the management frequency was greater.

A difference in the techniques and frequency of the brush management between public and private lands was found, but specific management techniques could not be directly related to the encroachment because management data was not specific enough.

5.7 Conclusion

Over the past ~50 years there was an overall increase in grass cover on pastures in western Canada, but this was due to the clearing of forests to create pastures. On sites that were originally grassed covered there has been an increase in forest cover, meaning woody encroachment is occurring on pastures in western Canada. Environmental factors, such as soil properties and vegetation cover trended along an east west gradient but do not have an impact on the presence or extent of encroachment on pastures. Patch statistics vary significantly between cover classes but no difference was found between sites with or without encroachment.

Differences were found between the groupings, public sites had an increase in grass cover, while private lands had a decrease. Alberta and Saskatchewan had an increase in grass cover while Manitoba had a decrease. Sites without management had an increase in woody vegetation while sites with management had a decrease. The increase in woody cover was of a lesser extent in the second time period. This is probably due to the increase in management during this time. Over 70% of the incidences of management on public pastures occurred since the 1970s.

The use of herbicides is twice as common on public lands compared to private lands while mechanical methods made up over half the methods used on private lands. Suggesting herbicides are more effective as a method of brush control, since grassland cover has increased on public lands. The use of fire as a control was rare on both private and public lands. Herbivory and winter feeding were only present on private pastures. The best thing to do when undertaking management of woody encroachment is to have a plan in place of what techniques should be used when and where and to monitor the outcomes to assess the future actions.

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