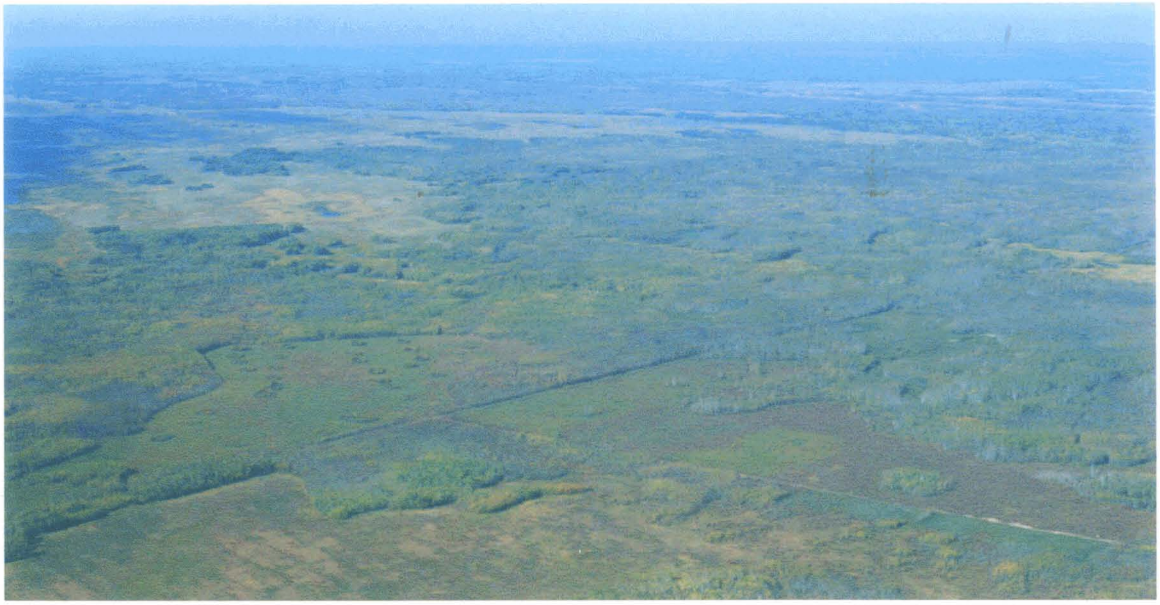
Determining Effective Aspen Management Strategies for Enhancing Habitat and Biological Diversity In Manitoba's Interlake



By

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A Thesis
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in Partial Fulfillment of the Requirements
for the Degree of

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ABSTRACT

Manitoba's Southern Interlake region is located in the Aspen Parkland, a zone of tension that historically experienced frequent fire events and grazing from large bison herds. These were two prominent factors in the historic disturbance regime that shaped and maintained habitat diversity in this dynamic ecosystem. More recently, the lack of frequent fire events, elimination of bison, and variation in precipitation have contributed to increased trembling aspen encroachment onto former grassland and shrubland habitats. Aspen encroachment has resulted in an increasingly homogeneous landscape that has negatively impacted wildlife populations and biological diversity.

Effective strategies are needed in order to restore some of the habitat and biological diversity that was historically found in the Narcisse Wildlife Management Area (NWMA). Rolling and scraping of aspen bush and shrubland complexes with a large drum roller and skidder have been used in the Interlake as a technique to eliminate larger vegetation species. However, substantial aspen suckering from the clonal root systems has been evident. This project evaluated the effectiveness of 4 secondary treatments (prescribed burning, Glyphosate applied with a wiper, mowing, and bark scraping) in reducing trembling aspen density and impacting biological diversity in the plant community. The study was set up in a randomized block design, with each treatment and an untreated control replicated 3 times. Measures of vegetative diversity were also taken in adjacent unrolled bush and shrubland complexes. Treatments were applied during mid-May to mid-June 2000, and surveyed during August 2000 and 2001. A 4 m^2 quadrat was used to evaluate trembling aspen stem density and health. A 1 m^2 quadrat was used to evaluate the plant community, utilizing the Daubenmire cover class method.

All treatments, including the rolling (*i.e.* control) had a lower trembling aspen biomass than the unrolled bush. However, each treatment resulted in an increase in overall live stem density. Prescribed burning, particularly a high intensity burn, was the most effective treatment in controlling aspen, as it had the lowest live stem density and was much more effective in killing preexisting woody stems than the second most effective treatment: bark scraping. Bark scraping was the cheapest treatment to apply, followed by herbiciding and burning, which had similar costs. Herbiciding was less effective than bark scraping in limiting aspen regeneration and killing preexisting woody stems. Mowing was the most expensive treatment, had the highest overall live stem density, and did not kill preexisting woody stems but simply altered their structure.

All treatments, including the control, had significantly ($p<0.05$) greater species richness than unrolled bush. The treatment with the most impact on biological diversity was fire, as it caused the plant community to become more of a grassland community. Species richness and effective richness were primarily determined by small-scale topographic variations in the landscape. Species richness increased as available light increased and moisture decreased. Effective richness was greater in intermediate areas than in moist or dry areas, and was heightened under greater light conditions and microtopic variations in the landscape.

For effective long-term aspen management, this project has shown that followup treatments need to address aspen shoot production. Prescribed burning was the most effective treatment in killing woody stems, and requires management for shoot production. Based on literature analysis, managers or landowners should consider an experimental, short-term intensive grazing strategy during mid-August using cattle or sheep. Other strategies such as mowing or herbiciding during August may be tested and evaluated. In order to enhance habitat management surrounding the NWMA, a biosphere reserve should be considered to promote continuous landscape level planning which would extend beyond the management area boundary. The proposed Narcisse Biosphere would benefit landowners with improved rangelands, habitat diversity, and potentially enhance biological diversity both within the NWMA and the surrounding region.

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CHAPTER 1: INTRODUCTION

1.1 Background

Trembling aspen (*Populus tremuloides*) is a member of the willow family, and is closely related to assorted poplars, such as cottonwoods (Mitton and Grant 1996; Peterson and Peterson 1992). According to one interpretation, the Latin name *Populus* stems from the Greek verb *papaillo*, which means to tremble or shake (Peterson and Peterson 1992). The concept of constant motion is consistent with the well-know characteristic of trembling aspen leaves fluttering under a light breeze. This tree species "in constant motion" is the most widely dispersed tree species in North America, a factor that contributes to a variety of common names dependent on the region (Figure 1.1) (Peterson and Peterson 1992).

Even though *P. tremuloides* is found in every province and two territories in Canada, an ecotype called the Aspen Parkland is found across the prairie provinces between the drier prairie region to the south, and the moister boreal forest to the north, and can be described as open grassland intertwined with groves of trees (Figure 1.2) (Bailey and Wroe 1974; Johnson *et al.* 1995).

Prior to European settlement, during a time period ranging from 3000 BC to 1750 AD., the Aspen Parkland was heavily populated with buffalo (*Bison bison bison*), and elk (*Cervus canadensis*) (Bird 1961). Buffalo was the primary staple food for the First Nations peoples, and their relationship with the buffalo impacted the Aspen Parkland. "The large game animals and the Indians in their hunting and fighting disturbed the parkland and interfered with successional changes but kept it in a relatively stable subclimax condition" (Bird 1961 pg 27). The number of bison that used to roam the prairie region was estimated to range as high as 30 to 75 million (Campbell *et al.* 1994). The impact of buffalo on the environment was described in Bird (1961): "The large herds of buffalo overgrazed sections of the prairie. Henry (Coues, 1897) wrote of the country west of the Red River: "The grass would be rather long were it not for the buffalo...By rubbing and trampling they destroyed small groves of trees"." (Bird 1961 pgs 27 - 28). In addition, herds of elk would browse on young oak and aspen trees (Bird 1961). The oak trees would have broken tops and a twisted appearance. Bird (1961) describes the impact of elk on regenerating aspen. "If elk are abundant they may destroy all sucker growth during their winter browsing. If this is repeated two years in succession, the trees are killed and grassland results. This happened, on occasion, in the Riding Mountain" (Bird 1961 pgs 54 - 55).

During the same time period (*i.e.* 3000 BC to 1750 AD.), fire occurred naturally in the prairie and Aspen Parkland, and local native groups would also frequently set fires. Fires were set to act as telegraphic communications, or to divert buffalo from a particular course (Bird 1961). "Fires were set so frequently that they maintained a prairie subclimax that would, if left undisturbed, be invaded by aspen" (Bird 1961 pg 29). The combination of frequent fire events and large bison herds maintained the prairie and parkland habitats in a dynamic, subclimax state (Baydack, pers. comm.). The dynamic, natural subclimax state may have included a 1/3 grassland, 1/3 shrubland, and 1/3 woodland mixture. However, European settlement marked the beginning of the end of this natural subclimax state (Bird 1961).

European settlement contributed to infrequent fire events, and the extirpation of bison from the province (Bird 1961). The substantial decrease in these 2 disturbances resulted in a forestation event, and was followed by an agricultural based economy by the late 1800's (Bird 1961). Agricultural settlements in the Aspen Parkland north of Winnipeg in the Manitoba Interlake began in the early 1900's (Gylywoychuk 1993). Land was given to veterans and families in the Narcisse - Chatfield region following the two World Wars, which resulted in livestock related subsistence farms (Berger 1989). Lands were cleared for planting hay crops, and the trees were used for building construction and fuel. Wildfires occurred frequently as fires were set to burn hay stubble on hayfields, and often escaped to neighbouring lands. Fire, cattle grazing, and the clearing of land changed the area from a coniferous and aspen forest, to a primarily Aspen Parkland ecotype, which was a good habitat for sharp-tailed grouse. From approximately the 1920's to the 1950's, it is speculated that the Manitoba Interlake was changed back to a 1/3 grassland, 1/3 shrubland, and 1/3 woodland ecotype, primarily from human interference (Baydack, pers. comm.; Sexton, pers. comm.). The fundamental difference between pre-European settlement and post-European settlement was that pre-settlement was a dynamic natural state, whereas post-settlement was primarily human-induced activities and disturbances. In 1963, the Prairie Farm Rehabilitation Administration (PFRA) helped create 5,300 ha of community pasture for cattle grazing (Berger 1989). However, since agricultural production was so poor, most farms were abandoned by 1968. In 1968, PFRA relinquished the lands to the Manitoba government for the establishment of a Wildlife Management Area. Therefore, the lack of frequent fire events, fire suppression in recent decades and limited cattle grazing because of abandonment of settlements has resulted in the Manitoba Interlake changing from an ecosystem that was formerly maintained in a subclimax condition to one of a mature Aspen Parkland.

1.2 Issue Statement

Prior to agricultural development from European settlement, fire historically was a disturbance that frequently swept across the Canadian prairie ecosystem (Bird 1961; Campbell *et al.* 1994). Bison herds were drawn to the young grasses and trembling aspen shoots found in these recently burned areas. The combination of these two historically natural processes, fire events and foraging of aspen shoots, restricted aspen from spreading onto grasslands and shrublands. The frequent fire events and the impact of large numbers of bison as described by Bird (1961) shows how incredibly resilient the prairie and parkland really are. However, the demise of the bison population and decreased frequency of fire events as well as more recent fire suppression, resulted in historical disturbance regimes no longer maintaining the parkland in a dynamic, subclimax state, resulting in a forestation event.

This Aspen Parkland forestation event included the Manitoba Interlake region. It is hypothesized, that during the early agricultural period between 1920 - 1950, the Manitoba Interlake had a mixture of 1/3 grassland, 1/3 shrubland, and 1/3 woodland (primarily aspen) (the so-called Sexton hypothesis) (Berger and Baydack 1992; Sexton, pers. comm.). The intertwining, mosaic structure of these three habitat types provided optimal habitat diversity because the landscape was heterogeneous (Kenkel, pers. comm.). The grasslands, shrublands and woodlands provided diversity in the vertical structure of the landscape. As well, the mosaic structure of these three habitat types provided good juxtaposition of these habitats, also an important factor for healthy wildlife populations and the maintenance of biological diversity in the region. However, the demise of the bison population near Winnipeg in the early 1800's, in addition to a large decrease in the frequency of fire events, fire suppression in recent decades, and changes in land use and management, have resulted in a substantial reduction in grasslands and shrublands on the landscape (Berger and Baydack 1992; Bird 1961). Hence, the aspen parkland today is no longer in a natural, dynamic state, but altered. Therefore, it appears that this landscape cannot be managed within the historical range of variability by removing and suppressing historical disturbances that were integral to the overall ecosystem for thousands of years.

1.3 Objectives

This project was developed to determine the most effective aspen management treatment to set back aspen encroachment onto former grassland areas in Manitoba's Interlake. Specific objectives included:

1. To determine effects of selected management treatments on aspen regeneration.
2. To determine effects of selected management treatments on the plant community.
3. To determine an aspen management plan for the Manitoba Interlake.

1.4 Scope

The study site was located in the Narcisse Wildlife Management Area (NWMA), north of Winnipeg in the Manitoba Interlake near Chatfield. The NWMA is comprised primarily of Aspen Parkland habitat (Gylywoychuk 1993). Management treatments used to emulate natural disturbance include: prescribed burning, herbicide applied with a wiper, mowing, bark scraping and a control. All treatment sites ranged in size from 1.06 - 1.71 ha, and were located in close proximity to each other to keep logistics and costs manageable.

Cattle grazing was initially considered at the outset of the study. However, cattle grazing was not included in the study, as the proposed requirements to implement the grazing component were perceived to be nearly impossible to carry out (Baydack, pers. comm.). Moreover, Wildlife Management Areas (WMA's) fall under the jurisdiction of three departments: the Department of Agriculture, Manitoba Conservation Wildlife Branch, and the Department of Industry, Trade and Mines (Suggett, pers. comm.). The fact that WMA's fall under 3 jurisdictions adds to the grazing in WMA conundrum.

Study site preparation began in June of 1997, when 93 ha were rolled. Considerable aspen regeneration was observed the following year, pointing to the need for additional treatment. The treatments were applied from late May to mid June 2000. Study site sampling was carried out during early to mid August of 2000 and 2001.

1.5 Organization

This thesis is presented in 7 chapters. In chapter 2, the literature review explores the ecology, wildlife values, and management of aspen. Chapter 3 describes the study site and methodology. Chapter 4 presents and discusses treatment impact on aspen regeneration, and chapter 5 discusses how the various treatments impact the plant community. Chapter 6 proposes a wildlife habitat management plan for the Narcisse Wildlife Management Area in the Manitoba Interlake. Finally, chapter 7 presents the summary and conclusions.

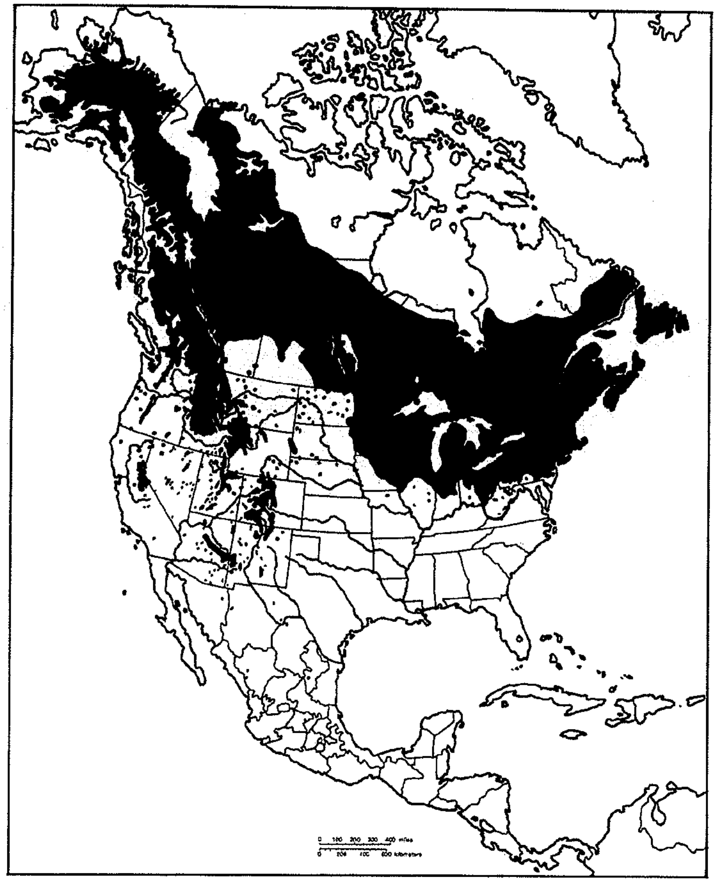


Figure 1.1: Distribution of trembling aspen (*Populus tremuloides*) in North America (Peterson & Peterson 1992).

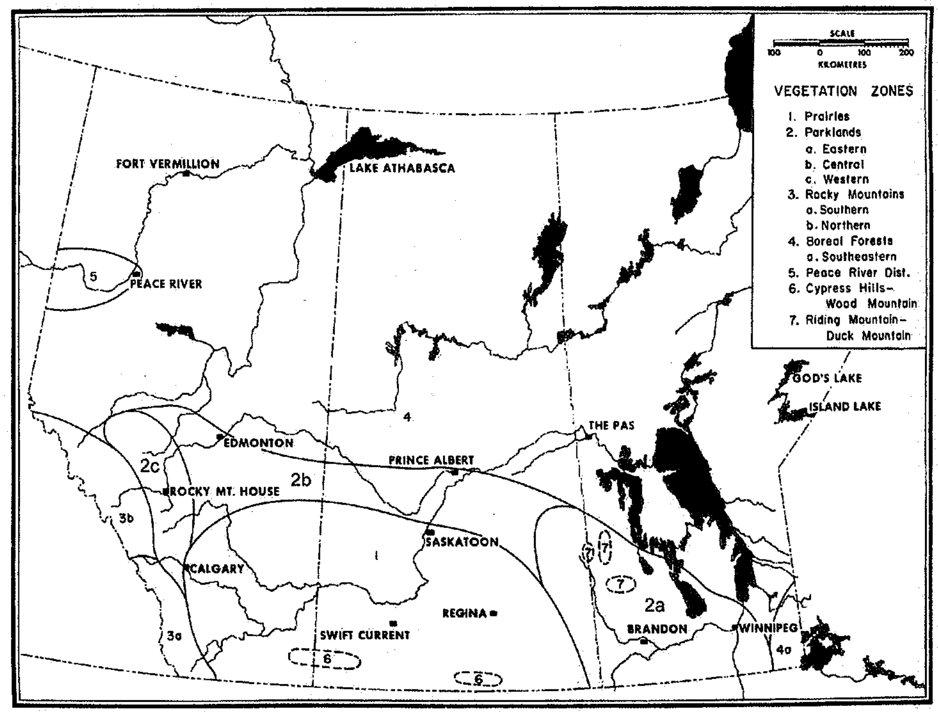


Figure 1.2: A map of the Aspen Parkland spanning the prairie provinces (After Looman and Best 1987).

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discusses the ecology of trembling aspen, examines the historical wildlife situation in Aspen Parkland habitats, and describes various aspen management techniques that have been used throughout the Aspen Parkland region. It is important to be knowledgeable of aspen ecology as this will promote a better understanding of why trembling aspen responds the way it does to commonly applied treatments. Knowledge of the historical and present wildlife situation will provide an understanding of historical disturbance regimes, and may contribute to planning for future management decisions.

2.2 The Ecology of Aspen

Trembling aspen are small to medium deciduous trees that possess a clonal structure and appear to adapt to a variety of environmental conditions (Johnson *et al.* 1995). In southern Manitoba, aspen can grow to approximately 17 m tall, and 15 to 20 cm in diameter (Bird 1930). The following subsections will describe the geographic range, bark, root system, and reproduction of trembling aspen, as well as the adaptations, influences of weather, and response to disturbance.

2.2.1 Geographic Range

Trembling aspen ranges longitudinally across Canada and the United States, from the east coast to the west coast (Figure 1.1 (Peterson and Peterson 1992)) (Mitton and Grant 1996; Peterson and Peterson 1992). The latitudinal range extends down to the mountains of Mexico, to as far north as Alaska and the Mackenzie River Delta in the

Northwest Territories. Furthermore, the elevation at which aspen grows ranges from sea level to 3,700 m (Mitton and Grant 1996). Therefore, aspen trees posses an ability to adapt to diverse environmental conditions.

2.2.2 Bark

The colour of the bark ranges from white to greenish-white, yellowish-white, yellowish-gray, yellowish-brown, gray, or simply green (Peterson and Peterson 1992). Chlorophyll is found in the bark of the main trunk, stems, and branches, which gives it a slightly green colour. The presence of chlorophyll in the bark gives aspen the ability to photosynthesize when no leaves are present. Photosynthesis from bark only contributes approximately 1-2% of the annual carbohydrate supply. Yet this small amount is enough to equal stem respiration, which is believed to increase the possibility of stressed trees being able to recover.

2.2.3 Root System

The trembling aspen root system differs from many forest tree species in two primary ways (Peterson and Peterson 1992). Firstly, aspen suckering occurs from the parent root system. Secondly, the aspen parent root system is interconnected and spreads widely in a lateral network. An example in Alberta found aspen trees 24 m tall and 79 years old that were still interconnected (Peterson and Peterson 1992).

Aspen trees have roots that penetrate laterally as well as vertically (Peterson and Peterson 1992). Most often, four or five very developed lateral roots develop from the base of a tree, from which cord-like branch roots, within 60 cm of the stem base, extend laterally.

These sucker-producing, cord-like branch roots penetrate the soil within one metre from the surface, (most of which are found 5-20 cm below the surface), and can extend in excess of 30 m into neighbouring clearings with limited branching.

There are two kinds of vertical roots (Peterson and Peterson 1992). Trembling aspen have strong, vertical roots found close to the base of the tree that provide complementary support to the lateral roots. In addition to these vertical roots, sinker roots may develop at any point along the lateral branch root and penetrate more than 2.7 m deep. The tips of the sinker roots branch superabundantly into a dense fan-like mat. These fine roots frequently occur when the sinker roots reach an impermeable layer, such as saturated soil, dense clay, or rock.

2.2.4 Aspen Suckers

Most aspen suckers originate from parent lateral branch roots that are less than 2 cm in diameter, or along portions of the lateral root that have tapered to under 2 cm (Peterson and Peterson 1992). Recently formed suckers depend on the parent roots for water and nutrients. The connection with the parent root gives aspen suckers a distinct advantage for survival and growth over many other plant species, including aspen stems derived from seeds. Aspen suckers that are under 2 years old rarely have well-developed independent root systems. It was determined from two aspen clones in Utah that 30% of stems were 18-26 years old, originating from the parent root, and had no independent roots or only one root that complemented the parent root. As a sucker stem matures, the degree of dependence it has on the parent root system decreases because it develops its own root system. However, even after stems derived from suckers have matured and developed their own root systems, the stems still remain attached to the parent root.

The parent root system is long-lived and tenacious (Peterson and Peterson 1992). In the lower foothills of the Rocky Mountains in Alberta, aspen suckers were found in nearly every forest stand, regardless of the age or density of the conifers present. Even under a very dense coniferous canopy, smaller aspen suckers, most of which would live just a few years, provided sufficient photosynthesis for the parent root system to remain alive.

2.2.5 Aspen Reproduction

Most trees reproduce sexually via male and female flowers (Grant and Kayne 1993). Some tree species have male and female flowers on a single tree. However, *Populus tremuloides* trees are either male or female. The flowers are small, somewhat obscure, and produced in catkins, which possess a string-like appearance (Mitton and Grant 1996). The flowering sequence, which includes seed maturation, is concluded in early spring prior to leaf production.

Aspen trees commonly flower after about 15 years of age, but can produce flowers as young as 10 years of age (Peterson and Peterson 1992). Upon reaching the flowering age, good seed crops are produced every 4-5 years. The seed production of a tree is positively correlated with the age and size of the tree (Mitton and Grant 1996). Older, mature trees have been known to produce 54 million seeds in one season. The seeds are carried by the wind, as far as 30 km via long, silky parachute-like structures (Johnson *et al.* 1995; Mitton and Grant 1996; Peterson and Peterson 1992). However, because aspen seeds lack endosperm, the seeds require almost immediate contact with moist soil to absorb water and nutrients for seedling establishment to occur. Once a seedling has been exposed to the soil, 1-5 years are required for establishment.

Trembling aspen regenerate primarily by sending up suckers from the lateral root system (Peterson and Peterson 1992). In addition, suckers may also be produced from stump sprouts or collar sprouts. Two main factors that stimulate the production of aspen suckers are the disruption of apical dominance, and increased soil temperature, the latter being the more important of the two. There are numerous factors that regulate the degree of aspen suckering. These include growth regulators, (particularly auxins and cytokinins); root carbohydrate reserves, root size, the intrinsic ability of each clone to send up suckers (suckering ability can vary as much as twenty times between clones), soil temperature, root depth (suckering occurs primarily from roots that are 4-12 cm below the surface), soil moisture, and the degree of stand disturbance.

Most suckering occurs during the first growing season following the disturbance (Peterson and Peterson 1992). Suckers that develop early in the growing season experience greater growth than suckers that develop later in the season. Under ideal conditions, a sucker's growth in the first year may be as much as 2.5 m (the average is 1-2 m), but decreases in subsequent years to 0.5-1.0 m/yr.

Sucker growth rate contrasts with that of aspen seedlings (Peterson and Peterson 1992). First year growth for a seedling is typically less than 15 cm, and usually 15-30 cm for the second growing season. This disparity in annual growth rate between aspen from sucker vs. seed origin can remain for up to 30 years. Studies suggest that stand density has limited impact on sucker height growth in the first 5 years. However, aspen sucker survival decreases with increased stand density.

Aspen's ability to reproduce asexually by root suckering is essentially cloning. A clone is defined as all the stems, leaves, and roots of one individual aspen tree (Grant and Kayne 1993). Biologists propose that western aspen clones are ancient, possibly 10,000 years to even 1 million years old (Mitton and Grant 1996). A large aspen clone was found in south central Utah and was named Pando, a Latin word that means, "I spread." Pando is the largest known living organism. Pando, a male aspen clone, covers 43 hectares, has more than 47,000 individual stems, all of which are genetically identical to each other, and weighs more than 6 million kilograms (Grant and Kayne 1993; Mitton and Grant 1996). This mass is almost 3 times greater than the largest giant sequoia tree (Grant and Kayne 1993). Trembling aspen clones are capable of spreading far across a landscape through root suckering. The distance a clone can spread depends upon its lifespan.

2.2.6 Clonal Adaptations, Meteorologic Influences, and Response to Disturbance

Genetic diversity of aspen clones allows them to survive in diverse regions in North America ranging from the northern Mackenzie Delta to regions of northern Mexico (Peterson and Peterson 1992). Aspen clones from western provinces are adapted to begin growth at lower accumulated degree-days than native clones from Michigan, United States. As well, aspen clones from higher altitudes or northerly latitudes stop growing earlier than Michigan clones. Evidence suggests that aspen display variations in the degree of sensitivity to photoperiod, which is dependent upon latitude (Peterson and Peterson 1992). Aspen clones of northern regions display a stronger response to photoperiod than do aspen trees of southern regions. These variances in growth features are attributed to clonal genetic variation and adaptation.

Adaptations also allow aspen to tolerate extreme temperatures, such as very frigid conditions, or drought conditions (Peterson and Peterson 1992). Trembling aspen of the boreal forests in northern Canada and Alaska have adapted to withstand the cold through the presence of a permeable membrane. A permeable membrane permits water to move out of a living cell quickly to prevent ice crystals from forming inside the cell. Aspen can withstand experimental freezing temperatures as low as -196°C. A strong tolerance toward freezing temperatures is actually a type of drought tolerance, because the water that has moved from the intracellular space to form the ice crystals in the extracellular space, places significant drying stress on the protoplasm.

Aspen are also well adapted to withstand relatively dry and nutrient-poor conditions through the adaptation of reproducing by suckering (Grant and Kayne 1993; Peterson and Peterson 1992). Aspen seedlings are most susceptible to drought conditions because their root systems are independent (Peterson and Peterson 1992). Aspen stems originating from suckers can essentially bypass the critical drought phase because they are connected to a root system network. Clonal roots that have access to an abundant water source can pass the water on to other stems and suckers of the same clone growing in a dry site (Grant and Kayne 1993; Peterson and Peterson 1992). Likewise, aspen roots that have sufficient access to nutrients can send nutrients to other parts of the same clone that may be nutrient poor. The ability for aspen to distribute water and nutrients throughout the clone enable it to survive in areas where other tree species would die.

Death of a single aspen stem impacts the entire clone (Grant and Kayne 1993). Under normal conditions, each aspen stem sends hormones into the root system, which suppresses the establishment of new suckers. However, when a stem dies, hormones are no longer sent into the root system. If a significant disturbance occurs causing a large number of stems in a clone to die, the hormone imbalance in the clonal root system stimulates a flush in sucker production. Sucker production can be as intense as 400,000 new shoots per hectare (Grant and Kayne 1993; Mitton and Grant 1996). Occasional disturbances keep an aspen stand regenerating. However, depending on conditions, a lack of disturbance for a prolonged period of time may cause the aspen stand to slowly die out, and be overtaken by shade tolerant tree species if soil conditions permit and there is a seed source in close proximity. Replacement may be more likely in the Northern Interlake or Boreal Forest than the Central or Southern Interlake, which has poorer soil conditions.

2.3 Historical Wildlife Components of the Aspen Parkland

Prior to the arrival of European settlers, wildlife species and population sizes were abundant in the Aspen Parkland (Bird 1961). Large populations of herbivores were found in the Aspen Parkland. A herbivore that dominated the region was the buffalo (*Bison bison bison*). Other larger herbivores included the pronghorn antelope (*Antilocapra americana*), an animal of the open plains that also ranged into the parkland, the elk (*Cervus canadensis*), an animal which grazes on grasslands near aspen groves, and the mule deer (*Odocoileus hemionus*). Predators that preyed on larger animals were the buffalo wolf (*Canis lupus nubilus*) and the plains grizzly bear (*Ursus horribilis*). Finally, one of the predominant parkland bird species was the sharp-tailed grouse (*Tympanuchus phasianellus*) (Bird 1961).

The bison were abundant in the plains prior to the arrival of Europeans (Bird 1961). The range of bison extended deep into the parkland and forested areas, as far north as Great Slave Lake in the Northwest Territories. The beginning of the end for buffalo came when firearms arrived onto the scene, and were traded with First Nations groups (Bird

1961). Bison were frequently slaughtered just for their tongues. The lack of an understanding of conservation led to the destruction of the bison population. The last wild buffalo seen near Winnipeg was in 1819.

Pronghorn antelope were often associated with buffalo and also ranged into the Aspen Parkland (Bird 1961). The primary centre of distribution for pronghorn was in the short grass prairie, but extended into mixed grasslands, which is presently parkland. Pronghorn did not enter the aspen groves, but their presence in this region was possibly attributed to frequent fires which reduced aspen cover. Pronghorn antelope have been extirpated from Manitoba.

Elk (*Cervus canadensis*), also called wapiti, were very abundant in the parkland during the early 1800's, second in numbers only to bison (Bird 1961). Elk preferred a habitat complex of prairie and aspen. They took shelter in the aspen woodland during the day, and grazed on the open prairie at night. When snow depth increased during winter, elk browsed on *Salix* (willow), *Amelanchier alnifolia* (saskatoon), *Prunus virginiana* (choke cherry), *Corylus cornula* (hazelnut), *P. tremuloides* (trembling aspen), *Quercus macrocarpa* (bur oak), and *Betula pumila* var. *glandulifera* (dwarf birch). Many elk were driven from the parkland into neighbouring hilly country and heavily wooded areas by hunting pressures and the advancements of settlement (Bird 1961). More recently, the Rocky Mountain Elk Foundation, together with Manitoba Conservation, have initiated an elk habitat management program to increase elk habitat and the elk population in the Manitoba Interlake (Baydack, pers. comm.). The Riding Mountain area now has one of the largest remaining elk herds in Manitoba.

Mule deer (*Odocoileus hemionus*) were common throughout the parkland in 1883 (Bird

1961). They preferred complex habitats that combined forest cover and open grasslands. However, as human settlement increased, the mule deer population decreased. The population declined steadily because they were not able to adapt well in settled regions. By 1911, mule deer were scarce, and were extirpated from Manitoba by 1928.

The buffalo wolf (*Canis lupus nubilus*) was very common and followed buffalo herds (Bird 1961). As the buffalo declined, the buffalo wolf began to prey on livestock. This action resulted in wolves being shot, poisoned, and trapped, leading to the extinction of this subspecies.

Bird species also played an important role in shaping the parkland. For example, the sharp-tailed grouse (*Tympanuchus phasianellus*) was the most common grouse in the parkland (Bird 1961). Sharptails feed on snowberries, rose hips, and buds from trees and shrubs. Bare areas, which were produced by bison's wallowing and trampling, were used by sharp-tailed grouse for dusting. Seeds from snowberry fruit that were consumed by sharp-tailed grouse would be deposited in their droppings onto the bare, dusty patches, resulting in the establishment of snowberry patches. Once established, the snowberry patches would out-compete the over-grazed grasses, and spread into the prairie.

Sharp-tailed grouse have habitat requirements that vary seasonally and with time of day (Johnsgard 1973). During the summer, daytime resting areas may be brushy sites, willow or aspen thickets, or immature coniferous stands. Evening roosting sites tend to be quite open upland sites with good ground cover. Lek sites or dancing grounds tend to be on dry open, elevated grasslands with good visibility, and are used during the spring and fall. Almost half of the nest sites are in shrubby cover (1 - 2 metres high), with none greater than three metres from woody or brushy cover. During winter, sharp-tailed grouse create snow burrows in dense marsh or swampy vegetation. Sharptails retreat to woody areas to rest during summer days, and for protection and thermal cover during winter.

Like the sharp-tailed grouse, the eastern loggerhead shrike (*Lanius ludovicianus migrans*) also requires a diverse, heterogeneous habitat. The eastern loggerhead shrike is an endangered species at the provincial and national level, and has been extirpated from New Brunswick and Nova Scotia (Cade and Woods 1997; Canadian Wildlife Service (CWS) 2001; Pruitt 2000). During 1998, there were only three single shrikes observed in Québec, and 31 pairs and 9 singles observed in Ontario (Environment Canada 2000). In Manitoba, only about 12 pairs were observed during the summer of 2000 (Bio Net Summer 2000.). Most of the *L.l. migrans* in Manitoba are now found in the southern Interlake, just north of Winnipeg (Blouin 2000; Sexton, pers. comm.). Historically, *L.l. migrans* were found as far as 120 km north of Chatfield at Lake St. Martin (Shortt and Waller 1937). The loggerhead shrike prefers open, lightly wooded sites, well-spaced shrubs, low trees, short grasses, herbaceous plants, and locations with exposed ground (Cade and Woods 1997). These conditions may be met in meadows, pastures, grasslands or native prairie, and thickets and hedges beside a road (Canadian Wildlife Service (CWS) 2001). Perching sites, such as dead branches, tall shrubs, young trees, and utility wires, are important locations to forage. The primary nesting shrub for the eastern shrike is hawthorn (De Smet and Conrad 1991). Spiny shrubs and even barbed wire fences are used to impale prey to aid in feeding or to cache food (Pruitt 2000).

Interestingly, the eastern loggerhead shrike and the sharp-tailed grouse share similar habitat features. They both require a complex, heterogeneous habitat possessing diversity in the vertical structure and species composition of the plant community. Each is dependent on grasslands and the shrubby component of the landscape, conditions which are increasingly limited in Manitoba's altered Aspen Parkland. Furthermore, both species are impacted by aspen encroachment onto grasslands and shrublands, and the resultant decrease in habitat diversity.

Therefore, the fact that both the eastern loggerhead shrike and the sharp-tailed grouse are negatively impacted by aspen encroachment, suggests that the Aspen Parkland is no longer in a natural state, but altered. The decline of the sharp-tailed grouse population may serve as a good indicator of the overall habitat condition, suggesting that ecosystem integrity has deteriorated. Disturbances that were historically a natural part of an ecosystem, which maintained the hypothesized 1/3 grassland, 1/3 shrubland, and 1/3 woodland mixture, have to a large degree been eliminated, thus resulting in an altered ecosystem where woodlands are now dominating parts of the landscape.

2.4 Wildlife Species That Increased Following European Settlement

Although European settlement resulted in reduced species abundance and populations for some species, other species benefited from settlement (Bird 1961). Such species included: white-tailed deer, white-tailed jack rabbit, the crow, barn swallow, mourning dove, and the robin.

White-tailed deer (*Odocoileus virginianus*) were not found in the Aspen Parkland prior to European settlement (Bird 1961). However, as human settlement advanced and increased, so did the white-tailed deer population, as they easily adapted in settled regions. Regions with European settlement provided white-tailed deer with protection from wolves, and hunting was limited to bucks for only a short season. Ideal deer habitat consisted of aspen groves interspersed among crop fields. During the summer, deer would eat broad-leaved plants such as sweet clover, choke cherry (*Prunus virginiana*), saskatoon (*Amelanchier alnifolia*), creeping juniper (*Juniper horizontalis*), and bur oak (*Quercus macrocarpa*) twigs.

White-tailed jack rabbit (*Lepus townsendii campanius*) increased as the degree and extent of agriculture increased (Bird 1961). The jack rabbit used cultivated fields the same manner as it used native prairie to feed, bed, and raise young. The first jack rabbit was observed near Winnipeg in 1896, and at Stoney Mountain in 1898.

Bird species that increased after European settlement included the crow, barn swallow, mourning dove, and robin (Bird 1961). Crows (*Corvus brachyrhynchos brachyrhynchos* Brehm) became common in the Aspen Parkland. Aspen groves and willow were preferred nesting areas, and they would feed in neighbouring cultivated fields and sloughs. Barn swallows in the Aspen Parkland relied on settled regions for nesting sites (Bird 1961). They used buildings with interior access to construct cup-shaped nests on rafters and walls, and fed on insects such as mosquitoes, house flies, and horse flies. The mourning dove (*Zenaidura macroura*) used agriculture as its abundant food supply, and shade trees in towns as nesting sites (Bird 1961). Robins (*Turdus migratorius*) like to nest in shade trees in close proximity to human dwellings and machinery (Bird 1961). They were attracted to earthworms in lawns and gardens, cutworms, and insects.

2.5 Aspen Management

The advancement and maturing of trembling aspen in the Manitoba Interlake has resulted in a loss of landscape complexity (Kenkel, pers. comm.). Diverse vertical structure in the plant community at the landscape level promotes landscape complexity. Landscape complexity is one key that promotes and maintains habitat diversity, and therefore biological diversity. It is this diverse vertical structure that is of great importance in maintaining diversity in the landscape, which in turn affects wildlife diversity. Therefore, a decrease in the vertical structure of the landscape will decrease diversity in the plant community, which may result in a decrease in wildlife diversity.

Juxtaposition among habitats and the differences among them is another important factor for wildlife populations and biological diversity (Litvaitis *et al.* 1996). Most wildlife species require diversity in habitat types within a specific proximity. For example, elk (*Cervus elaphus*) and white-tailed deer (*Odocoileus virginiana*) require wintering habitats that provide them with thermal cover, that are closely located to feeding habitats. Poor juxtaposition of habitat types (e.g., grasslands, shrublands, and woodlands) will decrease habitat suitability, resulting in declining wildlife populations and biological diversity. Therefore, inadequate juxtaposition of suitable, diverse habitats and decreasing diversity in the vertical structure of the plant community points to the need for effective aspen management to restore grassland and shrubland habitats.

There still does not appear to be a quick and inexpensive method to turn a trembling aspen forest into a permanent pasture (Peterson and Peterson 1992). The following sections will describe various treatments used to restore habitat diversity and improve habitat quality.

2.5.1 Introduction

Historically, prairie fires and large bison herds restricted trembling aspen encroachment (Anderson and Bailey 1980; Campbell *et al.* 1994; Converse and Echardt

1988; Nicoll 1999). According to Moss (1932), early European settlers claimed that aspen groves were expanding and more numerous than a number of years previously. Today, ranchers are losing grazing land to aspen spread, and land managers are contending with the increasing problem of loss of landscape heterogeneity and diversity. Over a 21-year period, some areas in the NWMA changed from aspen parkland to aspen forest (Berger and Baydack 1992). The NWMA experiences aspen encroachment at a mean rate of 1.8% annually. The following sections will address various aspen management techniques being used today. They are shearblading, rolling, mowing, bark scraping, herbicide, burning, grazing, and burning and grazing combined.

2.5.2 Shearblading

Shearblading is a mechanical treatment where the blade in front of a bulldozer is positioned just above the ground while advancing through a trembling aspen stand (Berger 1989). Positioning the blade above the ground also keeps soil displacement and erosion to a minimum. Areas can be cleared of aspen using a linear strip method.

Shearblading independent of another treatment applied during the summer would not be effective, as aspen trees are flexible, and would bend and eventually spring back rather than be sheared at the base (Berger 1989). However, if a bulldozer shearblades and simultaneously pulls a heavy roller, the tree bark would be scraped by the shearblade and the rolling action would make it less likely for the trees to spring back. Shearblading is best applied during the coldest part of winter, which results in frozen trembling aspen trees being sheared off at the base.

2.5.3 Rolling

Rolling is a mechanical treatment accomplished by pulling a weighted, cylindrical drum behind a tractor, skidder, or bulldozer. If a blade is used in front of the pulling unit, it not only protects the unit from the bush, but also scrapes the tree bark before they are rolled. Rolled trees would be damaged, and the former understory vegetation would experience greater light conditions. Rollers vary in size, weight, and construction, but generally produce the same results. The roller size and weight used will depend upon the power, size, and traction of the implement pulling it.

More than 5,600 ha of PFRA pastures in Western Canada's Aspen Parkland are taken over by bush encroachment annually (Nicoll 1999). When the tree canopy shades much of the understory, grass production decreases by 75%. Rolling is one technique used to restore habitat diversity and increase forage production. The roller used at the Narcisse study site weighed approximately 3,600 kg when filled with water, and had a drum with a smooth surface. The ability to add and drain water increased its mobility from one site to another.

Another type of roller has metal blades on it to chop up the brush into smaller pieces, thus making it easier for cattle to graze following the rolling treatment (Nicoll 1999). A bladed roller is more effective on softer, sandy soils than rocky soils. Very good results were obtained when the root crown was also pulled out of the soil by the bladed roller, causing those particular trees not to sucker (Nicoll 1999). Benefits to using the bladed roller include aeration of the soil, stimulation of grass growth and seed production, and increased water absorption, particularly after heavy rains result in decreased soil loss in runoff. However, since much of the Manitoba Interlake has thin, rocky soils, a bladed roller would not be an effective means to roll trembling aspen, and would probably result in equipment damage.

2.5.4 Mowing

Mowing consists of using an industrial mower mounted in front or behind a skidder or tractor to chop all vegetation down to approximately 10-15 cm above the ground. A heavy duty mower will chop larger diameter aspen than a light duty mower. Therefore, the type of mower selected may depend on the site being mowed.

A heavy duty rotary mower was used at the Calder-Togo Community Pasture in Saskatchewan to evaluate aspen management (Bowes 1995; Bowes and Kirychuk 1996). The site was mowed on July 13, 1993, and two years later mowing was found to have a better canopy kill of small aspen than bark scraping (Bowes and Kirychuk 1996). In addition, the degree of suckering was similar in both the mowing and bark scraping treatments.

Very little has been published on the effects of mowing on Aspen Parkland plant communities. Mowing may be a useful tool to improve or maintain species richness, as it increases light availability within 10 cm above the ground (Collins *et al.* 1998). However, the impact of mowing on species richness may vary from one plant community to another.

2.5.5 Bark Scraping

Bark scraping consists of using a skidder or tractor to drag heavy metal blades over the ground to remove a strip of bark of sufficient length to girdle the tree (Bowes and Kirychuk 1996). The scraper is pulled over a tree, the tree bends, and a portion of the bark is scraped by the sharp metal blades, thereby killing the tree over time. In greater detail, phloem is located in the bark, and when trees are girdled from the scraping action, the flow of photosynthate from the leaves down to the roots is disrupted (Converse and Echardt 1988). The leaves will remain green and appear healthy because they still receive water and minerals in the xylem. However, since the roots experience a significant reduction in photosynthate replenishment, their reserves become depleted, making them less likely to support aspen suckers.

There are three kinds of bark scraper units: the motor-grader blade bark scraper, the I-beam bark scraper, and the cat rail bark scraper (Bowes and Kirychuk 1996). The motor-grader blade scraper uses five grader blades bolted to each other to produce a "gang". There are three gangs, that are attached behind a heavy metal pipe, which make up the scraping unit. This scraper design was similar to the one used in the Narcisse study. The I-beam scraper uses a serrated ice scraping blade welded to a large I-beam, as well as railroad tracks to complete the unit. The cat rail scraper uses D7 and D8 cat rails (or tracks, with pads removed) and drill pipe to complete the unit.

These three bark scrapers were tested on a trembling aspen stand in a good growing area (*i.e.* above average growing conditions for aspen), with small trees ranging from 3.2 m to 3.7 m, and juvenile trees ranging from 1.1m to 1.7 m (Bowes and Kirychuk 1996). The I-beam scraper was marginally better in killing the small aspen tree canopy. However, all three scraper units were equally effective in killing the juvenile aspen trees, and aspen suckering response was occasionally greater with the cat rail scraper. Treatments conducted in June or July were both effective at reducing the aspen canopy cover. Therefore, the I-beam scraper with its serrated edge was slightly better in killing trees in the 3.2 to 3.7 height class, but no difference was found between the scrapers for the juvenile height class.

A cat rail bark scraper was used on an aspen site to determine if the effectiveness of the treatment increased as the number of iterations of the treatment increased (Bowes and Kirychuk 1996). The site was an aspen cover with sandy soils resulting in poor growing conditions. Although the Manitoba Interlake has thin stony soils rather than sandy soils, inferences may be drawn since both sites have poor growing conditions. The kill percentage of the small aspen canopy (1.7 - 2.2 m) increased from one to three treatments, after the first year of treatment. However, after the second year there was no significant difference. Suckering increased as the number of treatment applications increased. Nevertheless, the greatest increase in sucker density occurred between the second and third iteration.

Making multiple passes with the scraper was conducted by reversing the direction of the pass with respect to the first pass (Bowes and Kirychuk 1996). However, this method is not recommended because reversing the direction of the pass causes small aspen stems to break off 50 - 100 cm above the ground, thereby creating a dangerous environment for cattle where they may be more prone to injury. The recommendation is that a repeat pass be conducted at a right angle to the first pass.

A motor grader bark scraper was used to determine the impacts of the time of year on the percentage of cover killed, and on suckering in an aspen stand 1 - 3 m tall (Bowes and Kirychuk 1996). Application dates were June 14, August 04, August 30, September 29, and October 29. Canopy kill was most effective from June until the end of July. Any later resulted in a lower percent cover kill. Aspen suckering was most noticeable early in the season, and progressively decreased as one got later into the summer and early fall. Therefore, sucker production was greater when there was a higher percentage of canopy kill, as compared to a lower percentage of canopy kill.

2.5.6 Herbicides

Aspen spread decreases available forage for cattle grazing and changes wildlife habitat (Bowes 1997b). Land owners and managers have used herbicides such as 2,4-D, Banvel, Escort, and Garlon to control aspen encroachment for many years. Another commonly used herbicide is Glyphosate, also known as Roundup © or Vision. Glyphosate enters a plant through the leaves, and spreads to roots, buds, and rhyzomes, which have high meristematic activity (Manitoba Natural Resources 1988). Upon entering the plant, high pH fluids within the plant causes Glyphosate to change to a water-soluble salt form. Accumulation of these water-soluble salts in areas of high meristematic activity restricts photosynthesis and growth, by interrupting the shikimic acid pathway and production of aromatic amino acids, resulting in death of the plant. Absorption and translocation of Glyphosate is influenced by light intensity, temperature, relative humidity, water stress, and photosynthate translocation.

Glyphosate's half-life ranges from a few days to several years depending upon the type of soil and the degree of microbial activity in the soil (Manitoba Natural Resources 1988). Factors that influence microbial degradation of pesticides in soil include: time, temperature, pH, adsorption, moisture, and the type of soil.

Both Glyphosate and 2,4-D have been used in attempts to permanently remove aspen (Peterson and Peterson 1992). In Ontario, an aerial application of 2,4-D was applied to five year old aspen suckers with limited success. Peterson (1992) states that the aspen diameter growth rate was reduced for only two years. However, Bowes (1997a) claims that all herbicides (2,4-D, Banvel, Escort and Garlon) were effective for sucker reduction. Furthermore, Banvel + 2,4-D, when applied two years following the initial treatment, resulted in excellent control of aspen suckers for 17 years, thereby prolonging the future application date. Bowes (1997a) states that in order to control aspen suckers, the time of treatment application is of greater importance (*i.e.* when suckers are 2 years old) than which herbicide is selected. Perhaps the different results experienced by Peterson and Peterson (1992), and Bowes (1997a) can be attributed to the age difference of treated aspen suckers.

After clearing a mature aspen site, the most effective method to kill aspen is to apply the herbicide 2 years after the treatment, when the aspen shoots are two years old (Bowes 1997a; Peterson and Peterson 1992). The objective is to reduce the aspen canopy to less than 5 percent cover, one year following the herbicide treatment (Bowes 1997a). If the aspen sucker canopy is greater than 10 percent cover, canopy growth will be similar to that of untreated sites (Figure 2.1). However, if the aspen sucker canopy is reduced to less than 5 percent cover, there will only be approximately 18 percent aspen cover ten years following the herbicide treatment, and would require 42 years to reach 80 percent cover. Reducing aspen percent cover to less than 5 percent would significantly reduce treatment frequency and long-term management costs.

Herbicides can be applied by simply spraying the ground using a spray apparatus mounted on a skidder, or selective stump application following the use of a brush saw (Philippot 1996). A 3 year study conducted in the Manitoba Model Forest revealed that ground application of Glyphosate was most effective at controlling aspen and shrubs.

Ground application of Glyphosate was also the most cost effective treatment. The significant decrease in aspen canopy cover resulted in a bountiful increase in herbaceous plants and grasses, which would be beneficial for cattle production. Another study near Edmonton, Alberta, showed that herbicide spraying following a prescribed burn was the most effective treatment for controlling sucker regrowth of aspen, balsam poplar, and willow (Peterson and Peterson 1992).

Another selective herbicide application technique is a wiper (or wick) (Bowes and Kirychuk 1996). The wiper consisted of a carpet saturated with herbicide suspended above the ground. Wiper applied Roundup © (Glyphosate) and Fencerow © test plots yielded the same kg/ha of grasses and forbs as the control. Both ground spraying and wiper application methods were effective in reducing the aspen canopy cover. Therefore, herbicide applied with a wiper was effective in reducing aspen cover without impacting grass and forb production. The study did not compare the response of foliar applied Glyphosate with that of wiper applied Glyphosate.

Despite the successes experienced with herbicide application, recent studies suggest that herbicides are not necessarily needed for aspen management (Peterson and Peterson 1992). Prescribed burning, and short-duration heavy grazing strategies are effective and attractive alternatives to herbicide use in the Aspen Parkland. Burning, followed shortly by heavy grazing, is a key factor that provides palatable grazing food, while at the same time restricting woody regrowth.

2.5.7 Prescribed Burning

Fire plays an important role in aspen dynamics, both historically and presently (Romme *et al.* 1995). Trembling aspen evolved with fire, and is impacted by both the presence and absence of fire. Reproduction of over mature aspen stands is threatened by a lack of fire (Peterson and Peterson 1992). Conversely, trembling aspen can be killed by fire. To kill aspen living tissue, the cambium, buds and leaves must be exposed to a temperature of 64°C or greater. Root tissue is more sensitive to mortality caused by excessive heat than above ground tissue. Yet the roots often survive a burn because they are sufficiently insulated by soil.

Prolific sucker development following a burn is a well-known occurrence, and the greatest density is often reached during the second year following a burn (Peterson and Peterson 1992; Romme *et al.* 1995). Aspen sucker production is stimulated by fire for a number of reasons (Peterson and Peterson 1992). Auxin is a hormone produced in the apical buds, and translocation to the roots constrains sucker production (Converse and Echardt 1988). If a fire kills stems in the clone, auxin production ceases because the apical buds have been killed, resulting in a flush of aspen suckers. In addition, the burned, dark soil surface absorbs more heat, and increased soil temperature stimulates aspen sucker production (Peterson and Peterson 1992). Furthermore, the burn that removed the above ground vegetation increases the light level striking the soil surface, which in turn slightly increases soil temperature. Increased soil temperature stimulates the production of adventitious buds on the lateral root system, leading to the development of aspen suckers the same season (Converse and Echardt 1988; Peterson and Peterson 1992).

Trembling aspen sucker production varies depending upon the degree of heat transfer to the lateral root system (Peterson and Peterson 1992; Quintilio *et al.* 1991). A low intensity fire (<100 kW/m) or medium intensity fire (~200 to 400 kW/m) will stimulate aspen sucker production if all the forest floor humus is not combusted and mineral soil is not exposed. However, a high intensity burn causes more heat to be transferred to the roots, and may result in decreased aspen sucker density as well as height growth.

Regardless of burn intensity, fire is an effective management tool to maintain the dominance of grasses in regions of the Aspen Parkland that experience encroachment of woody plant species (Anderson and Bailey 1980). Burning usually enhances the production of forbs. Furthermore, annual burning enhances the number of sedge, grass, and forb species, and induces a shift from fewer large plants to numerous small plants. Annual burns also decrease aspen sucker vigour and abundance, and prevent litter build-up on grasslands within the parkland, resulting in a more effective seedbed than areas left unburned (Anderson and Bailey 1980; Peterson and Peterson 1992).

Benefits of prescribed burning may vary depending on the time of year the burn is conducted (Converse and Echardt 1988; Peterson and Peterson 1992; Sample and Mossman 1997). Springtime burns have a tendency to suppress cool season grasses, and foster the production of warm season grasses (Sample and Mossman 1997). Yet spring burns may not be as successful as late spring or summer burns in controlling trembling aspen encroachment (Converse and Echardt 1988). Spring burns tend to have higher ground, leaf, and herb moisture levels than summer burns. In addition, trembling aspen root systems have lower carbohydrate reserves during the summer, and therefore would be more prone to fire damage. A single fall burn also increases aspen sucker density, but they have less vigour, as determined by volume growth.

The time of year a burn is conducted is not of great importance if a repeated burning strategy is adopted (Converse and Echardt 1988). Repeated burning, whether applied during the spring, summer, or fall, was found to effectively reduce aspen sucker density, and therefore aspen encroachment into grasslands. Treated sites burned 3 times, with 2 years between each burn, almost eliminated aspen suckers (Converse and Echardt 1988).

2.5.8 Grazing

Grazing historically consisted of bison foraging on the plains and Aspen Parkland. Bison grazing, combined with frequent fire events, were two historical disturbances that shaped the prairie and Aspen Parkland, by inhibiting aspen encroachment onto neighbouring grasslands. From 1830 to 1880, the plains bison population was decimated, declining from numbers in excess of 30 million to just a few thousand individuals (Knapp *et al.* 1999). Recently, fire suppression and limited grazing have resulted in aspen encroachment into grasslands. Today, landowners and managers may use cattle combined with a specific grazing strategy to manage the response of trembling aspen on a land unit. Grazing intensity must be recognized as an important factor for an effective grazing strategy.

A grazing study was conducted during the late 1960's in Alberta's Aspen Parkland to determine the impact of grazing intensity on an aspen stand, as cattle grazing may be a tool to control some woody vegetation (Peterson and Peterson 1992; Sample and Mossman

1997). The three grazing intensities analysed were: ungrazed, low, and heavy (Peterson and Peterson 1992). None of the three grazing intensities made a significant impact on trembling aspen. However, the source does not state the time of year, duration, or animal stocking density used in the study.

Grazing intensity can have an impact on wildlife populations in the Aspen Parkland (Peterson and Peterson 1992). Light grazing was found to be beneficial to ruffed grouse, but heavy grazing was detrimental. Grazing also negatively impacted the snowshoe hare population. This negative impact may be attributed to the lack of appropriate summer cover caused by a reduction in tall herbaceous cover. The lack of suitable summer cover may have also been the most limiting factor for white-footed mice (*Peromyscus leucopus*), which also experienced a population decline. White-throated sparrows (*Zonotrichia albicolis*) sustained a slight decline as grazing intensity increased.

The results of this study were limited to an untreated trembling aspen stand. Furthermore, the source does not state the time of year, duration, or animal stocking density used in the study. Therefore, it appears that cattle grazing may be more appropriate following a prescribed burn.

2.5.9 Burning and Grazing Combined

The invasion of trembling aspen onto neighbouring grasslands is problematic for ranchers because it decreases available forage for cattle (Bailey *et al.* 1990). A study was conducted at the University of Alberta Ranch to determine which grazing strategy, early or late season short duration heavy grazing, was more effective in controlling woody vegetation following a spring burn. Early season grazing took place during early to mid June, and late season grazing in mid August.

The late season short intensive grazing strategy was the most effective grazing period for controlling aspen suckers (Bailey *et al.* 1990; Fitzgerald and Bailey 1984; Peterson and Peterson 1992). Almost all the aspen suckers were eliminated the year following the August grazing (Bailey *et al.* 1990; Fitzgerald and Bailey 1984). However, under the early season grazing strategy, suckers continued to regenerate, and took 7 years to be reduced to 7 percent of the original stem density (Bailey *et al.* 1990). Grazing of aspen suckers in early fall induced the plant to respond by stimulating shoot primordia growth which is too late in the growing season to effectively develop winter hardiness. In addition, defoliation of aspen suckers in the fall prevented them from going into dormancy, rendering them vulnerable to winter kill.

However, the shrub-herb complex was better controlled with the early season grazing strategy as opposed to the late season strategy (Bailey *et al.* 1990). The early season grazing strategy, applied shortly after the burn, resulted in greatly reduced competition of woody suckers with forage seedlings. This permitted the forages to become quickly established, as opposed to forages established with the late season grazing or the control. Conversely, late season grazing nearly eliminated new aspen suckers, resulted in a much greater density of western snowberry (*S. occidentalis*) as opposed to the early grazing, and wild rose (*R. acicularis*) density was greater than the control, and not much less than the early grazing strategy. Both grazing periods resulted in a gradual decline in woody species density, and an increase in smooth brome grass (Bailey *et al.* 1990). Hence, it appears that the time of year a grazing strategy is applied impacts the rate of succession of the plant community, but it is the presence or absence of a heavy, short-term grazing strategy that shapes the final composition of the plant community.

Canada Agriculture has recommended that trembling aspen management should be carried out during the spring, when root carbohydrate reserves are at their lowest (Fitzgerald and Bailey 1984). However, perhaps there should be a paradigm shift as the study shows that aspen sucker management may be most effective during mid to late August. Cattle are an effective tool for controlling woody plant species and enhancing herbaceous forages in the Aspen Parkland. When selecting a grazing strategy, land owners and managers need to establish a set of priorities. If the primary objective is to allow seeded forages to become quickly established and manage woody species, then one should choose the early season, short duration heavy grazing strategy, applying it approximately six weeks following the spring burn. However, if the primary objective is to eliminate regenerating trembling aspen suckers and enhance shrub habitat for wildlife, the late season short duration heavy grazing strategy should be applied during mid to late August, the same year of the burn.

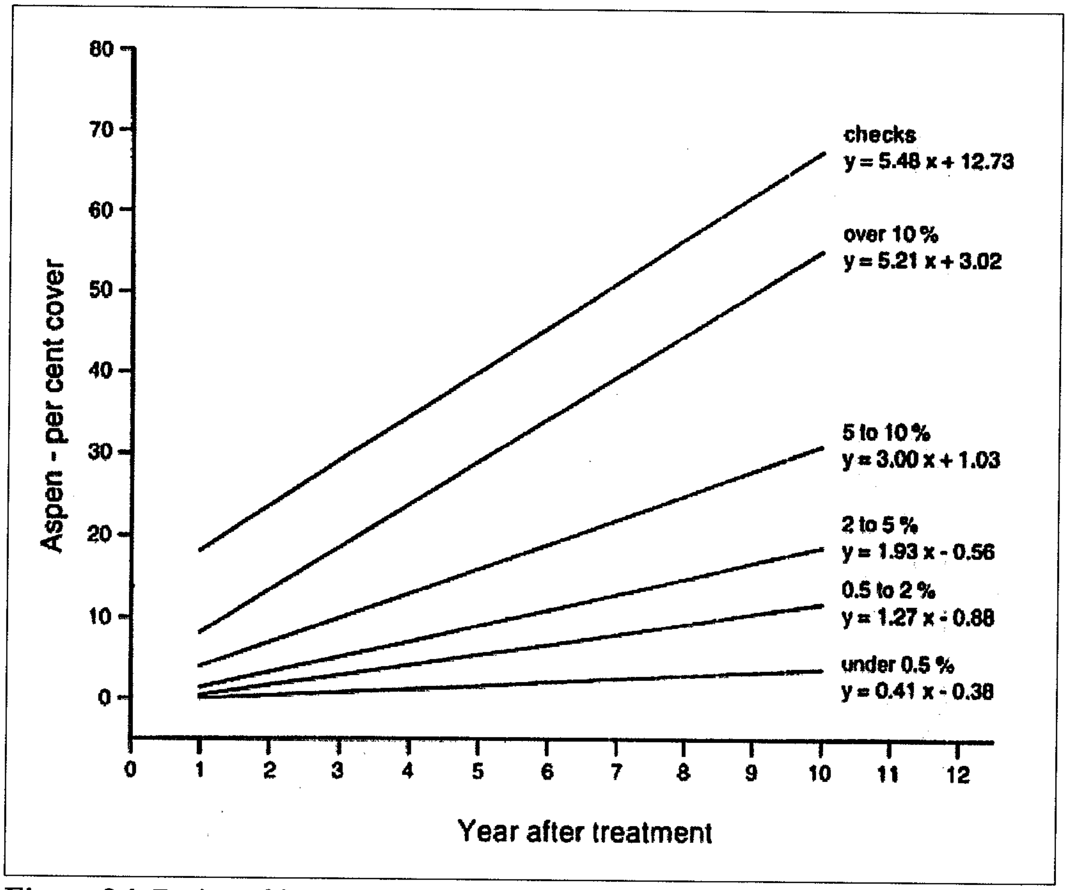


Figure 2.1: Projected increase in percent cover of aspen in pastures at different growth stages (from Bowes 1997a). Labels on the right represent aspen percent cover 1 year after treatment application. Aspen percent cover is then projected up to 10 years. Checks are the untreated control sites.

CHAPTER 3: STUDY SITE DESCRIPTION AND METHODS

3.1 Narcisse WMA Description

3.1.1 Introduction

The first Wildlife Management Area (WMA) in Manitoba was designated in 1961 (State of the Environment Report 1997). WMA's are Crown Lands that are allocated to facilitate the management, conservation, and augmentation of wildlife resources (Sustainable Development 1994). These areas were established to help maintain biological diversity and biological integrity, by protecting critical habitats, preserving the integrity of natural lands, and improving the habitat's ability to support numerous species. WMA's are also used for recreational activities and conducting research, and are also of importance to subsistence hunters, recreational hunters, those who trap, and ecotourists (State of the Environment Report 1997; Sustainable Development 1994).

3.1.2 Location and Size

The Narcisse Wildlife Management Area (NWMA) is located approximately 120 kilometres north of Winnipeg, Manitoba, in the Rural Municipality of Armstrong in Manitoba's Interlake, near the town of Chatfield (50° 47' N, 97° 34' W) (Figures 3.1, 3.2) (Gylywoychuk 1993; Land for Wildlife and People 1998; Land Resource Unit 1999; Sexton and Dixon 1978). The elevation of this region ranges around 274 metres above sea level, which is approximately 26 metres higher than Lake Manitoba to the west, and 57 metres higher than Lake Winnipeg to the east (Pratt *et al.* 1961). The NWMA is 11,882 ha in size and is classified as an Aspen Parkland plant community (Gylywoychuk 1993; Land for Wildlife and People 1998; Sexton and Dixon 1978).

3.1.3 Species Composition

The NWMA is home to a variety of species. Some of the common bird species found in this area include: ruffed grouse (*Bonasa umbellus*), sharp-tailed grouse (*Tympanuchus phasianellus*), red-tailed hawk (*Buteo jamaicensis*), (Appendix A) (Gylywoychuk 1993; Sexton 1979). Other species found include: elk (*Cervus canadensis*), white-tailed deer (*Odocoileus virginianus*), coyote (*Canis latrans*), and snowshoe hare (*Lepus americanus*). The red-sided garter snake is also found in large numbers throughout the region (*Thamnophis sirtalis*) (Gylywoychuk 1993; Sexton 1979).

A list of common plants found in the NWMA is provided by Sexton (1979). In addition, a more recent comprehensive list is found in Appendix B.

3.1.4 Geology and Soils

The Narcisse Wildlife Management Area lies in the historical Lake Agassiz basin (Weir 1983). There are small bedrock outcrops on the landscape, and the glacial flutes or drumlins are oriented in a northwest/southeast direction, generally parallel to the historic glacial ice flow. The topography ranges from generally flat to gently undulating with much of the area containing slopes from zero to two percent, and some areas with 2 to 5 percent slopes where the limestone bedrock nears the surface (Land Resource Unit 1999; Weir 1983). Soil drainage in the region is classified as largely imperfect, indicating that water drainage is slow enough to keep the soil moist for a large part of the growing season (Land

Resource Unit 1999). However, there are some regions where soil drainage is classified as 'well', indicating that water is removed from the soil (but not quickly), to very poor, where soil water is removed at a rate slow enough to maintain the water table at or just above the soil surface for a good part of the spring and summer.

Microtopographic variations in the landscape that impact water drainage characteristics also greatly impact plant communities (Kenkel, pers. comm.). Low areas where the water table is at or just above the soil surface would possess a wetland plant community. Conversely, areas with good drainage would typically have grassland communities, and areas with intermediate drainage might have the water table just below the soil surface, and would have a forest community.

Variations in water drainage and microtopography is also associated with various soil types. Soil materials in the NWMA were deposited during the glacial Lake Agassiz time period (Land Resource Unit 1999). The loamy, glacial till soils are strongly calcareous, very stony, and are derived largely from Paleozoic carbonate rock (Land Resource Unit 1999; Weir 1983). Thin Brunisolic and Dark Gray Chernozemic soils are dominant in sites that are well drained to imperfectly drained, and are also closely associated with Humic Gleysol soils found in poorly drained areas (Land Resource Unit 1999).

3.1.5 Climate

The Narcisse Wildlife Management Area climate can be associated with weather data from Ericksdale, located approximately 40 kilometres northwest of Chatfield, and Fisher Branch, which is just north of Chatfield (Land Resource Unit 1999). The average annual temperature is 1.0°C, and region has a mean frost-free period of 99 days (Land Resource

Unit 1999; Pratt *et al.* 1961). Mean summer temperature for July and August in Fisher Branch range from 20.7 to 23.9°C (Appendix C). Conversely, the mean winter January temperatures drop below -19°C (Pratt *et al.* 1961). Prevailing winds are from the northwest (Gylywoychuk 1993). The mean annual precipitation is 499 mm, with approximately 75 percent of the precipitation being in the form of rain from April to October (Land Resource Unit 1999; Pratt *et al.* 1961). Total precipitation for July and August range from 26 to 64 mm (Appendix C).

3.1.6 NWMA Land Use

Agricultural settlements sprang up around the Chatfield area during the early 1900's, as land was given to veterans following the post World War years (Berger 1989). Fire and clearing of land changed the area from a coniferous and aspen forest to an Aspen Parkland ecotype. In 1963, the Prairie Farm Rehabilitation Administration (PFRA) helped create 5,300 ha of community pasture near Chatfield for cattle grazing. Grazing activity improved sharp-tailed grouse habitat because it maintained grassland habitat (Berger 1989) and increased the heterogeneity of the landscape, by augmenting contrast in the plant community's vertical structure between grazed areas and areas that were not grazed (Hobbs 1996). However, farms surrounding the community pasture were soon abandoned because soils were thin, stony, and had low fertility (Berger 1989). In 1968, the Manitoba government purchased a portion of the community pasture and also private lands for a Wildlife Management Area, which then became the Narcisse Wildlife Management Area (NWMA). During the early 1970's, aspen encroachment decreased grassland availability in the NWMA. This decrease in grassland habitat was a result of the fact that the Aspen

Parkland is a dynamic transition zone, where the natural succession of the plant community progresses to a aspen climax community. Therefore, the abandonment of farms resulting in decreased grazing, combined with impacts of fire suppression, facilitated the degradation of sharp-tailed grouse habitat.

3.1.7 NWMA Recreational Use

The Narcisse Snake Dens are located between Narcisse and Chatfield (Figure 3.2), and are an international attraction, giving visitors the chance to see large numbers of red-sided garter snakes in unusual mating rituals (Gylywoychuk 1993). Additionally, accessible trails permit activities such as hiking, cross-country skiing, and horseback riding. There are also opportunities for hunting, bird watching, and wildlife viewing.

3.2 Study Site

The study site is primarily Aspen Parkland habitat and is located just west of Chatfield in the Narcisse Wildlife Management Area about 120 km north of Winnipeg, Manitoba (Figures 3.1, 3.2) (Gylywoychuk 1993). Agricultural activities in the Interlake such as hay fields and cattle grazing, combined with occasional fires, limited aspen encroachment and kept grasslands open during the early to mid 1900's.

Fires in the NWMA during the 1960's to 1980's helped to maintain some grassland habitat. In 1967, a 400 ha fire burned south of Chatfield (Berger 1989). Two controlled burns occurred in 1972: a 250 ha burn approximately 4 km south of Chatfield, and another burn about 3 km west of Chatfield north of P.R. 419. Fires occurred generally west of Chatfield during 1975, 1976, 1980, 1981, and 1988 (Berger 1989). The 1975 and 1981 burns may have reached my study site. Fire records indicate that over the years, a patchy distribution of approximately 6,000 ha was burned (Berger 1989). However, fire suppression in recent decades, limited grazing activity, and the designation of agricultural lands for a Wildlife Management Area, thus restricting land use activity, have resulted in a substantial degree of aspen encroachment onto grasslands and shrublands. This encroachment can be observed in a series of air photos taken of the study site, spanning a few decades (Figure 3.3). Trembling aspen cover on abandoned sharp-tailed grouse dancing grounds has increased by 81 percent since the 1970's, and aspen encroachment continues at a rate of 1.8 percent annually (Berger and Baydack 1992).

3.3 Methods

3.3.1 Field Methods

During June of 1997, Sharptails Plus, a non-profit Manitoba organization, rolled approximately 93 ha of established aspen woodland in the NWMA that was historically open grassland/shrubland habitat to increase habitat diversity (Figure 3.4) (Caldwell and Haag 2000). A bulldozer was used to pull a 3,600 kg drum roller (Caldwell, pers. comm.). The blade was positioned just above the ground to minimize soil disturbance and still scrape the bark of the aspen trees. The scraped trees were immediately pressed by the roller.

The treated site was inspected during the summer of 1999 (Caldwell and Haag 2000). Rolling appeared to be only effective in killing 3-6 metre aspen, while younger aspen shoots and stems were not greatly impacted (Caldwell, pers. comm.). In addition, there was considerable aspen suckering found throughout the site resulting from the rolling treatment. This signified the need for further aspen treatment.

Upon consultation with Manitoba Conservation, Sharptails Plus Foundation decided to evaluate four follow-up treatment methods: prescribed burning, herbicide, mowing, and bark scraping (Caldwell and Haag 2000). The four treatments were applied during the spring of 2000, and each treatment, including the control, were replicated three times, thus giving a total of 15 treatment plots. All treatment and control sites were situated within the area that was rolled in 1997, and ranged in size from 1.1 to 1.7 ha (Figure 3.5).

Implementation of treatments began by Sharptails Plus selecting a contractor to create fireguards around 3 burn treatment plots on March 14, 2000 (Caldwell and Haag 2000). Manitoba Conservation of Gimli, and the Fire Protection Branch of Hodgson implemented the burn. Burns were conducted on May 10, 2000 between 2 and 5 pm, under a light northerly wind, utilizing the surround burn method (Figure 3.6).

Herbicide, composed of a 20 percent concentration of Roundup © (Glyphosate), was applied to three herbicide plots on June 11, 2000, using a wiper mechanism suspended approximately 20 cm above the ground, and mounted in front of a skidder (Figure 3.7). Monsanto recommends that Glyphosate be applied after leaves have fully emerged (Farm Central 2002b) during the summer to early fall (Farm Central 2002a). The early application was carried out because of contractor time constraints (Caldwell, pers. comm.). Herbicide was sprayed onto the suspended carpet, and only the plants that came into contact with the saturated carpet received the herbicide treatment. All herbicide plots received only one pass. This selective application process resulted in applying herbicide to vegetation greater than 20 cm tall, thereby minimizing impact on the herb layer.

Three plots were mowed by contractor G&G Slashing on May 29-30, 2000, with a heavy duty 2.1 metre flecko-chop mower mounted in front of a 4 wheel drive tractor

(Figure 3.8) (Caldwell and Haag 2000; Roberts, pers. comm.). All mowing treatment plots received only one pass (Caldwell, pers. comm.). G&G Slashing also had a 4.5 metre light duty mower capable of cutting aspen stems up to 2.5 cm in diameter (Wilgenbush, pers. comm.). However, the owner felt that he could make better time with the smaller heavy duty mower as it could cut larger diameter stems and put more torque through the gearbox, allowing him to mow at a higher speed.

On May 30-31, 2000, bark scraping was conducted on standing aspen, utilizing 3 gangs of vertically oriented, road maintainer blades (Caldwell, pers. comm.). Each gang weighed more than 220 kg, and the unit was pulled behind a skidder (Figure 3.9). As the gangs were dragged over the ground, bark on the aspen shoots and woody stems was scraped. Each of the three bark scraping plots received two passes, with each pass being 180° from the first (Caldwell, pers. comm.).

Figures 3.10 and 3.11 show aerial views of the study site taken following treatment application in early September 2000.

The study site was set up in a randomized block design. Each treatment plot, including the control, was situated on the rolling pretreatment area and replicated 3 times (Figure 3.12). GPS locations were recorded at the corner of each treatment plot and at the 4 corners of the sampling grid within each treatment (Appendix D). Each treatment and control plot contained a grid of 24 sampling points (Figure 3.13). All sample plot centres were represented by a 30 cm spike, and each plot centre was 15 metres apart. Therefore, with a sampling grid of 4x6, each treatment plot was sampled over an area of 45 metres by 75 metres. In each treatment site, the sampling grid was set up in the area that best represented the overall site. The numbering sequence of a sampling grid in each treatment plot was maintained from year to year to better evaluate change in the community.

Vegetation and aspen surveys were conducted at each plot centre during the summers of 2000 and 2001 (Appendix E provides a list of plant species found in this study). Unfortunately, there was only sufficient time to conduct the vegetation and aspen surveys on the three fire treatment plots prior to the treatment application in spring 2000. A 1m x 1m quadrat was used to sample vegetation using the Daubenmire cover class method to estimate percent cover of each plant species found within the quadrat. A 2m x 2m quadrat was used to count and measure the height of each aspen stem within the quadrat. The diameter of each woody stem (*i.e.*, greater than 1 yr old) was also measured. Furthermore, the 'health' of each woody stem inside the quadrat was rated utilizing a 5-scale ranked system ranging from 1 (unaffected) to 5 (dead). This provided an estimate of the effectiveness of each treatment in killing the pre-existing woody stems. Health was not enumerated in the mowing sites during 2000 and 2001 because all vegetation was mowed to 12 cm above the soil surface. In addition, health was not enumerated on control sites during the 2000 survey because the sites were not manipulated like the other treatments following the 1997 rolling. However, health was enumerated in the control sites during the 2001 survey to obtain an estimate of natural mortality.

Following the 2000 field season, it was determined that it would be beneficial to sample in the representative unrolled bush. For the 2001 field season, 8 treatment plots were selected adjacent to each of the 3 blocks (Figure 3.12). A sampling site was randomly selected more than 20 m from the bush edge, and each successive sampling site was placed approximately 20 m apart. Sampling in standing bush provided data on aspen stem density and plant species composition if the site had not been rolled in 1997.

3.3.2 Data Analysis and Statistical Methodology

SmartDraw 6 was used to produce the study site layout diagram (Figure 3.12). Corel Quattro Pro was used to produce graphs. Both aspen and vegetation data were entered into Microsoft Excel spreadsheets. Data were analysed in Excel, Data Desk 6.1, and CANOCO. Microsoft Excel was used to organize and manage data, and to determine means, percent cover values, species richness, and effective richness using the Simpson's Index. The Simpson's Index of Diversity (D) stems from probability theory, and gives limited weight to rare species (Krebs 1994). That is, the Simpson's Index is the "probability of picking two organisms at random that are different species", and is expressed as: $D = 1 - \sum(p_i)^2$ (Krebs 1994 pg 705).

CANOCO 3.11 was used to perform Principal Components Analysis (PCA) and Redundancy Analysis (RDA) on the vegetation data. These linear models were selected as the vegetation data was considered to be linear. For example, plant species were not restricted to a limited elevation range on a slope, with no individuals above or below that particular range. Rather, species abundance varied with the inherent microtopic variability of the landscape. Small topographic variations in the landscape were recognized, but calculations were based on the mean frequency of occurrence for each plant species over 24 sampling points within each of the 15 treatment sites.

Mean plant species frequency was the data format chosen for analysis rather than mean percent cover. It is possible for a few plant species individuals to have a relatively high percent cover, and appear to be fairly dominant on the landscape. It is also possible to have plant species that are small, ubiquitous across the landscape, and still have a small percent cover value. This study was more interested in studying the frequency of occurrence across the landscape, rather than percent cover of species. Only vegetation frequency data were used from the 2001 field (Appendix F), as it was more thorough since the author had gained plant identification experience from the previous season. The only exception was comparing pretreatment data collected in spring of 2000, to post-treatment data collected in 2001. On account of differences in plant identification, only plant species identified in both surveys were used in the analysis.

PCA is an ordination method that uses data redundancy to identify shared trends, and should only be applied to linear data, as only linear trends are summarized (Kenkel 2001a). Data points are plotted in an s-dimensional space (Pielou 1984). The first axis measures the strongest trend in the data, thereby maximizing the variance (Kenkel 2001a). The second axis is orthogonal to the first axis, while still accounting for as much of the residual linear variation as possible. Components are found by eigenanalysis of a symmetric pxp covariance matrix. The first eigenvalue represents the primary trend in the data (PCA 1), and the second eigenvalue summarizes the second most dominating trend in the data (PCA 2). The origin is at the centre of the data, and the number of dimensions is not reduced.

Two types of PCA analyses were performed to analyse the vegetation data. One was a standard PCA with no covariables, to look at plant species and treatment block relationships (PCA_1 and PCA_3). The second type of PCA used blocks as covariables (PCA_2), and was a more restrictive analysis as it removes variation attributed to blocks . All

PCA analyses used a squareroot transformation because the data set was frequency data. Microsoft Excel and Data Desk 6.1 were used to create and view biplot results.

Redundancy Analysis (RDA) was also used to look at the correspondence between treatments and vegetation, with variation attributable to blocks removed as covariable. RDA is an asymmetric analysis (Legendre and Legendre 1998). The table of response variables is Y, and X is the table of explanatory variables. That is, the ordination of response variables (Y) is constrained in a way that the resultant ordination vectors are linear combinations of explanatory variables (X). RDA could also be viewed as an extension of PCA, as the canonical ordination vectors are linear combinations of the response variables (Y). However, RDA ordination vectors differ from those in PCA because the ordination vectors computed on the Y table are constrained to be linear combinations of X variables (Legendre and Legendre 1998). The RDA analysis was also squareroot transformed, as frequency data was analysed.

Finally, the common names of plant species to be discussed in subsequent chapters are based on the nomenclature found in the book "Flora of the Great Plains" (Great Plains Flora Association 1986). Each plant's corresponding Latin name can be found in Appendix E.

3.4 Definition of Terms

Shoot, new shoot, or sucker: a shoot originating from below ground (Harris and Harris 1994 p.101).

a sprout produced by the roots of some plants and that gives rise to a new plant (Raven *et al.* 1992 p.759).

Resprout: a stem that has sprouted part way up a dying or damaged woody stem (Figure 3.14).

Native: a species that occurs naturally in an area, and therefore one that has not been introduced by humans either accidentally or intentionally. Of plants found in a particular place, the term is applied to those species that occur naturally in a region and at the site (Allaby 1994 p.264).

Species richness: the number of species found in a community. Differences in abundance are not considered (*i.e.* very rare and very common species are equally "weighted") (Brewer 1994; Kenkel 2001a p.8).

Effective Species Richness: a measure of the degree that species abundances in a community are equal (*i.e.* a handful of plant species that dominate a community will appreciably decrease the effective species richness or evenness) (Kenkel 2001a p.9). In this document, effective species richness is based on Simpson's Index.

Habitat: the specific set of environmental conditions under which an individual, species or community exists. Sometimes restricted to conditions of the physical environment (Brewer 1994 p.755).

the place in which an organism lives, which is characterized by its physical features or by the dominant plant types (Oxford 1996 p.238).

Weed: a plant in the wrong place, being one that occurs opportunistically on land or in water that has been disturbed by human activity (Allaby 1994 pg 408). For the purposes of this study, the following species will be considered weeds: (*Cirsium arvense*) Canada thistle, (*Geranium bicknellii*) Bicknell's geranium, (*Lactuca tatarica*) Blue lettuce, (*Sonchus arvensis*) field-sow-thistle (perennial), (*Sonchus oleraceus*) sow-thistle (annual), (*Taraxacum officinale*) common dandelion, and (*Tragopogon dubius*) goat's-beard.

Figure 3.1: Study site location (After Stanford 1998).

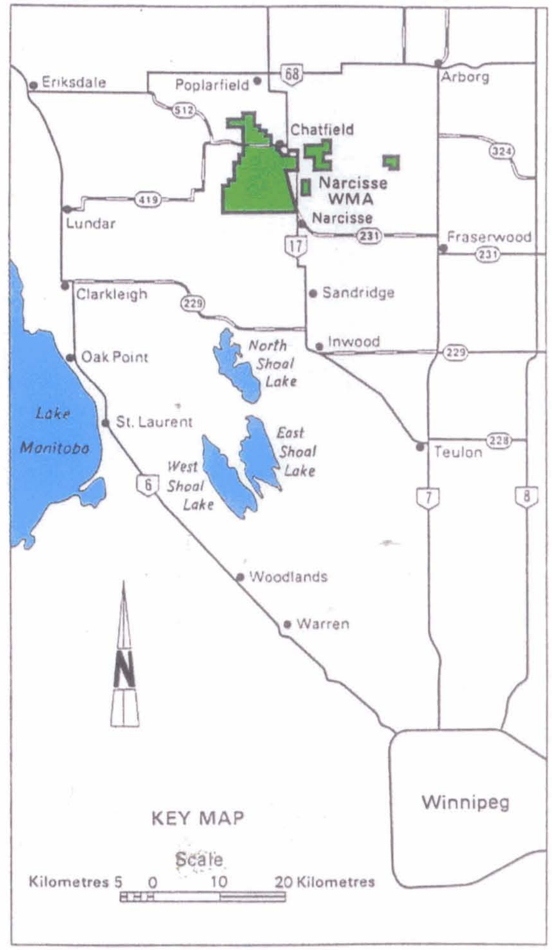
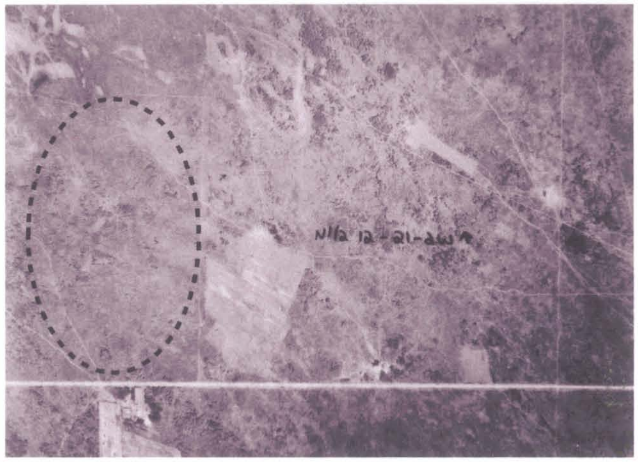
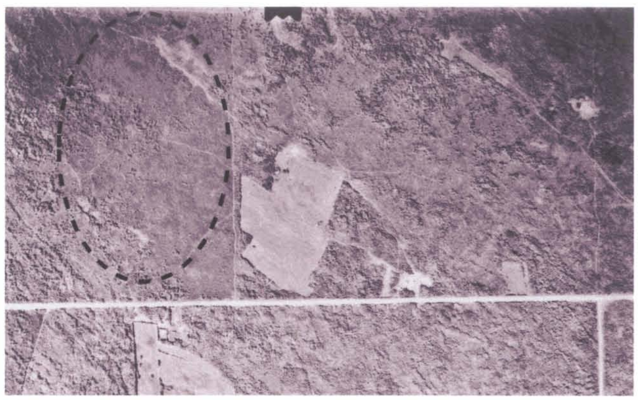


Figure 3.2: Location of the Narcisse Wildlife Management Area (After Gylywoychuk 1993).



1949



1961

1981

Figure 3.3: Series of air photos taken in 1949, 1961, and 1980 showing evidence of forestation in the Narcisse Wildlife Management Area

Figure 3.4: Study site following the June 1997 rolling. The brown portion is the area that was rolled, and the bright green areas are grasslands.

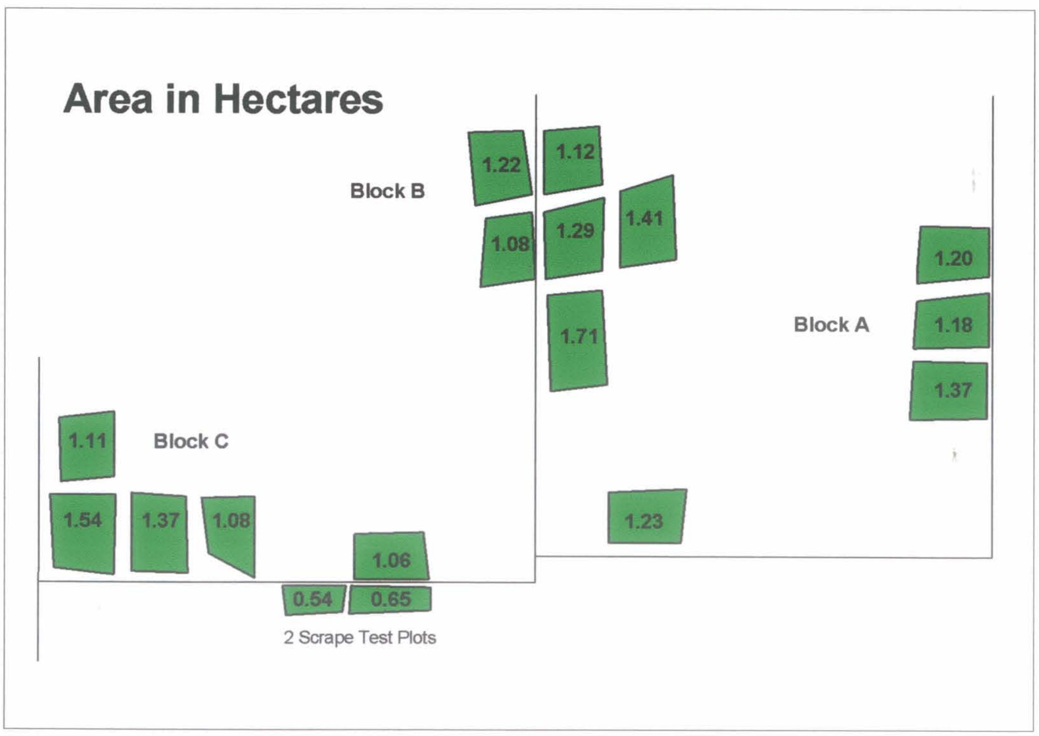


Figure 3.5: Treatment plots with areas measured by GPS.

Figure 3.6: Prescribed burning.

Figure 3.7: Herbicide wiper applying Roundup ©.

Figure 3.8: Mowing with a 2.1 metre wide mower.

Figure 3.9: Bark scraper with 3 gangs of grader blades.

Figure 3.10: An aerial view of the west portion of the study site. The fire plot block C is located just to the right of the trail apex near the centre.

Figure 3.11: This aerial view is just east of the above photo. Block A is to the left, and block B sites are slightly off-centre to the right.

Figure 3.12: Study site layout. Numbers in each corner of the treatment plot indicate the first and last quadrat sampled in each treatment plot.

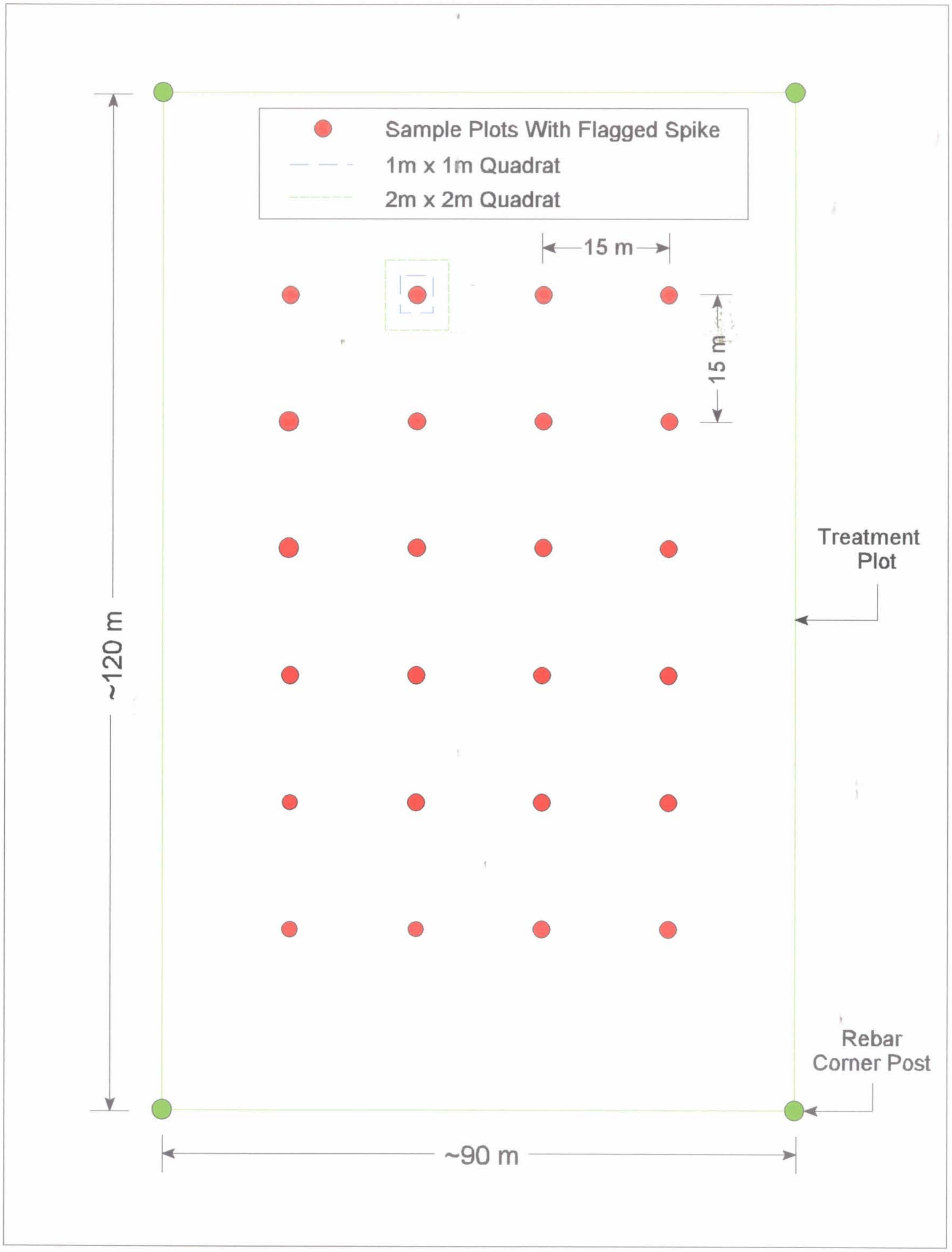


Figure 3.13: Sampling grid used to enumerate aspen and vegetation response to the applied treatments.

Figure 3.14: A resprout growing off a chopped stem in a mowing site.

CHAPTER 4: MANITOBA INTERLAKE HABITAT RESTORATION: REDUCING TREMBLING ASPEN REGENERATION

4.1 Introduction

Under conditions of sufficient moisture, trembling aspen will take over prairie grassland habitat when frequent fires do not occur (Bird 1961). The NWMA has such conditions, possessing a high water table and infrequent fire events, resulting in aspen encroachment at a rate of 1.8 percent annually (Berger and Baydack 1992). The resultant decrease in habitat diversity in the Manitoba Interlake from aspen encroachment onto grasslands and shrublands suggests the need for habitat restoration to protect biological diversity. This chapter addresses the first objective of this study, which involves determining treatment effects on trembling aspen regeneration. The chapter provides results of the treatment impacts on trembling aspen under the two following parameters: live stem density (including shoots, resprouts, and live woody stems), and the health of treated woody stems. Basal stem diameter is assessed in the unrolled bush sites to determine if there is a trend in the age of the clone. Finally, treatment costs are evaluated following the discussion.

4.2 Live Stem Density

By combining the aspen shoot, resprout, and live woody stem data, densities and stem classes were compared among the various treatments. The control treatment had the lowest mean aspen stem density of all the treatments in 2000 (Table 4.1). Mowing had the greatest live stem density, followed by bark scrape, herbicide, and fire. There was no significant ($p<0.05$) difference in stem density among the 5 treatments, or among the 3 blocks (Table 4.2).

In 2001, the unrolled bush, which was not evaluated in 2000, had the lowest live stem density (Table 4.3). Mowing still had the greatest live stem density, followed by herbicide, bark scrape, fire, and control. Since the control was also situated on the site that was rolled in 1997, it appears that all treatments, including rolling, resulted in increased live stem density. Moreover, live stem density varied between sites within the same treatment. For example, live stem density among the 3 mowing sites varied substantially during 2000 and 2001 (Tables 4.4, 4.5). Therefore, no significant ($p<0.05$) difference in live stem density was found in 2001 between all treatments or the 3 blocks, which included the unrolled bush (Table 4.2).

Prescribed burning, herbicide, mowing, and bark scraping all resulted in shoot production during 2000 and 2001 that was much greater than the control (Tables 4.1, 4.3). Fire had the highest shoot density in 2000 and 2001, followed by bark scrape, mowing, and herbicide in 2000, and mowing, bark scrape, and herbicide for 2001. Only the unrolled bush had a lower shoot density than the control. In addition, prescribed burning had the greatest proportion of shoots in 2000 and 2001, followed by bark scrape, mowing, herbicide, control, and unrolled bush (Figures 4.1, 4.2). Therefore, any form of disturbance, including rolling, results in increased shoot production, with fire possessing the greatest shoot density in 2001, and herbicide the lowest of the 4 applied treatments.

Resprout density was lowest in the fire treatment in both 2000 and 2001, even lower than the control and unrolled bush (Tables 4.1, 4.3). This low resprout density was probably reflected in the effectiveness of prescribed burning in killing woody stems. In

2000, mowing had the greatest resprout density, followed by bark scrape, herbicide and control. During 2001, mowing again had the highest resprout density, followed by herbicide, bark scrape, control, and unrolled bush. Moreover, mowing had the greatest proportion of resprouts, followed by herbicide, bark scrape, control, unrolled bush, and finally fire with the lowest percentage of resprouts in both 2000 and 2001 (Figures 4.1, 4.2). Clearly, mowing does not kill preexisting woody stems, but simply alters their structure, resulting in greater resprout production and overall live stem density as compared to any other treatment.

Since mowing simply lowered the vertical structure of preexisting woody stems, live woody stem density in the mowing treatment will not be compared to other treatments. The control had the greatest live woody stem density during 2000 and 2001 (Tables 4.1,. 4.3). The unrolled bush had a slightly lower live woody stem density than the control in 2001. Fire had the lowest live woody stem density of all the treatments in 2000 and 2001, followed by bark scrape and herbicide. Similarly, fire had the lowest percentage of live woody stems, followed by bark scrape, herbicide, and control in 2000, and bark scrape, herbicide, control, and finally unrolled bush in 2001 (Figures 4.1, 4.2). Therefore, prescribed burning was the most effective treatment in reducing live woody stems/ha, followed by bark scrape at a much lower percentage. Conversely, herbicide was the least effective treatment in reducing live woody stem density.

Pretreatment and 2 post-treatment surveys were conducted to monitor changes in aspen live stem density. Only the 3 fire sites received pretreatment surveys (Table 4.6). The number of live stems/ha in the fire treatment increased appreciably from before the treatment to about 3 months after the treatment. Overall live stems/ha decreased from

2000 to 2001 in all the treatments. The change in overall live stem density in the unrolled bush from 2000 to 2001 is not known, as the bush was not surveyed in 2000.

Interestingly, shoot density increased from 2000 to 2001 on some treatments, while others decreased (Tables 4.1, 4.3). Shoot density increased dramatically in both the control and herbicide treatments, which perhaps was a response to an appreciable dieback in live woody stems over the winter. Hence, there appeared to be a delayed response in the herbicide killing the woody stems. Conversely, the burn and bark scrape treatments experienced a decrease in shoot density (Tables 4.1, 4.3). A decrease in shoot density was accompanied by a relatively stable resprout density, and a decrease in live woody stem density from a preexisting low density. The decline in shoot density in the bark scrape treatment also had a decrease in resprout and live woody stem density. This response differs from that of the herbicide treatment, where a decrease in live woody stem density was met with an appreciable increase in shoot density.

At the individual block level, stem density in fire blocks A, B, and C increased from the pretreatment to the 2000 post-treatment (Table 4.7). In 2001, stem density decreased for blocks B and C from the 2000 densities, while block A increased (Table 4.7). However, block B was the only treatment that came within 39 percent of its pretreatment density. This may be attributed to block B having the greatest burn intensity of the 3 blocks. When the burns were conducted, block C appeared to have a cooler burn than blocks A and B, as it was burned earlier in the day and may have had a greater moisture content in the vegetation (Caldwell, pers. comm.). Block B may have had the highest burn intensity resulting from a higher percentage of shrub cover (which will be shown in Chapter 5), and this shrub cover would provide more fuel, resulting in a greater intensity burn. As well, more weeds were found in fire block B than any other treatment (although still not a great amount), suggesting that more mineral soil was exposed because of the high burn intensity, thus increasing the opportunity for weeds to establish. This high burn intensity would also cause greater damage to the aspen root system in the shallow Interlake soil. Therefore, perhaps a portion of the root system died over the winter, resulting in a delayed response which contributed to a decrease in shoot density observed in fire block B during 2001.

This greater degree of heat transfer to the root system may be the primary factor attributing to the varying number of shoots/ha in each height class for the three blocks in 2000 (Figures 4.3 - 4.5) and 2001 (Figures 4.6 - 4.8). Notice particularly the 10 - 20 and 20 - 30 cm height classes in 2000, and the 20 - 30 and 30 - 50 cm height classes in 2001. The shoot density was much lower in blocks A and B than in block C. In addition, note the shape of the shoot distribution curve in 2001 (Figures 4.6 - 4.8). The distribution curve resembles a rain drop sliced in half vertically, and layed horizontally, with the aspen stems in taller height classes gradually decreasing in number (Figures 4.6, 4.7). This contrasts with block C in 2001, which has a prominent bell-shaped curve, lacking any shoots in the 110 - 130 and 130 - 150 cm height classes (Figure 4.8). This may be attributed to increased competition for resources because of the high stem density, thereby limiting the height that shoots could attain.

4.3 Health of Treated Woody Stems

Treatment impact on preexisting woody stems was evaluated on the fire, herbicide, and bark scrape treatments in 2000, and on all the treatments in 2001 (Table 4.8). A significant difference in treatment impact on health of woody stems was found between the fire, herbicide and scrape treatments in 2000, and fire, herbicide, scrape, control, and the unrolled bush in 2001 (Table 4.9). No significant blocking effect in woody stem health was found in 2000 or 2001. Prescribed burning had the greatest impact on woody stem health in both 2000 and 2001, followed by bark scrape, herbicide, control, and unrolled bush (Table 4.8). Bark scrape did not appear to have a much greater impact on woody stem health as compared to the herbicide treatment. Treatment impact on woody stem health increased from 2000 to 2001 for both bark scrape and herbicide, suggesting that the full impact of the treatments were delayed until the following year.

Recording preexisting woody stem health also allowed one to determine which treatment had the greatest percentage of dead woody stems. There was a significant ($p<0.05$) difference in stem mortality between the fire, herbicide and scrape treatments in 2000, and the control, unrolled bush, fire, herbicide, and scrape treatments in 2001 (Tables 4.10, 4.11). There was no significant blocking effect in stem mortality in 2000 or 2001 (Table 4.10). All treatments had greater woody stem mortality than the control and unrolled bush, both of the latter possessing less than 20 percent mortality (Table 4.11). Bark scrape had greater woody stem mortality than herbicide in 2000 and in 2001 (Table 4.11). Both treatments realized an increase in stem mortality from 2000 to 2001, suggesting again that there was a delay in treatment impact. Prescribed burning resulted in the greatest woody stem mortality in both 2000 and 2001, with a low of 93% mortality in 2000, and a high of 100% mortality in 2001, approximately double the mortality found in the herbicide and scrape treatments (Table 4.11). Therefore, prescribed burning was the most effective treatment in killing preexisting woody stems.

4.4 Unrolled Bush Basal Stem Diameter

Basal stem diameter measurements were recorded for the unrolled bush sites, and block A was found to have the lowest mean diameter, the lowest maximum, and the smallest range (Table 4.12; Figure 4.9). Sites in block B had an intermediate basal diameter range, while block C had the greatest range and maximum basal stem diameter. No significance ($p<0.05$) in basal diameter was found between the 3 blocks (Table 4.13). In addition, not only did block A have the lowest diameter range and maximum, it also had the shortest canopy height of the 3 blocks (Appendix G, Figures G-1, G-2, G-3). Therefore, the aspen stand in block A may be the youngest of the 3 sites, and sites in block C may be the most mature.

4.5 Discussion

The response of trembling aspen to disturbance (treatment) appears to vary depending on the type and degree of disturbance. The following sections discuss how the response of trembling aspen to treatments applied in my study compared to each other, studies in the literature, and will close with a summary.

4.5.1 Control

While evaluating the response of trembling aspen, one must be cognisant of the fact that the control was also"treated". All three control plots were established in an area that was rolled in June 1997, and the majority of woody stems being evaluated presently were shoots that came up following the rolling treatment, or younger stems that survived the treatment. Aspen suckers are very dependent on the clonal root system for the first few years. After a flush of shoots have been produced, aspen undergoes a natural self-thinning process caused by competition for resources, resulting in a decreasing stem density over time (Peterson and Peterson 1992). Stem density does not influence mean sucker height during the first five years, but it does result in lower survival rates as stem density increases. Sucker development occurring early in the season experience greater growth than suckers emerging later in the season. Less vigorous aspen suckers die from competition, leaving the dominant suckers. Therefore, the drop in live woody stem density may not be attributed to outside agents, but the natural thinning effect resulting from the rolling treatment of June 1997.

The overall live stem density in the control sites decreased from 2000 to 2001, and was compensated by varying degrees of shoot production. Two factors that could have contributed to the woody stem dieback are insects and disease. Such a dieback would lead to significant root sucker production (Converse and Echardt 1988). In addition, the difference in shoot production across the 3 control blocks may be in part a result of interclonal differences. The ability to send up suckers, growth rate, and ramet density (genetically identical stems), varies from one aspen clone to another. Differences in quantity of carbohydrate reserves in the root system as well as the age of the clone can also impact shoot production (Alexander 1995). It appears that a limited dieback in live woody stems in 2001 may have resulted in a flush of shoots and resprouts. Apparently, even the death of a small number of aspen stems impact the entire clone (Grant and Kayne 1993). The live woody stem dieback was appreciably greater in blocks A and B than in block C. In turn, aspen regeneration in the form of shoots and resprouts was more than doubled in blocks A and B than block C. Therefore, it appears that aspen regeneration was roughly in proportion to the decrease in woody stem density.

Mean shoot density found in my study was only approximately 1,000 stems/ha during 2000, and up to 8,000 stems/ha for 2001. These shoot densities were substantially lower than the mean unburned control shoot density found in a Yellowstone study, where the density was 18,000 shoots/ha. (Romme *et al.* 1995). However, one must be cognisant of the fact that the Yellowstone habitat is different from that of the Manitoba Interlake, resulting in a different degree of regeneration response.

Even though the control had greater live stem density compared to the unrolled bush, field observations suggest that rolling did reduce live aspen biomass and vertical height, thereby increasing the ease of future aspen management.

4.5.2 Fire

It has been well documented that prescribed burning results in a flush of aspen shoot production (Alexander 1995; Bailey *et al.* 1990; Bowes and Kirychuk 1996; Converse and Echardt 1988; Fitzgerald and Bailey 1984; Horton and Hopkins 1965; Peterson and Peterson 1992; Quintilio *et al.* 1991; Romme *et al.* 1995). There are two reasons why burning stimulates aspen suckering (Peterson and Peterson 1992). Firstly, the hormone auxin is produced in the apical buds, and is translocated to the roots, which inhibits aspen suckering (Converse and Echardt 1988). When the overstory is removed or killed, auxin is no longer produced and sent to the root system, resulting in the production of aspen suckers from the shallow roots. Secondly, an increase in soil temperature stimulates sucker production (Converse and Echardt 1988; Peterson and Peterson 1992). Heat from a fire increases soil temperature surrounding the roots, and the dark, black soil which follows the burn results in greater heat absorption, thereby stimulating sucker production. As well, removal of competing vegetation increases the amount of ground surface exposed to open sunlight, thus stimulating the development of shade intolerant aspen shoots.

Following the prescribed burn, shoot density on the study site increased to 24,896 - 77,083 shoots/ha. Other study sites observed similar densities. Following the Yellowstone fire, sprout densities ranged from 7,000 - 125,000 shoots/ha (Romme *et al.* 1995). Other findings include 9,000 - 58,000 shoots/ha in Idaho and western Wyoming, 2,000 - 38,000 in New Mexico, and 27,000 - 36,000 shoots/ha near Jackson, Wyoming (Bartos and Mueggler 1981; Romme *et al.* 1995).

The fire treatment in blocks B and C reached their highest shoot density during the first year (*i.e.* the summer following the treatment), while the shoot density in block A was greatest during the second year. Burns conducted during the first half of the growing season usually results in a burst of sucker production later that same season, followed by another flush the next year (Peterson and Peterson 1992). Therefore, the majority of suckers appear within the first 2 years after a burn. A study conducted by Brown and DeByle recorded the highest sprout density 1 - 2 years after the burn (Romme *et al.* 1995). Another study by Jones and Trujillo reported that maximum shoot density was usually observed the year after the burn (Romme *et al.* 1995). Hence, the shoot densities obtained during the first 2 seasons after the burn do correspond with that of other studies.

This study found a large difference in shoot density between 3 treatment plots ranging from 24,500 - 75,000 shoots/ha, and this large difference suggests that there may be other processes, such as different fire intensities impacting this wide range in shoot density.

Recent studies suggest that low to medium intensity fires result in a high degree of aspen suckering, while high intensity burns have a lower degree of aspen suckering (Horton and Hopkins 1965; Peterson and Peterson 1992; Quintilio *et al.* 1991). Two studies, one in eastern Canada, and the other in northwestern Wyoming, showed that after the first year, a medium intensity burn had a higher shoot density than a low intensity burn, and a high intensity burn had a lower shoot density than the low intensity burn (Bartos and Mueggler 1981; Horton and Hopkins 1965). It appears that blocks A and B may have had higher intensity burns, as the shoot density on these blocks each increased approximately 53%, while block C appeared to have had a lower intensity burn and a shoot density that increased by about 124%.

Burns conducted in the eastern Canadian study all had higher stem densities than the control (Horton and Hopkins 1965). The results from my study and the eastern Canadian study contrast with the Wyoming study. One year following the burn, both the intense and light burns had lower stem densities than the pretreatment areas (Bartos and Mueggler 1981). Perhaps soil thickness was a factor in the Wyoming study, as thicker soils contain the aspen lateral root system at greater depths, and thereby experience greater protection from heat transfer. By the second year, shoot densities in the intense burn had risen above that of the light intensity burn, but still below the medium intensity burn, thus having similar results to the eastern Canadian study. The shoot density results of this project, the eastern Canadian site, and the Wyoming study contrast with yet another study done by Brown and DeByle (Peterson and Peterson 1992). They found that shoot density was greatest in fires of moderate to high intensity. Perhaps soil depth was greater, limiting the heat transfer to the root system. The higher burn intensities would not have damaged the root system, but merely intensified sucker production.

At the NWMA, it appeared that the burn in block C did not burn as hot as the burns in blocks A and B (Caldwell, pers. comm.). Block C was burned earlier in the day than blocks A and B, and it is suggested that the vegetation in blocks A and B had more drying time, as the wind picked up somewhat during the afternoon, drying off the vegetation more thoroughly from the previous day's rain. The drier vegetation permitted hotter burns, resulting in a more effective kill of woody stems, caused by a greater degree of heat transfer to the shallow root system (Quintilio *et al.* 1991).

The differences in burn temperature also appeared to be reflected in the overall percentage of dead woody stems in 2000 (Table 4.6). Block C had the lowest percentage of dead woody stems compared to blocks A and B. The more effective kill may also be reflected in the number of resprouts found on the three blocks, but the difference may not be significant. A woody stem killed by the burn will not produce a resprout. However, a woody stem that has been damaged by the fire may likely produce a resprout(s). In 2000, the same year the fire occurred, no resprouts were found on block A, while only a few were found in blocks B and C. However, in 2001, no resprouts found in block B, and block A had a few more resprouts than even block C. This may be attributed to a lack of significance, as the actual number of resprouts found on each block was very small (six or less), or it could be on account of a delay, as the stems may have been killed during the winter. Quintilio *et al.* (1991) claims that aspen stems are easily killed by fire. Therefore, perhaps shoot density better reflects the temperature difference of the burns, as more heat would be transferred to the root system in a hot burn.

As stated above, aspen stems are easily killed by fire (Quintilio *et al.* 1991). In my study, woody stem health in the fire treatment was nearly dead, while the herbicide and bark scrape treatments were not as effective in killing woody stems. This effectiveness also carries over to the percentage of dead woody stems found in the various treatments. In 2000, more than 93% of woody stems in burned plots were killed, and more than 98% for 2001. No other treatment was as effective in killing woody stems as prescribed burning. Agriculture Canada reported a mean of only 79, 80, and 77% of woody stems killed by fire and grazing combined for 1993, 1994, and 1995 respectively (Bowes 1995; Bowes and Kirychuk 1996). The study site was near Calder, Saskatchewan, and perhaps the site had deeper soils than in the Manitoba Interlake. Deeper soils would allow the aspen lateral roots to penetrate the soil at a lower depth, thereby being more insulated from the effects of fire. Aspen root tissue is more sensitive to mortality from heat than above-ground tissue (Peterson and Peterson 1992). Therefore, aspen roots tend to be insulated in deeper soils, thus allowing them to survive burns. In addition, the burn at Calder was conducted on April 20, or 20 days earlier in the year than this study. Perhaps waiting a few weeks to allow further leaf maturity results in a more effective kill.

4.5.3 Herbicide Wiper

Glyphosate was applied in a 20% concentration with a wiper, which resulted in a flush of aspen suckers from the root system in both 2000 and 2001. This was expected, as essentially any form of disturbance that the aspen clone experiences results in aggressive root suckering (Fitzgerald and Bailey 1984). Furthermore, it appeared that a greater aspen canopy kill resulted in a more prolific shoot production (Bowes 1995). The resultant shoot density was lower than the densities observed in the mowing, burning, and scraping treatments, in both 2000 and 2001. Even though the overall shoot density increased in 2001, mean shoot density was still lower than fire, mowing, and bark scrape treatments, but greater than the control and unrolled bush. All individual herbicide blocks in 2001 experienced more than an 86 percent increase in shoot density. However, block A had the largest increase of 142%. This may be related to the aspen clone being younger in block A than the other 2 blocks. One hypothesis is that a fire which escaped a nearby garbage dump in 1990 possibly reached into the eastern portion of the study site, which was the location of this treatment plot (Roberts, pers. comm.). Or, an alternative hypothesis may be that aspen encroachment occurred from the west to the east over the past few decades, resulting in a younger aspen stand in the eastern part of the study site than the west. A younger aspen stand has greater root mass and total soluble carbohydrates than an older aspen stand (Alexander 1995). Aspen roots with greater mass and total soluble carbohydrates have a higher density of shoots/root than roots with a smaller percentage of total soluble carbohydrates and mass. Hence, the evidence suggests that the aspen clone in block A may be younger than the clones in blocks B and C, resulting in more prolific regeneration from the root system.

The application of herbicide with a wiper is a relatively new application technique, and little published literature addressing its success regarding sucker production was found. Agriculture Canada used a herbicide wiper in 2 projects, but assessing aspen sucker density following treatment application was not part of the study objectives (Bowes 1997a; Bowes 1997b; Bowes and Kirychuk 1996).

The overall resprout density increased 6.94% from 2000 to 2001 (Tables 4.19, 4.20). However, the individual blocks reveal a very different picture. Blocks B and C had a lower resprout density than block A by about 75 and 32% respectively, while block A increased by an amazing 1,711% (Table 4.4). Again, just as block A had the largest increase in shoot density from 2000 to 2001, it also had the largest increase in resprout density, possibly attributed to greater root mass and total soluble carbohydrate reserve. In addition, the resprout and shoot response may reflect the effectiveness of the herbicide treatment in killing the woody stems.

One field observation was that if an aspen stem(s) was situated on the far side of a bush, by the time the wiper passed over the bush and reached the aspen, the tree(s) were not killed because the carpet in the wiper was no longer saturated with solution. Perhaps a higher application rate would alleviate that problem.

I found different results with the herbicide treatment as compared to other studies. An aspen control study conducted by Agriculture Canada on a poor site (*i.e.* poor growing conditions for aspen, ranging from 1.7 - 2.2 m tall) apparently had good results killing suckers up to 4 years old using Glyphosate at 20%, applied with a wiper on June 15 (my study was on June 11) (Bowes and Kirychuk 1996). It was noted that the herbicide was actually applied too early in my study, as some leaves were just beginning to flush, thereby decreasing the amount of herbicide translocated to the root system (Caldwell, pers. comm.). In addition, my study site also had taller stems that survived the rolling in 1997, and many were likely more than 4 years old. The Agriculture Canada study concluded that the herbicide treatment was more effective on suckers younger than 4 years. Herbicide treatment was effective on 1 year old shoots, but was most effective on 2 year old shoots

(Bowes and Kirychuk 1996; Peterson and Peterson 1992). Therefore, perhaps the reason my study did not have results that were as strong as Agriculture Canada's results was because not as much herbicide was translocated to the root system resulting in a lower percentage of dead woody stems, and that my study treated older aspen stems, which may not be as greatly impacted by Glyphosate as 2 year old stems.

Other studies have employed different application dates. Manitoba Conservation applied Glyphosate with a wiper on July 05, 2000, around a sharp-tail grouse lek site in the NWMA, south of the study site (Roberts, pers. comm.). Visual observation of this site in September 2000 and 2001 indicated that they had an effective canopy kill in 2000 and 2001 (nearly 100%) (Roberts, pers. comm.), and had very little aspen suckering compared to my study site. This was accomplished with a single pass, using only a 12% Glyphosate solution. Perhaps the later application date resulted in better translocation to the root system, resulting in a more complete kill.

Another study was conducted in the Manitoba Model Forest, using a brush saw to cut the stems and then applying Glyphosate to the stumps, as well as a ground application of Glyphosate (Philippot 1996). Although herbicide treatments are traditionally applied in June, both treatments were carried out in August, which is the time commonly used by Pine Falls Paper Company. The brush saw treatment was normally carried out in mid August, and late August for the ground application. Admittedly, these are different herbicide treatment methods than those used in my study, as well as different habitat conditions. However, the point of interest here is the timing of herbicide application. The brush saw treatment combined with herbicide saw a 73% decrease in stem density in one site, and an 81% decrease in another, both occurring in the following year. The ground application treatment resulted in a 97% and 98% decrease in stem density the following year. Their study actually reduced aspen stem density for two years following application, whereas my study increased stem density two years following treatment. Therefore, even though these were different methods from the wiper used in my study, the late application date in August appeared to be very effective in controlling aspen, with no visual signs of regrowth

4.5.4 Mowing

The 3 individual mowing treatment plots show varying degrees of aspen regeneration (Tables 4.3, 4.4). Block A had the highest shoot density, block B was intermediate, and block C the lowest shoot density among the mowing treatments for both 2000 and 2001. The increase in shoot production (by percent) from 2000 to 2001 among the three blocks was very similar to that of the herbicide treatment. It appears that shoot density decreased as one moved across the study site from east to west. Figure 4.12 shows that the age of the aspen clone appears to increase from the east to west across the study site. Perhaps younger aspen clones can regenerate more intensely, and the capability for strong regeneration may be related to the clone being younger in this part of the study site, as the air photos in figure 3.3 appear to show that aspen encroachment may have occurred from west to east, or that the 1990 fire that may have gone through the eastern part of the study site.

In addition, the number of live stems/ha in block A was approximately double than that of blocks B and C, in both 2000 and 2001. Live stem densities in blocks B and C were similar to that of the herbicide and scrape treatments. The very strong aspen regeneration response in block A may be attributed to greater total soluble carbohydrate reserves in the root system than the other two blocks.

Focussing on resprouts among the individual blocks shows a similar trend as shoots, decreasing from east to west, but with one exception. Block A had the greatest resprout density in 2000 and 2001, but block B had a lower resprout density than block A and even block C, for both 2000 and 2001. Perhaps resprout density was more limited by soil moisture availability, with block B being the driest of the three sites (this will be shown in chapter 5).

The increase in aspen regeneration experienced for 2 consecutive years in my study site was comparable to 2 studies conducted in the Calder-Togo Community Pasture in Saskatchewan (Bowes 1995; Bowes and Kirychuk 1996). Since the plot sizes of these 2 studies were only 10m - 30m, and only 10 sampling points were used in each treatment plot measuring a 0.2 m^2 area, I feel it would be inaccurate to attempt to extrapolate their density results to shoots/ha, and compare it to my study because of such a small sample size. It was also interesting to note that the 2 studies obtained a 100% and 95% aspen canopy kill for the mowing treatment. It is difficult to understand how a percent canopy kill measurement could be applied in a mowing treatment. The author of the study did mention that the tractor tires did roll over some small aspen, causing them not to be reached by the mower (this problem was not encountered in my study, as the mower unit was mounted in the front of the skidder) (Bowes 1995; Bowes and Kirychuk 1996). However, chopped aspen stems frequently respond by producing resprouts (as many as 9) on that same stem, and begin to take over that stem 1.5 years following treatment (Figure

4.9). Hence, I suggest that the chopped aspen stems were not really killed, but only temporarily altered structurally, and consequently delayed in their growth.

Therefore, the effectiveness of mowing trembling aspen appears to be questionable at best, as it seems to result in increased shoot production for 2 years and merely delays growth of chopped stems. Mowing reduces the height of the aspen canopy, but increases density for 2 consecutive years.

4.5.5 Bark Scrape

In this study, live stem density in 2001 was considerably less than the mowing treatment, somewhat less than the herbicide treatment, but still greater than the fire, control and unrolled bush. Another study found that bark scraping did reduce aspen canopy percent cover, but they were not satisfied with the degree of reduction (Bowes and Kirychuk 1996). It also noted that the number of new shoots produced from a June or July scrape were sufficient to maintain or even increase the overall aspen stem density. Therefore, it is possible that a single treatment application at the end of May is not effective in reducing aspen stem density.

Results from a study in Saskatchewan noted that a June scrape also had an appreciable degree of resprout production in both the same year and year following treatment (Bowes 1995). He also found that the time of year a scrape is conducted impacts shoot production and the effectiveness of the treatment. Scrapes conducted in early summer (*i.e.* mid June) result in a higher degree of shoot production than late October. However, the effectiveness of the scrape in killing the aspen stems also decreases from early June to late October.

Aspen height also impacts the effectiveness of the bark scrape (Bowes and Kirychuk 1996). They noted that scraping was more effective on small aspen (3.2 to 3.7 metres tall) than juvenile aspen (1.1 to 1.7 metres tall). Most of the trees in my study would have been considered juvenile aspen. Therefore, the difference in live woody stems densities from the three blocks could not be explained by greater stem height.

The effectiveness of single versus multiple passes with the scraper in killing aspen has been addressed in literature (Bowes and Kirychuk 1996). My study site had 2 passes at 180° from each other applied on the same day. Bowes (1996) suggested that a single pass with the bark scraper one year followed by another pass over the same plot a year later was more effective in decreasing percent cover than a single, one-time pass. However, the author of the study did state that aspen regeneration following either treatment method resulted in significant shoot production, enough to at least replace itself or increase in stem density (Bowes and Kirychuk 1996). Similar results were also found in my study. Although pretreatment surveys were not conducted on the scrape plots in my study, compared to the control, the scrape treatment resulted in an increase in aspen stem density. Therefore, bark scraping did not decrease aspen stem density in this particular study in the Interlake.

4.5.6 Unrolled Bush

Unrolled bush (*i.e.* aspen woodland habitat that was similar to what was rolled in 1997) was sampled in 2001 to obtain an estimate as to what the stem density and plant community was prior to the 1997 treatment. Data obtained from these sites indicate what the aspen stem density and plant community diversity was like prior to the 1997 rolling. These data would help determine if the aspen management techniques employed are effectively removing trembling aspen from the landscape, and increasing biological diversity in the plant community (biological diversity will be addressed in chapter 5).

According to the fire record for the NWMA provided by Berger (1989), the unrolled bush, which was similar to what was rolled in 1997, was approximately 20 to 26 years old at the time of the 2001 sampling. Aspen trees in upland forests that would have escaped fire, would have been 50 to 60 years old in 2001 (Rusch *et al.* 1978).

Although neither live aspen biomass nor stem heights were recorded in the woodlands, field observations showed that the greatest biomass and stem heights were in the unrolled bush. However, this habitat type with a greater aspen biomass also has a lower stem density.

Shoot and resprout density was much less than the control or any other treatment, except for resprout density in the fire treatment. At the individual block level, only block A had a much greater shoot density than blocks B and C. This was probably attributed to the unrolled bush in block A being a younger site than the bush in blocks B or C. There is a positive correlation between the age, diameter, and height of an aspen stem (Peterson and Peterson 1992). Aspen in block A appeared to be a younger stand because they had the lowest mean, maximum, and range in basal diameter of the 3 blocks. In addition, shoot density decreases as the aspen stand matures (Peterson and Peterson 1992). Shoot density was clearly the greatest in block A. Moreover, there was evidence that a burn occurred previously in block A. The burn was confirmed by Manitoba Conservation, stating that a burn escaped the dump nearby, possibly burning into the east end of the research site (Roberts, pers. comm.). While block A had the lowest mean and maximum basal diameter, block C had the greatest range and maximum basal diameter, including block B. The larger diameter stems found in the western portion of the study site suggest that the trembling aspen stands get progressively older as one moves from the east portion of the study site to the west.

4.6 Treatment Costs

The estimated treatment costs obtained were based on 2002 pricing. Variability in treatment cost exists with each treatment. Factors impacting the treatment costs will be described for each applicable treatment. Estimates do not include taxes or transportation costs where applicable. Treatment cost description is broken down into the following categories: prescribed burning, herbicide wiper, mowing, bark scraping, and rolling. A table summarizing treatment cost is provided (Table 4.14).

4.6.1 Fire

The burn estimate is based on a minimum of 8 hours to conduct a 100 acre burn (Roberts, pers. comm.). This includes: fireguard burning, the primary burn, and fully extinguishing the fire. Two fire fighting crews with a total minimum of 10 trained personnel would be $150.00/hr. Fire equipment, such as a tank wagon, pumps, hoses, backpacks, flappers, and shovels, would be $50.00/hr. This brings the total hourly rate to $200.00/hr. Therefore, a 100 acre burn would cost approximately $1600.00, breaking down to approximately $16.00/acre.

4.6.2 Herbicide Wiper

Two estimates are provided, one with a skidder, and one without. The first estimate includes all equipment, including the skidder. The equipment unit with the skidder was the same arrangement used in this study. The estimate is based on applying herbicide with a wiper to 100 acres. Application rate could be faster than 6 acres/hr, depending on bush density (Roberts, pers. comm.). However, 6 acres/hr was chosen to keep the estimate more realistic. The second estimate is based on the landowner using his own tractor, and a herbicide wiper from Prairie Farm Rehabilitation Administration (PFRA) (Moss, pers. comm.). The cost includes herbicide at 33% concentration, equipment, and labour, but not equipment depreciation. This second estimate may be a more economic choice for many landowners.

1.	Skidder rental (a Clark 664D with 100 hp)	$70.00/hr
	Herbicide wiper	$10.00/hr
	Estimated equipment cost/acre at 6 acres / hr	$13.33/acre
	Approximate herbicide cost/acre	
	Glyphosate at 2 litres/acre, $10.00/litre	$20.00/acre
	Total cost/acre	$33.33/acre
	Total cost for 100 acres	$3,333.33
2)	Cost/acre	$15.00/acre
	Cost for 100 acres	$1500.00

4.6.3 Mowing

G & G Slashing 2001, the contractor that mowed the plots in this study, has two mowers; a 2 m heavy duty mower, and a 4.5 m light duty mower (Wilgenbush, pers. comm.). The 2 m mower is mounted in front of the skidder, and can take on dense bush. The light duty mower is pulled behind the tractor unit, and can only take aspen stems 2.5 cm in diameter or less. The rate is $94/hr, and does not include transportation (transportation costs were determined on a case by case basis). The contractor was reluctant to give a general figure for acre/hour, on account of variability in bush density, terrain roughness, etc. In lighter bush he could travel 6 - 8 km/h, whereas in heavy bush he would only be able to travel 3 - 5 km/h. The contractor stated that he could generally go faster with the smaller mower, because he could put more torque through the gearbox. Previous contracts with Manitoba Conservation resulted in a mean of 1.5 acres/hr for the 2 m mower (Roberts, pers. comm.). Therefore, an estimated cost/acre would be $62.67/acre, and $6,266.67 for 100 acres.

Another company that accepts mowing contract work is Midland Vegetation Management. Midland Vegetation Management has a lighter duty mower unit that is 1.8 m wide, and can cut aspen up to 5 cm in diameter (Everett, pers. comm.). The rate at which a mower can cut depends largely upon the bush density, terrain roughness, and even weather. If there would be no thicker diameter bush, and mowing plots would be under 100 acres, the cost would be $75/hr. A mowing rate of 1.5 acres/hr was thought to be high, but a rate closer to 1 acre/hr was thought to be more realistic because bush density and terrain are not consistent. Therefore, a conservative cost per acre would be $75, or $7,500 for 100 acres.

No company was found in Manitoba that simply rents brush mowers. If a land owner or organization wanted to purchase a quality mower unit, Shulte brush mowers could be purchased from Ag West Equipment Ltd. in Portage La Prairie, Manitoba. The author observed a 4.5 m Shulte brush mower at a demonstration near Carberry, Manitoba, and was pleasantly surprised at the size of aspen that could be cut with the unit. A 3 m wide mower would require a 60 - 75 hp tractor and retails for $13,500, while a 4.5 m wide mower requires a 70 to 90 hp tractor, and retails for $17,500 (Enns, pers. comm.). Both mowers are rated to cut aspen up to 3.5 inches in diameter.

4.6.4 Bark Scrape

The bark scrape estimate is based on a once over scrape, and a mean rate of 7 acres/hr. Skidder rental (based on a Clark 664D with 100 hp) would be $70.00/hour (Roberts, pers. comm.). The cost to rent Sharp-tails Plus scraper unit would be $5.00/hour. Therefore, the combined total to rent a skidder and scraper would be $75.00/hour, or $10.71/acre, and the cost to scrape 100 acres would be approximately $1,071.00.

4.6.5 Rolling

Rolling costs can vary tremendously depending on the diameter of aspen being rolled, terrain conditions (*i.e.* rocks and ground moisture), and air temperature (high temperatures may cause overheating) (Moss, pers. comm.). During the summer of 2001, rolling was carried out in a Mulvihill pasture. As a result of high temperatures and rough terrain, rolling costs climbed to $39/acre. Conversely, Lyle McKay carried out some rolling in Manitoba last year that only cost $15/acre (Moss, pers. comm.). Therefore, on account of variable environmental conditions, treatment costs may generally range between $20 -

$25/acre (Moss, pers. comm.). This does not include the cost of the roller (one would try to arrange for use of the Sharp-tails Plus roller). If a cat is being considered to pull the roller, a D8 cat would be recommended to increase rolling speed and decrease overheating problems and the associated down-time. For the purpose of this treatment estimate, to roll 100 acres at $22.50/acre would cost $2,250.

4.7 Summary

None of the treatments successfully reduced live stem density with one application. Of the 4 applied treatments, prescribed burning had the lowest overall live stem density, the lowest live woody stem density, and was the most effective treatment in killing preexisting woody stems (nearly 100%) (Table 4.15). Prescribed burning was significantly ($p<0.05$) more effective in killing woody stems than the second-most effective treatment: bark scrape. Bark scrape was the cheapest treatment to apply, followed by herbicide, and burning being nearly the same price as herbicide. Glyphosate was the second least effective treatment in reducing live stem density, live woody stem density, and its effectiveness in killing preexisting woody stems. Perhaps if the herbicide had been applied a couple of weeks later, after full leaf flush had been achieved, more favourable results may have been obtained. Finally, mowing was the least effective and most expensive treatment, as it resulted in the highest live stem density. Mowing did not kill preexisting woody stems, but simply reduced their height and altered their structure with a multitude of resprouts growing from the chopped stems. These findings suggest that trembling aspen cannot be successfully managed with single treatment applications, and therefore require followup treatments.

Table 4.1: Overall live stem density for each treatment in 2000.

2000 Overall Live Stems / ha				
Treatment	Shoots	Resprouts	Live Woody Stems	Total
Control	1,215	1,354	28,785	31,354
Fire	44,618	278	590	45,486
Herbicide	13,785	7,500	26,944	48,229
Mowing	31,424	34,722	0	66,146
Bark Scrape	38,160	8,646	14,931	61,736

Table 4.2: Stem density significance using a random block design ANOVA.
* Bush was not sampled in 2000.

Live Aspen Stem Density Significance			
Treatments	Source	2000	
		F-ratio	Probability
Control / Fire / Herbicide / Mowing / Scrape *	Treatment	1.4809	0.2945
	Block	0.91961	0.4370
		2001	
Control / Unrolled Bush / Fire / Mowing / Herbicide / Scrape	Treatment	1.9867	0.1664
	Block	0.78969	0.4804

Table 4.3: Overall live stem density for each treatment in 2001.

2001 Overall Live Stems / ha				
Treatment	Shoots	Resprouts	Live Woody Stems	Total
Control	6,111	2,778	20,799	29,687
Fire	41,111	174	69	41,354
Herbicide	29,167	8,021	10,139	47,326
Mowing	36,493	20,312	0	56,806
Bark Scrape	36,424	3,750	4,722	44,896
Unrolled Bush	2,083	833	20,208	23,125

Table 4.4: Shoot, resprout, and live woody stem densities for 2000 in each treatment plot. Control woody stem density represents both live and dead stems, as health was not enumerated in 2000.

2000 Live Stems / ha					
Treatment	**Block**	**Shoots**	**Resprouts**	**Live Woody Stems**	**Total**
Control	A	1,458	1,771	26,042	29,271
	B	1,042	1,146	31,979	34,167
	C	1,146	1,146	28,333	30,625
Fire	A	34,271	0	208	34,479
	B	24,479	208	208	24,896
	C	75,104	625	1,354	77,083
Herbicide	A	14,271	938	37,292	52,500
	B	12,188	17,292	17,813	47,292
	C	14,896	4,271	25,729	44,896
Mowing	A	43,646	59,375	0	103,021
	B	28,125	15,729	0	43,854
	C	22,500	29,063	0	51,563
Bark Scrape	A	38,438	10,208	18,229	66,875
	B	39,792	8,229	11,250	59,271
	C	36,250	7,500	15,313	59,063

Table 4.5: Shoot, resprout, and live woody stem densities for 2001. Mowing has no woody stems as they were chopped.

2001 Live Stems / ha					
Treatment	**Block**	**Shoots**	**Resprouts**	**Live Woody Stems**	**Total**
Control	A	8,125	4,688	17,604	30,417
	B	6,979	3,125	21,771	31,875
	C	3,229	521	23,021	26,771
Fire	A	37,813	417	104	38,333
	B	22,500	0	0	22,500
	C	63,021	104	104	63,229
Herbicide	A	34,583	16,979	6,250	57,813
	B	25,208	4,167	8,229	37,604
	C	27,708	2,917	15,938	46,563
Mowing	A	52,813	31,771	0	84,583
	B	32,083	11,354	0	43,438
	C	24,583	17,813	0	42,396
Bark Scrape	A	25,625	2,500	2,083	30,208
	B	38,750	3,958	3,438	46,146
	C	44,896	4,792	8,646	58,333
Unrolled Bush	A	4,688	1,250	18,750	24,688
	B	313	625	23,125	24,063
	C	1,250	625	18,750	20,625

Table 4.6: Mean live stem density for each treatment for pretreatment, 2000, and 2001. The fire pretreatment density includes live and dead stems, as health was not enumerated.

Treatment	Pre-treatment		2000		2001	
	Stems / m²	Stems / ha	Stems / m²	Stems / ha	Stems / m²	Stems / ha
Control	NA	NA	3.14	31,354	2.97	29,688
Fire	2.43	24,340	4.55	45,486	4.14	41,354
Herbicide	NA	NA	5.64	56,389	4.73	47,326
Mowing	NA	NA	6.61	66,146	5.68	56,806
Bark Scrape	NA	NA	6.17	61,736	4.49	44,896
Unrolled Bush	NA	NA	NA	NA	2.31	23,125

Mean Number of Live Stems / ha

Table 4.7: Mean live stem density for each treatment block, including the pretreatment, 2000, and 2001 surveys. The fire pretreatment includes live and dead stems.

Treatment	Block	Pre-treatment		2000		2001	
		Stems / m²	Stems / ha	Stems / m²	Stems / ha	Stems / m²	Stems / ha
Control	A	NA	NA	2.93	29,271	3.04	30,417
	B	NA	NA	3.42	34,167	3.19	31,875
	C	NA	NA	3.06	30,625	2.68	26,771
Fire	A	2.24	22,396	3.45	34,479	3.83	38,333
	B	1.63	16,250	2.49	24,896	2.25	22,500
	C	3.44	34,375	7.71	77,083	6.32	63,229
Herbicide	A	NA	NA	6.56	65,625	5.78	57,813
	B	NA	NA	5.41	54,063	3.76	37,604
	C	NA	NA	4.95	49,479	4.66	46,563
Mowing	A	NA	NA	10.30	103,021	8.46	84,583
	B	NA	NA	4.39	43,854	4.34	43,438
	C	NA	NA	5.16	51,563	4.24	42,396
Bark Scrape	A	NA	NA	6.69	66,875	3.02	30,208
	B	NA	NA	5.93	59,271	4.61	46,146
	C	NA	NA	5.91	59,063	5.83	58,333
Unrolled Bush	A	NA	NA	NA	NA	2.47	24,688
	B	NA	NA	NA	NA	2.41	24,063
	C	NA	NA	NA	NA	2.06	20,625

Number of Live Stems / ha

Table 4.8: Health of pretreatment woody stems as determined on a 5 scale ranked system: 1=healthy, unimpacted by the treatment;2=light; 3=moderate; 4=heavy; 5=dead.
* Not determined in 2000.
** Surveyed only in 2001.

Mean Health of Woody Stems			
Treatment	**Block**	**2000**	**2001**
Control	A	*	2.75
	B	*	2.61
	C	*	1.59
Fire	A	4.90	4.94
	B	4.99	5.00
	C	4.90	4.99
Herbicide	A	3.49	4.06
	B	3.82	4.10
	C	3.20	3.40
Bark Scrape	A	3.76	4.26
	B	4.08	4.32
	C	3.85	3.77
Unrolled Bush	A	**	1.71
	B	**	1.47
	C	**	1.61

Table 4.9: Random block design ANOVA results for determining health significance.
* health in the control and bush was not evaluated in 2000

Health Significance			
Treatments	**Source**	**2000**	
		F-ratio	**Probability**
Fire / Herbicide / Scrape *	Treatment	71.363	0.0007
	Block	3.5576	0.1295
		2001	
Control / Unrolled Bush / Fire / Herbicide / Scrape	Treatment	71.218	< 0.0001
	Block	4.2197	0.0561

Table 4.10: Pretreatment woody stem mortality significance using a random block design ANOVA.
* health in the control and bush was not evaluated in 2000

Woody Stem Mortality Significance			
Treatments	Source	2000	
		F-ratio	Probability
Fire / Herbicide / Scrape *	Treatment	258.83	< 0.0001
	Block	4.2032	0.1040
		2001	
Control / Unrolled Bush / Fire / Herbicide / Scrape	Treatment	155.39	< 0.0001
	Block	2.9389	0.1104

Table 4.11: Overall percentage of dead pretreatment woody stems found in 2000 and 2001.
* Health was not assessed.
** Unrolled Bush was not surveyed in 2000.

Overall Percentage of Dead Woody Stems			
Treatment	Block	2000	2001
Control	A	*	11.11
	B	*	19.31
	C	*	4.74
Fire	A	98.47	98.28
	B	97.44	100.00
	C	93.63	99.08
Herbicide	A	26.03	41.75
	B	27.54	52.12
	C	15.12	36.10
Bark Scrape	A	26.78	53.49
	B	40.00	58.54
	C	25.38	46.50
Unrolled Bush	A	**	16.67
	B	**	10.84
	C	**	16.67

Table 4.12: Summary statistics for basal stem diameter of woody stems found in blocks A, B, and C in the unrolled bush.

Summaries
No Selector

Variable	Count	Mean	Median	StdDev	Min	Max	Range
Block A	71	27.6479	25	13.6173	7	63	56
Block B	83	30.7108	28	17.1297	7	72	65
Block C	72	30.625	23	17.5334	9	77	68

Table 4.13: Testing basal stem diameter significance between blocks using a two-sample t-test assuming unequal variances.

t-Test: Two Sample				
Block	Mean	Variance	P(T<=t) one-tail	t Stat
A	27.648	185.43	0.1093	-1.2354
B	30.711	293.43		
A	27.648	185.43	0.1292	-1.1349
C	30.625	307.42		
B	30.711	293.43	0.4878	0.0307
C	30.625	307.42		

Table 4.14: Estimated treatment costs based on 2002 pricing. Costs do not include taxes or equipment transportation costs if necessary.

Treatment Costs			
Treatment	Cost / hour	Cost / acre	Cost / 100 acres
Prescribed Burn	$200.00	$16.00	$1,600.00
Herbicide Wiper	-	$15.00	$1,500.00
Mower	$94.00	$62.67	$6,266.67
Bark Scraper	$75.00	$10.71	$1,071.00
Roller	-	$22.50	$2,250.00

Table 4.15: Summary of treatment effectiveness in aspen management. Shaded area represents best treatment for that category. 1 = least; 6 = greatest

Treatment	Overall Live Stem Density	Live Woody Stem Density	Percentage of Dead Woody Stems	Treatment Cost
Control	2	5	1	4
Fire	3	**1**	**5**	3
Herbicide	5	3	3	2
Mowing	**6**	-	-	**5**
Bark Scrape	4	2	4	**1**
Unrolled Bush	**1**	4	2	-

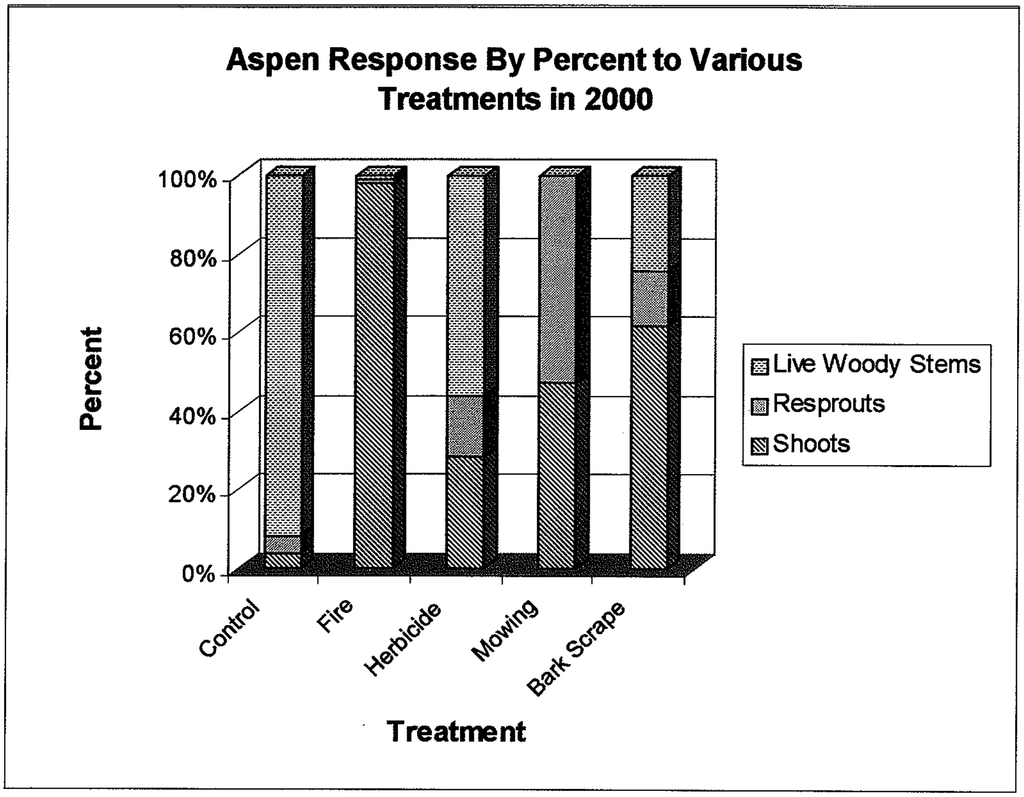


Figure 4.1: Proportion of live woody stems, shoots, and resprouts found in the various treatments in 2000.

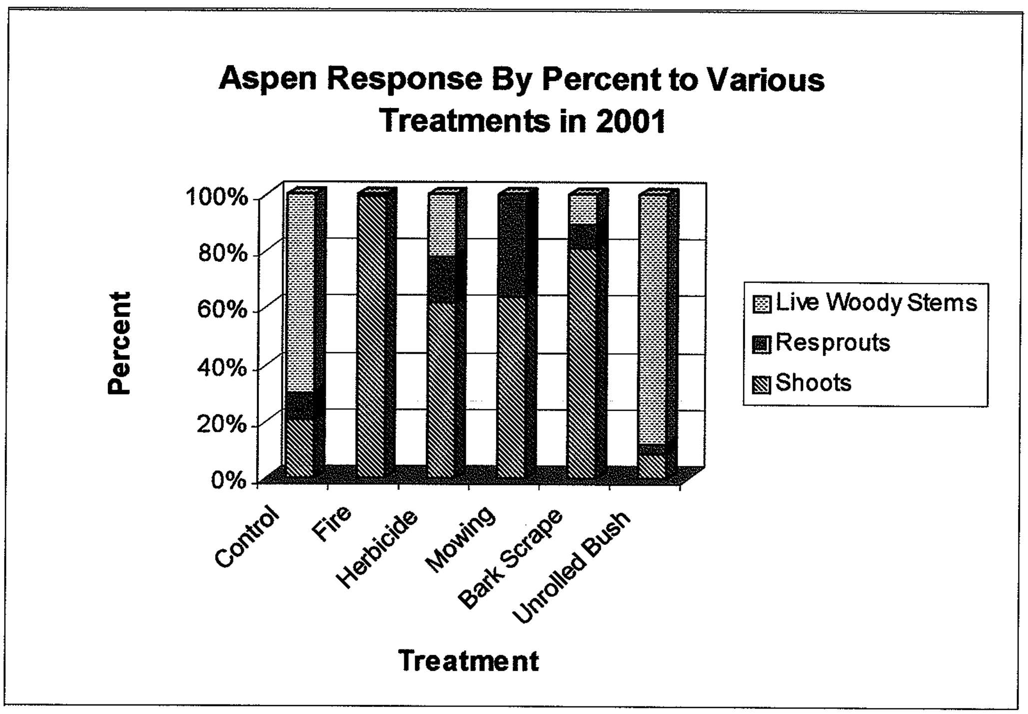


Figure 4.2: Proportion of live woody stems, shoots, and resprouts found in the various treatments in 2001.

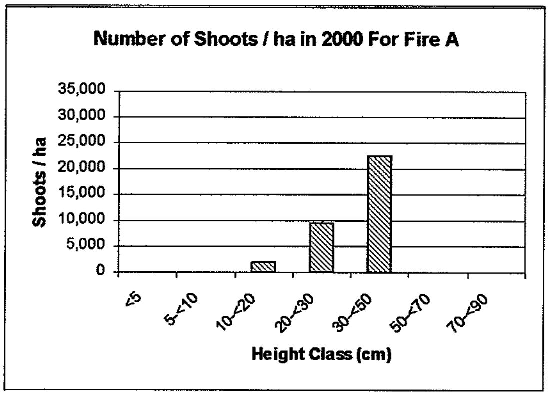


Figure 4.3: Shoot density in their respective height classes for Fire Block A in 2000.

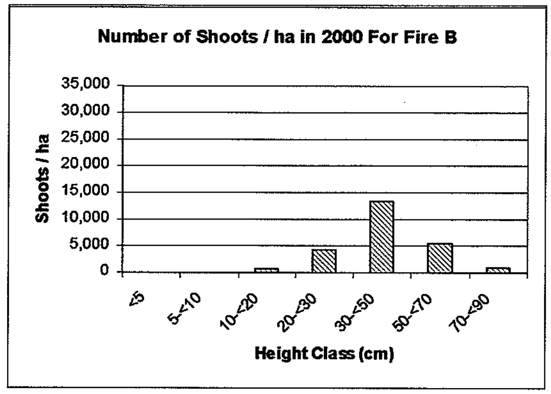


Figure 4.4: Shoot density in their respective height classes for Fire block B in 2000.

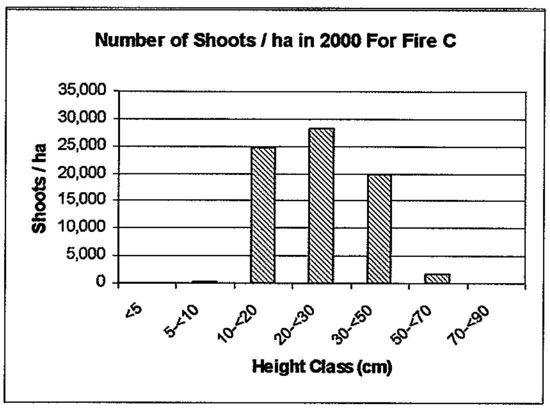


Figure 4.5: Shoot density in their respective height classes for Fire block C in 2000.

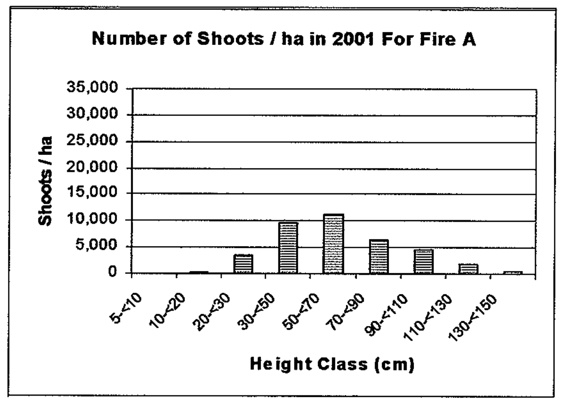


Figure 4.6: Shoot density in their respective height classes for Fire block A in 2001.

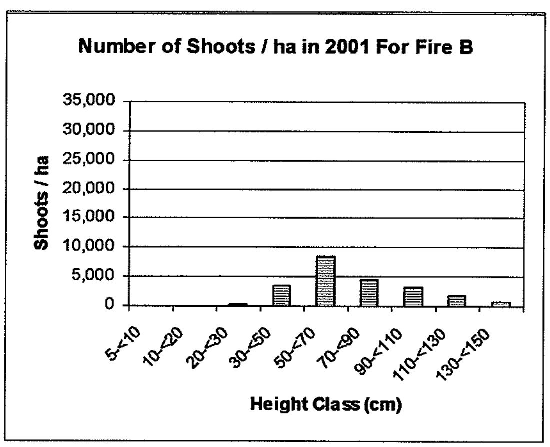


Figure 4.7: Shoot density in their respective height classes for Fire block B in 2001.

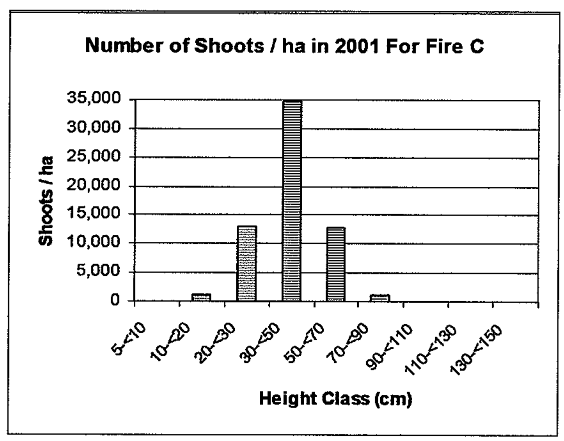


Figure 4.8: Shoot density in their respective height classes for Fire block C in 2001.

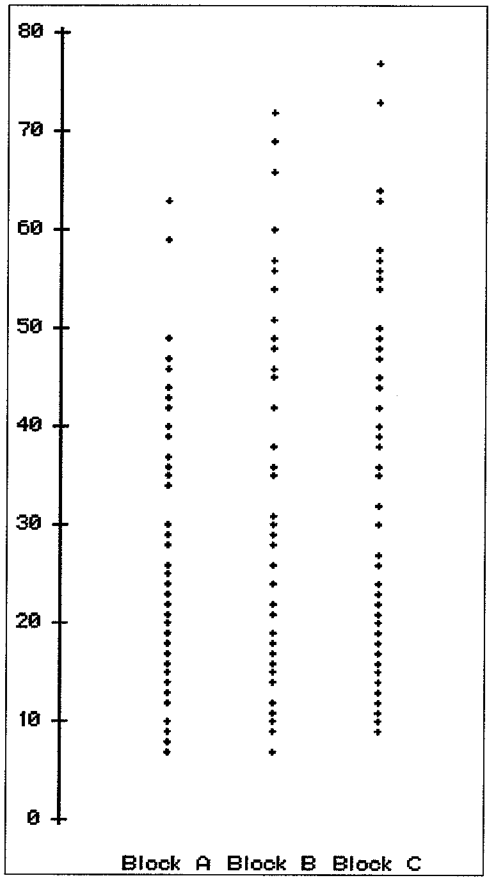


Figure 4.9: Dotplot of basal stem diameter (mm) of live and dead woody stems in the unrolled bush.

CHAPTER 5: MANITOBA INTERLAKE HABITAT RESTORATION: ASSESSING TREATMENT IMPACT ON THE PLANT COMMUNITY

5.1 Introduction

Natural disturbances, such as frequent fires, climatic variation, and grazing activity from large bison herds and to a lesser degree elk, historically maintained a diverse habitat structure in the Aspen Parkland, including the Manitoba Interlake (Bailey and Wroe 1974; Bird 1961; Campbell *et al.* 1994). The Aspen Parkland evolved over thousands of years under this natural disturbance regime, resulting in a mosaic pattern of plant communities with extensive horizontal and vertical diversity. The suppression of these historical natural disturbances within the last 100 years has caused changes to the plant community and the proportion of grassland, shrubland, and woodland habitats available at the landscape level.

Today, various treatments are employed by landscape managers and landowners in an attempt to restrict aspen encroachment, by emulating natural disturbances and restoring the historical landscape complexity of the Aspen Parkland. These treatments include prescribed burning, herbicide, mowing, and bark scraping. This chapter will address how these treatments impacted the plant community in the Narcisse Wildlife Management Area, as well as the plant community's species richness and effective richness.

5.2 Impact on Plant Community Results

5.2.1 Results of Principal Component Analysis $_1$

Principal Component Analysis (PCA_{1}) showed the relationships among the vegetation species and sites based on a covariance matrix (Table 5.1; Figure 5.1). The resultant analysis showed that 28% of the data were summed up in the first axis, and 21.3% in the second axis, for a total of 49.3% in the first two axes.

The resultant PCA_1 analysis revealed that there appeared to be a blocking effect, where sample sites in block B were clearly separated from the other sites (Figure 5.1). In other words, some plant species tended to be associated with blocks with their inherent environmental variables. For example, low shrubby and open, dry grassland species such as bearberry were found most frequently in block A, whereas in block B bearberry was least abundant (Table 5.2; Figure 5.2). Stiff goldenrod, spike-like goldenrod, and heart-leaved alexanders were least abundant in block B. In addition, shrubby cinquefoil and Richardson's needle grass, which were found in similar frequencies in blocks A and C, were least abundant in block B. However, seneca root located in the upper left of the biplot, had similar frequency abundance in blocks A and B, but very low abundance in block C. Lily of the valley, spreading dogbane, purple peavine, western snowberry, and blue lettuce were all plant species that were most frequently found in block B. Field-sow-thistle, and Canada thistle, were both found at similar frequencies in blocks B and C. Prairie sage, three-flowered avens, and star-flowered false solomon's seal occurred most frequently in block C. Therefore, as one identifies various plant species around the perimeter of the biplot, species appeared to be associated with blocks where they were found more or least frequently.

The frequency with which a plant was found depended largely upon its surrounding environment. The differences among the species were subtle, but general trends were apparent. The x-axis appeared to be a moisture gradient, possibly declining from the upper left to the lower right (Figure 5.2). The same gradient could also represent open, dry grassland species in the upper left to taller shrubs and weedy species in the bottom right.

The y-axis may represent the degree of shade tolerance of plant species (Figure 5.2). An inclining trend may represent shade intolerant species in the bottom left to shade tolerant species in the upper right. Interestingly, all sites in block B (except for Fire B) were located near the top of the y-axis, separated primarily along the x-axis. It appeared that many species in block B ranged from dry, open forest species to moist, closed forest species. This apparent association of a few plant species with particular blocks may be attributed to variability in the landscape and its inherent environmental conditions.

This blocking effect was also apparent when one compared the relative abundance of cover types with respect to the blocks. Blocks A and B generally experienced greater microtopical variations than block C. In addition, treatment sites located near the northern area of the study site generally had higher, drier ground than treatment plots in the southern portion of the study site. These microtopic variations were reflected somewhat in the variation of cover types (Table 5.3). Block C had the greatest abundance of tall shrubs (which compete well in areas of greater moisture), as well as the least abundance of low herbs (which require greater light conditions). The relative abundance of low shrubs was greater in block A than C. However, block C still had a greater abundance of low shrub as compared to block B. This may be attributed to a greater degree of rolling topography in block B versus block A. A greater presence of low to intermediate areas will limit the existence of low shrub species. Therefore, microtopic variations appear to play a significant role in determining species composition, perhaps even more so than treatment effects. The microtopic variation in the landscape at my study site was at a much finer scale than the block design. This increased the complexity in determining if the results were attributed to environmental effects or treatment effects.

5.2.2 Results of Principal Component Analysis $_2$ With Blocks As Covariables

Recognizing that a block effect exists, a Principal Component Analysis (PCA_2) was used to examine the residual information specific to the treatments once the information unique to the blocks was removed (Table 5.1). Based on the eigenvalues obtained from the analysis, 26.1% of the information was attributed to the first axis, 11.8% for the second axis, and a sum of all unconstrained eigenvalues of 76.7%.

The 3 control sites appeared to be 'pulled out' on the y-axis, and the fire sites on the x-axis (Figure 5.3). The x-axis could be thought of as expressing a treatment effect or a disturbance gradient. The control sites were within close proximity of zero on the x-axis, and the other treatment sites were approximately within +/-1 on the x-axis, with the exception of herb B and fire B.

The differences between fire A, B, and C on the PCA_2 biplot is of interest (Figure 5.3). Fire B was maximally different from fire C along the x-axis. This may be attributed to inherent differences in soil moisture availability, as fire B was the site with greatest moisture, and fire C was the driest of the 3 fire sites. Of the 3 burned sites, the most frequently observed plant species indicating dry conditions in fire C included: bearberry, wild bergamot, fringed brome, shrubby cinquefoil, and harebell (Appendix H, Table H-1). These same species had the lowest observed frequency in fire B, and an intermediate frequency in fire A. In addition, fire C had the lowest relative abundance of tall shrubs and weeds, and the greatest abundance of low shrubs, while fire B had the highest relative abundance of tall shrubs and weeds, and did not have a low shrub cover. Fire A had intermediate relative abundance values for these cover types (Appendix H, Table H-2). Therefore, it appeared that fire B was the site with greatest moisture, fire A intermediate, and fire C was the driest burn site.

There also appeared to be a correlation between site moisture conditions and burn intensity. It was believed that fire A and B had hotter burns than fire C, as they were burned later in the day, thus allowing the vegetation to dry out more thoroughly and in turn permit a hotter burn (Caldwell, pers. comm.). Unfortunately, burn temperatures were not quantified, and therefore must be inferred. A high burn temperature would require more fuel for the fire, or special conditions that would permit fuel to be consumed at a faster rate. Fire B had less topographic relief than Fire A, and appeared to be generally a lower area with greater moisture (Appendix H, Table H-3). Fire B had the greatest relative abundance of grass and low herbs, nearly the greatest percentage of sedges and trees, and more than 20% relative abundance of tall shrubs (Appendix H, Table H-2). The higher grass and sedge cover may contribute to producing a relatively thick organic layer. This organic layer, combined with a greater abundance of woody vegetation, could have been the primary fuel source that contributed to a high burn temperature in Fire B.

Of all the fifteen treatment sites, Fire B had the greatest relative abundance and strongest association with weedy species (Appendix H, Table H-2). The relative abundance of weeds was still low (only 2.18%), and weedy species were found in all the sites, including the control and the unrolled bush. The greatest proportion of weedy species in Fire B could be attributed to a greater proportion of the organic layer being burned off, and exposing the mineral layer, which would permit seed establishment. Since the soils in the Interlake are quite thin and rocky, the aspen root systems would be found near the surface. The high burn temperature that exposed more mineral soil for weeds, also appeared to have damaged the aspen root system, as described in chapter 4. Fire B was the only burn site to have experienced a decrease in aspen stem density from 2000 to 2001. Therefore, it appears that Fire B had the hottest burn of the 3 burn sites.

Fire A appeared to have had a burn intensity that was second to Fire B, and was also associated with weedy species (Appendix H, Table H-2). The relative abundance of weedy species was less than 1%, but still greater than Fire C. This may be attributed to a lower burn intensity than Fire B, where the lower temperature burn consumed less of the duff layer, exposing less mineral soil. Lower exposure of mineral soil would provide less opportunity for weedy species to invade. Fire A was also observed to have an appreciable degree of topographic relief, possessing low, intermediate, and high areas (Appendix H, Table H-3). The higher areas would presumably have a lower fuel load, resulting in a somewhat lower burn intensity.

Of the 3 burns, fire C was burned first, at around 2:00 pm (Caldwell, pers. comm.). Fire C appeared to have the coolest burn, as the vegetation in the other two blocks had more time to dry out. The coolest burn would expose the least amount of mineral soil, thereby minimizing invasion from weedy species (Appendix H, Table H-2). A cool burn would also result in a strong increase in aspen shoot production compared to an intense burn, which was reported in chapter 4. Interestingly, prior to the burn, fire C had the greatest abundance of trees, low shrub species, and was least abundant in sedges and tall shrubs. Fire C also had the least variation in topographic relief, as it appeared very flat (Appendix H, Table H-3). The apparent lack of topographic relief may have contributed to minimizing the abundance of tall shrub species because of less soil moisture availability, which may have decreased its potential fuel load, and contributed to its lower burn intensity.

Therefore, it appears that sites with greater soil moisture availability result in high intensity burns that consume more of the organic layer, exposing more of the mineral soil to weedy species, whereas sites with low available moisture may tend to have low intensity burns and little exposed mineral soil and weed infestation.

Interestingly, fire B and herb B are at opposite ends of the x-axis, which means they are maximally different (Figure 5.3). A closer examination at their cover types reveals some striking differences (Table 5.4). Fire B had a considerably greater abundance of grasses and tall shrubs, as well as having more legumes, trees, and weeds. However, one category that clearly stood out was low shrub. Herbicide B had nearly 20%, while fire B had none. Table 5.5 shows that low shrubs were not present prior to burning the treatment site in block B. Therefore, the treatment sites were inherently different from each other naturally, showing that a significant proportion of the differences between fire B and herbicide B were not so much treatment effects, but natural, inherent variations in the landscape.

The y-axis in Figure 5.3 separated the 3 control sites from most of the mowing, scraping, herbicide, and burn treatments. Interestingly, mowing A, B, and C were separated along the y-axis from the top, centre, and to the bottom, even though they were all the same treatments. The relative abundance of herbs, legumes, low herbs, and weeds were similar across all 3 treatments (Table 5.6). However, mowing A had the least abundance of grasses, sedges, and tall shrubs, and the greatest abundance of low shrubs and tall trees (the greater abundance of trees in mowing A may also relate to that site possibly having a younger aspen clone, which could respond with greater shoot production intensity as described in chapter 4). However, mowing C had the least abundance of low shrubs, and the greatest abundance of tall shrubs. This suggests that mowing A was in a drier location, whereas mowing C was in a relatively moist location. These mowing sites show a clear relationship between low and tall shrubs. As the relative abundance of low shrubs decreases, the abundance of tall shrubs increases. Therefore, since considerable variation could be seen within the same treatment, it appeared that the treatments were exerting minimal effects on the plant community, and that many of the observed differences may be attributed to variations in the landscape.

The PCA_2 scatterplot presented an arrangement of plant species in various community types (Figure 5.6). The x-axis may be thought of as a moisture gradient, with plants characteristic of dry conditions on the left, and moist conditions on the right. It may also be dry grassland species on the left compared to moist, shrub and weedy species on the right. The y-axis could be thought of as a plant community gradient, with plants characteristic of woodlands and shrublands on the bottom to grassland species on the top. The plant species appeared to be loosely arranged into relatively 4 community types. Dry grassland species, such as seneca root, harebell, bearberry, fringed brome, and spike-like goldenrod appeared grouped on the left, and moist grassland species such as sedge, Richardson's needle grass, and three-flowered avens appeared grouped in the upper centre. Moist shrub and woodland species such as lily of the valley, veiny meadow rue, and low birch appeared somewhat grouped in the lower centre, and finally shrub species such as willow, western snowberry, and choke-cherry, and weed species such as dandelion, blue lettuce, field-sow-thistle, and Canada thistle were on the right. Therefore, even with blocks removed as covariables, there still appeared to be some general grouping of plant species according to optimal moisture and light conditions.

There also appeared to be some relationship between plant species, and the frequency with which they were encountered in respective treatments. The dry grassland species such as bearberry, fringed brome, wild bergamot, and yarrow were most frequently observed in herbicide B, but were also frequently found in fire C, herbicide C, mowing B, and scrape B (Appendix H, Table H-4). Of the moist woodland species, lily of the valley was most frequently observed in Control B, veiny meadow rue was found frequently in Control C, short-stemmed thistle in control A., and snakeroot was most common in controls B and C. A few of the shrub and weed species observed most frequently include: willow in mowing C and fire A, dandelion in fire B and control B, and choke-cherry and blue lettuce were observed most frequently in fire B. Finally, moist grassland species included Richardson's needle grass in scrape A, and three-flowered avens in scrape C. The impression that some treatments, even the same treatment, appeared to be more associated with various vegetation communities such as a shrub/weedy community or a moist grassland community, suggests that the treatments exert little impact on the vegetation communities. Therefore, much of the variation within and among the treatments appear to be inherent within their respective treatment sites. Fire may be an exception, where it appeared that as burn intensity increased, the invasion of weedy species also increased. However, the significance of this trend may be questionable, as dandelion was found in both fire B and control B at equal frequencies (Appendix H, Table H-4). Therefore, a more restrictive analysis should be conducted to determine trends and relationships.

5.2.3 Redundancy Analysis Results

Redundancy Analysis (RDA) was the most restrictive analysis used to isolate relationships between plant species and treatments. Treatments were the constraining variable, and blocks were the covariable, leaving the residual information for analysis. Data redundancy was found to be 39.5% (Table 5.7). An RDA biplot of selected plant species is provided in Figure 5.5, and it appears to be very similar to the results from PCA_2, Figure 5.4, except that the y-axis is inverted. Low shrub and dry grassland species such as bearberry, and wild bergamot were still on the left, and moist grassland species such as Richardson's needle grass, prairie sage, and heart-leaved alexanders were in the lower central portion of the biplot. Woodland species such as spreading dogbane, veiny meadow rue, and short-stemmed thistle were found in the upper centre of the biplot. Finally, taller shrub species such as prickly rose, willow, western snowberry, and choke-cherry, and weedy species such as dandelion, blue lettuce, and common-sow-thistle were found on the right portion of the biplot. Therefore, it appears that there is a gradient from the lower left to the upper right, moving from grassland conditions to woodland/shrub/weedy conditions.

The treatment sites tend to be somewhat aligned with plant species in their proximity (Figure 5.5, 5.6). The control treatment appeared to be associated with woodland species, such as spreading dogbane, veiny meadow rue, and short-stemmed thistle, whereas the scrape treatment appeared to be associated with moist grassland species, such as Richardson's needle grass, and heart-leaved alexanders (Appendix H, Table H-5). The burn treatment appeared more associated with shrub species like prickly rose, willow, western snowberry, and choke-cherry, and weedy species such as dandelion, blue lettuce, and common-sow-thistle, though the actual relative abundance of the weedy species combined was quite low (Appendix H, Table H-5; Table 5.8). Moist and dry grassland species were predominant in the herbicide treatment, which included: shrubby cinquefoil, heart-leaved alexanders, wild bergamot, and bearberry (Appendix H, Table H-5). The mowing treatment site was oriented not far from the centre of the biplot (0 x-axis, 0 y-axis), and therefore would have plant species observed at intermediate frequencies from various community types (Figure 5.6). The intermediate frequencies found in the mowing treatment site were also reflected in the relative abundance of cover types, where the various cover types were often at an intermediate level (Appendix H, Table H-2; Table 5.8).

All of the applied treatments, including the control, differed dramatically from the unrolled bush. Since both PCA and RDA were sensitive to outliers, data from the unrolled bush were not included in the analyses, as it would have minimized differences between other treatments, and hidden trends in the data. Plant species that were observed with much greater frequency in the bush than in other treatment sites included primarily woodland species such as veiny meadow rue, snakeroot, spike oat, spreading dogbane, and lily of the valley (Appendix H, Table H-5). Conversely, species that were observed with much lower frequencies than other treatments included shade intolerant grassland species such as slender wheat grass, prairie sage, yarrow, wild bergamot, bearberry, stiff goldenrod, and harebell.

Differences in plant composition between the bush and treatments remained apparent even when species were grouped into cover types. The unrolled bush had a significantly greater relative abundance of sedge, lily, and tree cover, and significantly less relative abundance of grass, herb, low herb, and low shrub cover as compared to the five treatments (Table 5.8). These differences in species frequency and relative abundance of cover types are intuitive, as tall, dense tree canopy will induce a low abundance of shade intolerant (*i.e.* grassland) species, and a greater abundance of shade tolerant (*i.e.* woodland) species.

Since the plant community in the unrolled bush was significantly different from all the other treatments, it appeared that the treatments, including rolling, caused a shift from a predominantly woodland plant community to a variety of community types that included moist and dry grasslands (Appendix H, Table H-5). However, differences between the various treatments appeared to be quite subtle. These differences may be largely attributed to the inherent variability of the landscape rather than treatment effects.

To determine if the differences between treatment sites were inherent or resulting from the treatments themselves, pre and post-treatment vegetation surveys were examined. Unfortunately, only the 3 fire treatment sites received pretreatment surveys. In addition, the pretreatment surveys were conducted by the individual who initiated this project. This adds further complications because one must be cognisant of factors such as observer bias in recognizing species, estimating species percent cover, as well as possible differences in sampling effort. To minimize these differences, analysis of the pre and post-treatment vegetation data were carried out only on species identified on both surveys using frequency of occurrence data, as well as by combining species into relative abundance of cover types.

5.2.4 Pretreatment Versus Post-treatment Principal Component Analysis

The PCA_3 performed on the pretreatment and post-treatment plant species in the burn sites in blocks A, B, and C resulted in 52.3% of the data being attributed to the first axis, and 32.9% to the second axis. Hence, 85.2% of the species data is attributed to the first two axes. The pretreatment vs. post-treatment PCA_3 biplot is illustrated in Figure 5.7. Note that all pretreatment sites were found on the far right on the x-axis, spread out along the y-axis, and all the post-treatment sites were on the far left of the x-axis, and spread out in the same order along the y-axis. The x-axis clearly represented a treatment effect, showing the direction and magnitude of change along the axis. Fire A was found near the centre, B at the top, and C near the bottom. Interestingly, the order of block placement along the y-axis did not change from pretreatment to post-treatment. Fire B remained at the top of the y-axis, fire A near the centre, and fire C at the bottom.

The vegetation biplot revealed an interesting grouping effect of various plant species (Figure 5.8). There were essentially two groups of plant species. The group along the x-axis was primarily grassland species, whereas the group along the upper half of the y-axis was shrubland and woodland species, as well as weeds and legumes. The y-axis may also represent a general trend from drier plant species at the bottom to moist plants at the top. The one exception may be low birch grouped with the grassland species. This was probably attributed to a block effect. Low birch was found with greater frequency in fire A, as compared to fire C (Appendix H, Table H-6). Fire B had no low birch, which probably resulted in the analysis pushing low birch near the base of the y-axis because Fire B was so different. This resulted in low birch being grouped with the grassland species along the x-axis.

Plant species on the positive side of zero on the x-axis were impacted negatively by the burn treatment, and species on the negative side benefited by the treatment (Figure 5.8; Appendix H, Tables H-6, H-7). For example, wild bergamot, pale comandra, sedges, and grasses (*Poaceae*) all increased in observed frequency from pretreatment to after the burn

(Figure 5.8; Appendix H, Table H-7). Conversely, bluegrass, avens, and bearberry decreased in observed frequency from before the burn to after the burn (Figure 5.8, Appendix H, Table H-6). The greater the positive or negative position along the x-axis, the greater the treatment effect in increasing or decreasing the observed frequency.

Keeping in mind the two plant groups, grassland species along the x-axis and shrubland, woodland, and weedy species further up the y-axis (Figure 5.7), a downward shift in the position of the 3 fire treatment sites was noticed. All 3 treatment sites moved from the right to the left and maintained the same order along the y-axis. As stated earlier in this chapter, fire B appeared to be the burn site with the greatest moisture, fire A was intermediate, and fire C was the driest burn site. Hence, the y-axis in Figure 5.7 and 5.8 may be representing a moisture gradient, as well as two different plant communities. In addition to the shift in treatment site position from right to left, all 3 burn treatment sites also had somewhat of a shift down the y-axis. This may represent a treatment effect, where the prescribed burn caused the plant communities in the moist, intermediate, and drier treatment sites to become more like a grassland community. Unfortunately, pretreatment surveys were not carried out on the other treatment sites. However, the results suggest that prescribed burning appears to be effective in changing a plant community to more of a grassland community, regardless of moisture conditions.

5.2.5 Impact of Moisture on Plant Community Structure

Small microtopic variations in the landscape were noted in the research site, and they appeared to impact the composition of the plant community. Plant species composition were noted along a changing moisture gradient in two locations. One location included 4 successive plots in the scrape treatment in block A (Figure 5.9). Quadrat 14 was located on higher, drier ground, quadrat 15 on the lowest site of the 4, and quadrats 16 and 17 were intermediate sites, slowly getting progressively higher. Plant species divided into 9 cover types showed appreciable plant community changes between quadrats along the moisture gradient (Table 5.9). Quadrat 14 was the driest site, as it was the only quadrat to contain any low shrub species. Quadrat 15 was the lowest site, as it clearly had the greatest relative abundance of sedge cover. The relative abundance of sedge cover got progressively less as the microtopic elevation increased. The driest site (quadrat 14) had the least relative abundance of tall shrubs, while the lower sites with greater moisture had a much greater relative abundance of tall shrub cover. Therefore, it appears that even though all 4 quadrats were scraped in 2000 and surveyed in 2001, small microtopic variations in the landscape play a significant role in shaping the plant species composition in the community.

The same results were obtained in the second site where the moisture gradient was outlined in fire block A (Figure 5.10). Low, intermediate, and high areas were easily determined from the clear differences in plant cover, and the 24 quadrats were grouped accordingly. The relative cover type abundance was compared between the 3 areas. Since the objective was to compare cover type differences between the 3 moisture gradients, quadrats 9 and 22 were not used in the comparison, as the boundary passed through these two quadrats, and would have complicated the findings.

The low area was found to have the lowest relative abundance of grass, herbs, legumes, and low herbs, and the greatest abundance of sedges, trees, and weeds (Table 5.10). The intermediate area had the highest relative abundance of tall shrub and legume cover, an intermediate relative abundance of tree, herb, sedge, and grass cover, and the lowest relative abundance of weedy species. Finally, the high area had the greatest relative abundance of grass, herbs, low herbs, and lily, and the least abundance of sedges, tall shrub, and tree cover. Interestingly, the high area was the only site to have any low shrub cover, which was nearly 18%. In addition, the only weedy species found in the high area were Bicknell's geranium and goat's beard (Appendix H, Table H-8). The other weedy species, blue lettuce, dandelion, and common-sow-thistle were found in either or both low and intermediate areas. These findings suggest that as a site decreased from greater to lower moisture, the relative abundance of grass, herb, low herb, lily, and low shrub cover increased, while the relative abundance of sedge, tree, and weed cover decreased.

In addition to studying plant community differences in low, intermediate, and high areas, the impact of prescribed burning in these moisture gradients was also investigated. The greatest decrease in the relative abundance of grass cover from before burning to after burning occurred in the low area, while the smallest decrease was in the high area (Table 5.11; Figure 5.11). The most significant decrease in tall shrub cover occurred in the intermediate area, followed by the low area. However, the high area experienced a slight increase in the relative abundance of tall shrub cover. This slight increase could in part be attributed to observer bias or sampling effort, as the pretreatment and post-treatment surveys were carried out by two different individuals. The greatest increase in relative sedge abundance occurred in the low area, while the smallest increase occurred in the high area. Herb, legume, low herb, and tree cover all increased from pretreatment to post-treatment as a result of treatment effects. Therefore, it appears that not only does variation in microtopic relief impact the composition of the plant community, but also the degree to which the plant community was impacted by the prescribed burning treatment. However, given the significance of microtopic variation in the composition of a plant community, the overall impact by the treatments appeared minimal.

5.3 Diversity

5.3.1 Species Richness

Mean species richness values were determined for each treatment block and for the overall treatment (Tables 5.12, 5.13). The control, fire, herbicide mowing and scraping treatments all had species richness values that ranged from 41 to 52 per treatment block (Table 5.12). The unrolled bush only had a mean of 35 - 39 plant species per treatment block. Interestingly, treatments in block B often had lower species richness values as compared to the other blocks, regardless of treatment. Treatments in block B were observed to have a number of low and intermediate areas (*i.e.* regions with greater moisture). Hence, it appears that an increase in soil moisture leads to a decrease in species richness. A random block design ANOVA showed that there was a significant difference between blocks, with or without the unrolled bush (Table 5.14). However, a significant difference was found between the treatments when the unrolled bush was included in the analysis, but not between the five treatments. Earlier in this chapter, block B was described to be the site that generally had greater moisture conditions. Thus, it appears that the environmental conditions in block B were significantly different ($p < 0.05$) from the other blocks. Differences between the treatments were significant ($p < 0.05$) only when the unrolled bush was used in the analysis. Hence, the treatments had significantly greater species richness than the unrolled bush, but species richness was not significantly different among the 5 treatments. Therefore, at this point in the analysis, the greatest impact on species richness among the treatment sites (excluding the unrolled bush) appears to be from a block effect (*i.e.* inherent environmental conditions), and the treatments do not significantly impact species richness compared to the control.

The mean species richness for each treatment was described in Table 5.13. The control had the greatest species richness, and the fire, herbicide, mowing, and scraping treatments had similar richness values. In addition, the unrolled bush had an appreciably lower mean species richness value as compared to any other treatment. A significant difference in species richness among the treatments was noted only when the unrolled bush was included in the analysis (Table 5.14). Therefore, it appears that all treatments, including rolling, significantly increased species richness compared to the unrolled bush.

At the overall treatment level, a blocking effect, or environmental factors, contributed more to impacting species richness than the treatments. However, species richness was significantly improved by the 1997 rolling. At the individual treatment level, all treatments improved species richness from the mature woodland state. Yet the control had the greatest species richness of all the treatments. This may be attributed to the random placement of the control sites. Control A was located in the upper portion of the research site, which inherently had drier conditions. The other two control sites had microtopic variations in the landscape which impacted species diversity. The low, intermediate, and high areas outlined for fire A resulted in the high area having the greatest species richness, and the low area with the least species richness (Table 5.15). Hence, the evidence suggests that there is an inverse relationship between available soil moisture and species richness. Therefore, the greater species richness counts in the control may be primarily attributed to a greater proportion of higher ground and its inherently greater species richness, rather than any treatment effects.

5.3.2 Effective Richness

The mean of the overall effective richness for each treatment was determined, and summarized in Table 5.13. Unlike species richness, fire had the greatest effective richness, followed by scrape, herbicide, mowing, control, and finally unrolled bush. An ANOVA analysis conducted on the five combined treatments plus the unrolled bush showed that there tended to be some blocking effect, but it was not significant ($p < 0.05$) (Table 5.16). There was a significant difference between the treatments, but the difference appeared to be attributed to the inclusion of the unrolled bush, as without the bush no significance was noted between the blocks or treatments.

An evaluation of treatment impact on effective richness was not possible in my study, as a pretreatment survey was not carried out on 4 of the treatments. As with the burn treatment, the survey was conducted by another individual, and upon looking at the raw data from the fire pretreatment survey, I was not comfortable with comparing species richness and effective richness values from pre to post-treatment. Prescribed burning may exert some effect on the effective richness of a plant community, as it is the most invasive treatment. However, it is also possible that effective richness may have been more influenced by environmental factors.

There appear to be 3 primary environmental factors that influence effective richness: light, moisture, and microtopic variations. All treatments, including the control, had a greater mean effective richness than the unrolled bush. A shaded environment, such as the unrolled bush, limits the number of plant species that can thrive under such conditions. Therefore, plants that are adapted to shaded conditions tend to dominate, thereby decreasing the effective richness.

Available soil moisture also appeared to impact effective richness. Just as species richness had an inverse relationship with soil moisture, effective richness also had an inverse relationship with soil moisture, but only up to a point. Effective richness increased dramatically from a low site with high moisture availability, to an intermediate site, as only a limited number of species can grow under high-moisture conditions (Table 5.15). However, effective richness decreased slightly from intermediate to dry conditions, as plant species would be less able to dominate a community when nutrient availability is low.

Complex, small-scale microtopic variations in the landscape appeared to influence effective richness. Fire block A was observed to have the most pronounced variations in microtopography of the 3 fire blocks, and had the greatest effective richness (Appendix H, Table H-3; Table 5.12). Fire A had distinct low areas, intermediate areas, and a higher grassland-like ridge in the plot. The moist and dry environments are limited to plants specifically adapted to such conditions. This range of environmental conditions results in an increased number of species found in the site, and the intermediate and dry areas limit species domination.

Finally, a wide range of effective richness was noted among sites that received the same treatment. Mean effective richness for prescribed burning ranged from 17 to 13, and from 12.6 to 16 for the herbicide treatment (Table 5.12). Therefore, the treatments had very little impact on the plant community (when compared to the control), as effective richness appears to be primarily determined by the inherent small-scale microtopographic variations in the landscape.

5.4 Discussion

None of the literature that described the impacts of herbicide or bark scraping on aspen addressed impacts on plant communities, species richness, or effective richness (Bowes 1997a; Bowes 1997b; Bowes and Kirychuk 1996; Converse and Echardt 1988; Philippot 1996). However, one article described how mowing could be a tool to enhance species richness in the tallgrass prairie when used in conjunction with prescribed burning (Collins *et al.* 1998).

A field experiment conducted in native tallgrass prairie at the Konza Prairie Long-Term Ecological Research site in northeast Kansas evaluated the impact of annual burning with and without supplemental nitrogen, as well as the impact of mowing on these sites with respect to species richness (Collins *et al.* 1998). Even though the study was conducted in a southern region, principles learned from the study could be applied to the Manitoba Interlake. Three years into the experiment, the results suggested that mowing increased species richness on sites that were only burned, as well as on sites that were burned and had supplemental nitrogen. The burn plus nitrogen treatment had the lowest species richness, while the same treatment with mowing had nearly the same species richness as the control, with no difference in significance. The burn only plus mowing had greater species richness than the control. Mowing effectively increases species richness by keeping the more dominant species in check, thereby increasing light availability for other plant species. Therefore, in systems that may not be nutrient deficient or contain dominating plant species, mowing may be an effective tool to lessen the dominance of tall plant species, increase light availability for smaller species, and increase species and effective richness (Collins *et al.* 1998; Knapp *et al.* 1999).

Since the mowing sites in this study were not surveyed prior to treatment, we are not sure if mowing increased species richness. The control sites in this study had greater species richness than the mowing treatment. However, the differences in species richness may be largely reflective of the inherent microtopic variation in the landscape rather than treatment effect. Only pretreatment surveys could definitively answer that question. Nevertheless, species richness in the mowing treatments were clearly greater than the unrolled bush.

The control in this study had greater species richness and lower effective richness than the burn. A study conducted in the tallgrass prairie in Oklahoma found the opposite to be true (Collins 1987). They found that the burn had greater species richness than the control, but lower effective richness. This was attributed to competitive exclusion, which eliminates less-competitive species. As the dominance of a species increased, the effective richness decreased. Only when grazing was combined with burning did species richness and effective richness become greater than the control, as well as the burn without grazing. The different treatment responses may be attributed to different habitat conditions. In addition, perhaps environmental conditions were more consistent between study plots, whereas in my study site, any microtopic change in the landscape resulted in a dramatic shift in the plant community. The scale of these microtopic changes were appreciably smaller than an individual treatment plot, as an individual treatment plot had low, intermediate, and high areas. Therefore, in my study, it was difficult to determine how much to ascribe differences in richness to treatment effects or environmental effects inherent in the landscape.

Just as there were some differing richness results between my study site and those from literature, there were also differences and similarities between the response of plant species in my study and other studies. Slender wheat grass, and northern bedstraw increased in percent frequency in my study, as well as in a study conducted in Wyoming containing a mosaic of grassland, aspen, and sagebrush habitat at 2,400 m elevation (Bartos and Mueggler 1981). A study by Quintilio *et al.* (1991) also found that the frequency of northern bedstraw increased following a prescribed burn. However, a study in the Alberta Aspen Parkland found that percent frequency of northern bedstraw experienced no significant change (Anderson and Bailey 1980). Perhaps northern bedstraw responded differently in the Alberta study because it was burned annually. Frequent burns may favour grass species, whereas sites that were less frequently burned tended to have a higher percent cover of forbs (Knapp *et al.* 1999). Bluegrass species declined significantly from the pretreatment to the post in my study, yet in the Wyoming study bluegrass species increased. The Wyoming study was at a 2,400 m elevation, and was burned in late August. Perhaps different environmental conditions or the late fall burn elicited a different response that was more favourable to bluegrass.

Another grass species, fringed brome, was found more frequently following the burn in my study. Yet in the Wyoming and Alberta studies, fringed brome decreased after burning (Anderson and Bailey 1980; Bartos and Mueggler 1981). Interestingly, in the Wyoming study, fringed brome increased following a light burn, but decreased after a moderate or intense burn (Bartos and Mueggler 1981). Western snowberry was another species that increased in frequency in my study, but decreased slightly in the Alberta study (Anderson and Bailey 1980). Other plant species included: choke-cherry, and saskatoon. Both of these tall shrub species increased in frequency in my study as well as the Alberta study (Anderson and Bailey 1980), but decreased in frequency in a second Alberta study by Quintilio *et al.* (1991).

Species that increased in percent frequency in my study and the Alberta study by Anderson and Bailey (1980) include: yarrow, prairie sage, sedge species, pale comandra, purple peavine, wild bergamot, trembling aspen, and wild vetch. Smooth wild strawberry increased in percent frequency after burning in my study, as well as the two Alberta studies (Anderson and Bailey 1980; Quintilio *et al.* 1991). Prickly rose was a shrub species in my study that remained relatively constant with respect to percent frequency, and decreased in the Alberta study (Anderson and Bailey 1980).

Burning in the Aspen Parkland increased species diversity of grasses, sedges, and forbs, and decreases shrub diversity (Anderson and Bailey 1980). At my study in the Manitoba Interlake, nearly all grass and forb species increased from the prescribed burning treatment, and sedges also increased. Two shrub species which are important to wildlife (*i.e.* sharp-tailed grouse), prickly rose, and western snowberry, were either not impacted by burning, or strongly benefited from the burning. Therefore, it appears that prescribed burning facilitates the shift of a plant community to more of a grassland community, increases species richness and effective richness, and maintains or increases frequency of abundance of plant species important to wildlife in the Manitoba Interlake.

5.5 Summary

Compared to the unrolled bush, the 1997 rolling (*i.e.* control) dramatically increased species richness, as light availability was the most limiting factor. However, when comparing the 4 applied treatments to the control, none of the treatments had a large impact on the vegetation community. The treatment with the greatest impact was prescribed burning, as it caused the plant community to shift towards more of a grassland community. The plant community's species and effective richness was primarily determined by the complex, small-scale microtopic variations inherent in the landscape. Species richness appeared to be determined by available light and soil moisture. All treatments had significantly greater species richness than the shaded environment of the unrolled bush. In addition, as available soil moisture decreased, species richness increased. Hence, areas with limited moisture had greater species richness than areas with abundant moisture. Effective richness appeared to be primarily determined by light, moisture, and microtopic variation. Shaded environments had lower effective richness than open environments. In addition, as moisture decreased, effective richness increased and then declined slightly under dry conditions. Finally, small-scale microtopic variations in the landscape contributed to heightened effective richness through increased diversity in environmental growing conditions.

Table 5.1: Statistical summary of techniques used to analyse the vegetation data (Principal Components Analysis and Redundancy Analysis).

Analysis	Data Set	Covariables	Constraining Variables	Transformation
PCA_1	Veg 2001Species Frequency Data	None	None	Squareroot
PCA_2	Veg 2001 Species Frequency Data	Blocks	None	Squareroot
PCA_3	Pretreatment & Veg 2001 Species Frequency Data	None	None	Squareroot
RDA	Veg 2001 Species Frequency Data	Blocks	Treatments	Squareroot

Table 5.2: Highlights of plant species for Figure 5.2 with different frequency values.

2001 Plant Species		% Frequency Summary		
Latin Name	**Common Name**	**Block A**	**Block B**	**Block C**
Apocynum androsaemifolium	Spreading dogbane	11.67%	31.67%	5.00%
Arctostaphylos uva-ursi	Bearberry	65.83%	52.50%	56.67%
Artemisia ludoviciana	Prairie sage	57.50%	57.50%	70.83%
Cirsium arvense	Canada thistle	0.00%	0.83%	0.83%
Geum triflorum	Three-flowered avens	4.17%	0.00%	15.83%
Lactuca tatarica	Blue lettuce	10.00%	14.17%	6.67%
Lathyrus venosus	Purple peavine	79.17%	93.33%	79.17%
Maianthemum canadense	Lily of the Valley	0.83%	15.00%	5.83%
Polygala senega	Seneca root	26.67%	25.00%	9.17%
Potentilla fruticosa	Shrubby cinquefoil	19.17%	6.67%	19.17%
Smilacina stellata	Star-flowered false solomon's seal	10.00%	8.33%	20.83%
Solidago rigida	Stiff goldenrod	35.83%	17.50%	32.50%
Solidago spathulata	Spike-like goldenrod	41.67%	32.50%	40.83%
Sonchus arvensis	Sow-thistle (perennial)	0.00%	0.83%	0.83%
Stipa richardsonii	Richardson's needle grass	15.00%	2.50%	11.67%
Symphoricarpos occidentalis	Western snowberry	49.17%	70.83%	67.50%
Zizia aptera	Heart-leaved alexanders	17.50%	14.17%	20.83%

Table 5.3: Relative abundance in percent of cover types from the 2001 data.

Cover Type	Block A	Block B	Block C	Bush
Grass	22.26	23.62	22.78	15.47
Sedges	6.58	6.15	6.53	14.52
Herbs	27.74	28.52	28.68	18.39
Legumes	5.13	5.82	3.50	5.71
Low Herbs	6.36	7.68	5.71	4.68
Lily	0.22	0.40	0.50	2.32
Low Shrub	10.82	8.47	9.54	1.66
Tree	8.19	6.58	8.11	19.88
Tall Shrub	12.15	11.98	14.33	16.85
Weeds	0.56	0.78	0.33	0.52

Table 5.4: Relative abundance of 001 cover types for fire B and herbicide B.

Relative Abundance of Cover Types in 2001		
Cover Types	**Fire B**	**Herb B**
Grass	13.67	3.97
Sedges	20.82	20.53
Herbs	24.16	27.95
Legumes	7.24	4.29
Low Herbs	8.24	9.17
Lily	0.07	0.29
Low Shrub	0.00	18.48
Tree	6.98	5.83
Tall Shrub	16.64	9.15
Weeds	2.18	0.34

Table 5.5: Relative abundance of pre-and-post-treatment cover types for the 3 burn plots.

Cover Type	Block A		Block B		Block C	
	Pre	Post	Pre	Post	Pre	Post
Grass	31.55	16.88	50.77	20.82	34.06	22.70
Sedges	6.15	13.22	5.74	13.67	2.24	3.06
Herbs	3.71	23.17	6.14	24.16	5.06	28.75
Legumes	0.63	7.44	0.60	7.24	0.46	2.39
Low Herbs	0.87	5.45	4.14	8.24	1.67	6.37
Lily	0.00	0.18	0.00	0.07	0.00	0.65
Low Shrub	20.98	6.29	0.00	0.00	36.02	13.76
Tree	5.60	6.11	11.41	6.98	12.95	7.93
Tall Shrub	30.52	20.56	21.15	16.64	7.54	14.29
Weeds	0.00	0.70	0.07	2.18	0.00	0.09

Table 5.6: Relative abundance in percent of 2001 cover types for the 3 mowing treatment sites.

Relative Abundance of Cover Types in 2001			
Cover Type	Mow A	Mow B	Mow C
Grass	17.85	29.75	25.00
Sedges	4.71	4.44	10.38
Herbs	27.64	27.49	25.41
Legumes	4.47	5.08	5.23
Low Herbs	6.46	6.43	5.42
Lily	0.18	0.30	0.63
Low Shrub	16.71	8.69	3.86
Tree	13.29	6.84	8.44
Tall Shrub	8.60	10.77	15.35
Weeds	0.09	0.21	0.28

Table 5.7: Redundancy Analysis of 2001 vegetation frequency data with blocks as covariables and squareroot-transformation.

RDA Summary	Axis 1	Axis 2
Eigenvalues	0.126	0.075
Species-environment correlations	0.758	0.881
Cumulative percentage variance of species data	16.4	26.2
Cumulative percentage variance of species-environment relation	41.5	66.3
	Sums	
Sum of all unconstrained eigenvalues (after fitting covariables)		0.767
Sum of all canonical eigenvalues (after fitting covariables)		0.303
Data Redundancy		39.50%

Table 5.8: Relative abundance (in percent) for cover types in respective treatments for 2001.

Cover Type	Control	Fire	Herbicide	Mowing	Scrape	Bush
Grass	25.26	20.13	21.83	24.20	23.00	15.47
Sedges	4.82	9.98	5.02	6.51	5.76	14.52
Herbs	28.67	25.36	28.63	26.85	32.06	18.39
Legumes	4.35	5.69	4.32	4.93	4.79	5.71
Low Herbs	6.74	6.69	6.88	6.10	6.50	4.68
Lily	0.40	0.30	0.39	0.37	0.40	2.32
Low Shrub	10.74	6.68	12.64	9.75	8.25	1.66
Tree	6.49	7.01	8.25	9.52	6.86	19.88
Tall Shrub	12.01	17.16	11.53	11.57	11.83	16.85
Weeds	0.52	0.99	0.51	0.19	0.56	0.52

Table 5.9: Relative abundance of cover types in the following quadrats found in the scrape treatment block A, during the 2001 survey.

Cover Type	Q14	Q15	Q16	Q17
Sedge	3.94	35.38	13.23	10.81
Grass	9.84	16.51	10.58	27.03
Herbs	35.83	9.43	26.46	32.43
Legumes	3.94	3.30	5.29	0.00
Low Herbs	4.72	10.38	3.70	5.41
Lily	1.18	0.00	0.00	0.00
Low Shrub	27.56	0.00	0.00	0.00
Tree	5.91	0.00	6.35	8.11
Tall Shrub	7.09	25.00	34.39	16.22

Table 5.10: Relative abundance of cover types in low, intermediate, and high areas in fire A during 2001.

2001 Fire A Post-treatment			
Cover Type	**Low**	**Intermediate**	**High**
Grass	10.43%	14.48%	22.56%
Sedges	40.98%	11.71%	4.98%
Herbs	8.49%	21.48%	31.61%
Legumes	4.92%	8.98%	6.64%
Low Herbs	4.02%	5.29%	5.97%
Lily	0.00%	0.07%	0.43%
Low Shrub	0.00%	0.00%	17.77%
Tall Shrub	20.12%	30.78%	5.21%
Tree	8.20%	6.82%	4.36%
Weeds	2.83%	0.39%	0.47%

Table 5.11: Relative abundance of pretreatment vs. post-treatment cover types in low, intermediate, and high areas in fire A.

Cover Type	Low		Intermediate		High	
	Pre	Post	Pre	Post	Pre	Post
Grass	63.51	10.43	30.39	14.48	24.28	22.56
Sedges	4.05	40.98	8.82	11.71	3.79	4.98
Herbs	0.68	8.49	3.59	21.48	4.90	31.61
Legumes	1.35	4.92	0.82	8.98	0.22	6.64
Low Herbs	1.35	4.02	0.16	5.29	1.78	5.97
Lily	0.00	0.00	0.00	0.07	0.00	0.43
Low Shrub	0.00	0.00	0.00	0.00	59.02	17.77
Tree	8.11	20.12	6.37	30.78	3.12	5.21
Tall Shrub	20.95	8.20	49.84	6.82	2.90	4.36
Weeds	0.00	2.83	0.00	0.39	0.00	0.47

Table 5.12: Mean species richness and effective richness for each treatment plot.

2001 Plant Community Diversity			
Treatment	Block	Species Diversity	Effective Richness
Control	A	52	11.87
	B	46	13.59
	C	51	11.15
Fire	A	49	17.01
	B	43	14.19
	C	48	13.33
Herbicide	A	49	16.10
	B	41	12.62
	C	48	13.51
Mowing	A	47	13.90
	B	46	11.24
	C	44	11.59
Bark Scrape	A	49	15.35
	B	44	13.17
	C	47	15.54
Unrolled Bush	A	39	11.27
	B	35	11.19
	C	37	8.86

Table 5.13: Mean species richness and effective richness for each treatment in 2001.

Treatment	Species Richness	Effective Richness
Control	49.67	12.21
Fire	46.67	14.84
Herbicide	46.00	14.08
Mowing	45.67	12.24
Bark Scrape	46.67	14.69
Unrolled Bush	37.00	10.44

Table 5.14: Species richness significance for blocks and treatments, with and without the unrolled bush using a random block design ANOVA.

2001 Species Richness		
Treatments	**F-ratio**	**Probability**
5 Treatments Including Unrulled Bush		
Blocks	14.463	0.0011
Treatments	20.599	<0.0001
5 Treatments Without Unrolled Bush		
Blocks	11.026	0.005
Treatments	2.3523	0.141

Table 5.15: Overall richness values found in low, intermediate, and high microtopic sites in fire A during 2001.

Overall Richness	Ground Type in Fire A		
	Low	Intermediate	High
Species Richness	19	37	41
Effecitve Richness	4.94	15.64	12.41

Table 5.16: Results of a random block design ANOVA on the combined 5 treatments with and without the unrolled bush.

2001 Effective Richness		
Treatments	**F-ratio**	**Probability**
5 Treatments Including Unrulled Bush		
Blocks	3.9757	0.0536
Treatments	5.7162	0.0095
5 Treatments Without Unrolled Bush		
Blocks	3.4462	0.0833
Treatments	3.0486	0.0841

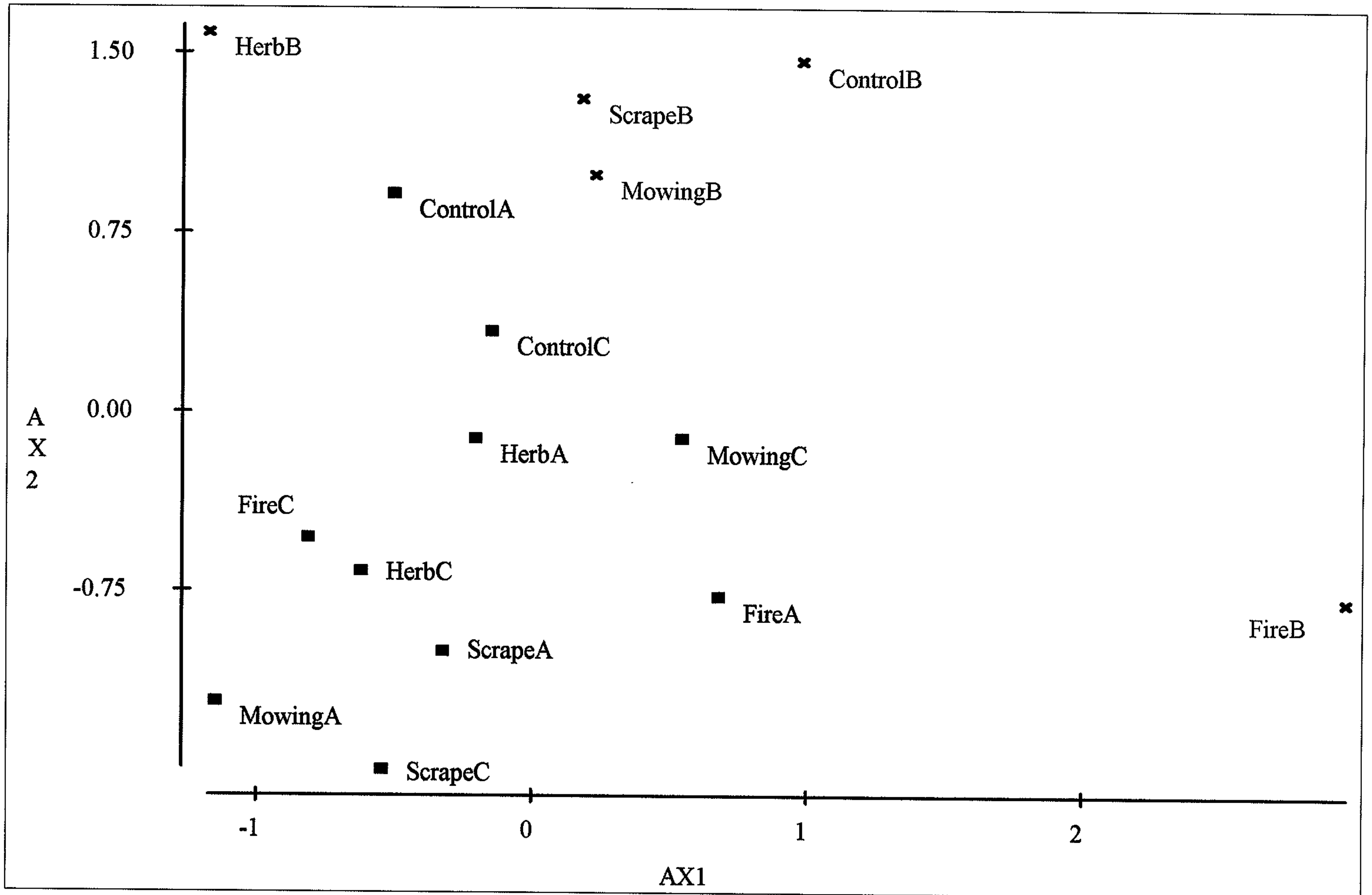


Figure 5.1: PCA_1 scatterplot on treatment site locations. Block B treatments are marked with an X and are blue. The remaining treatments are black.

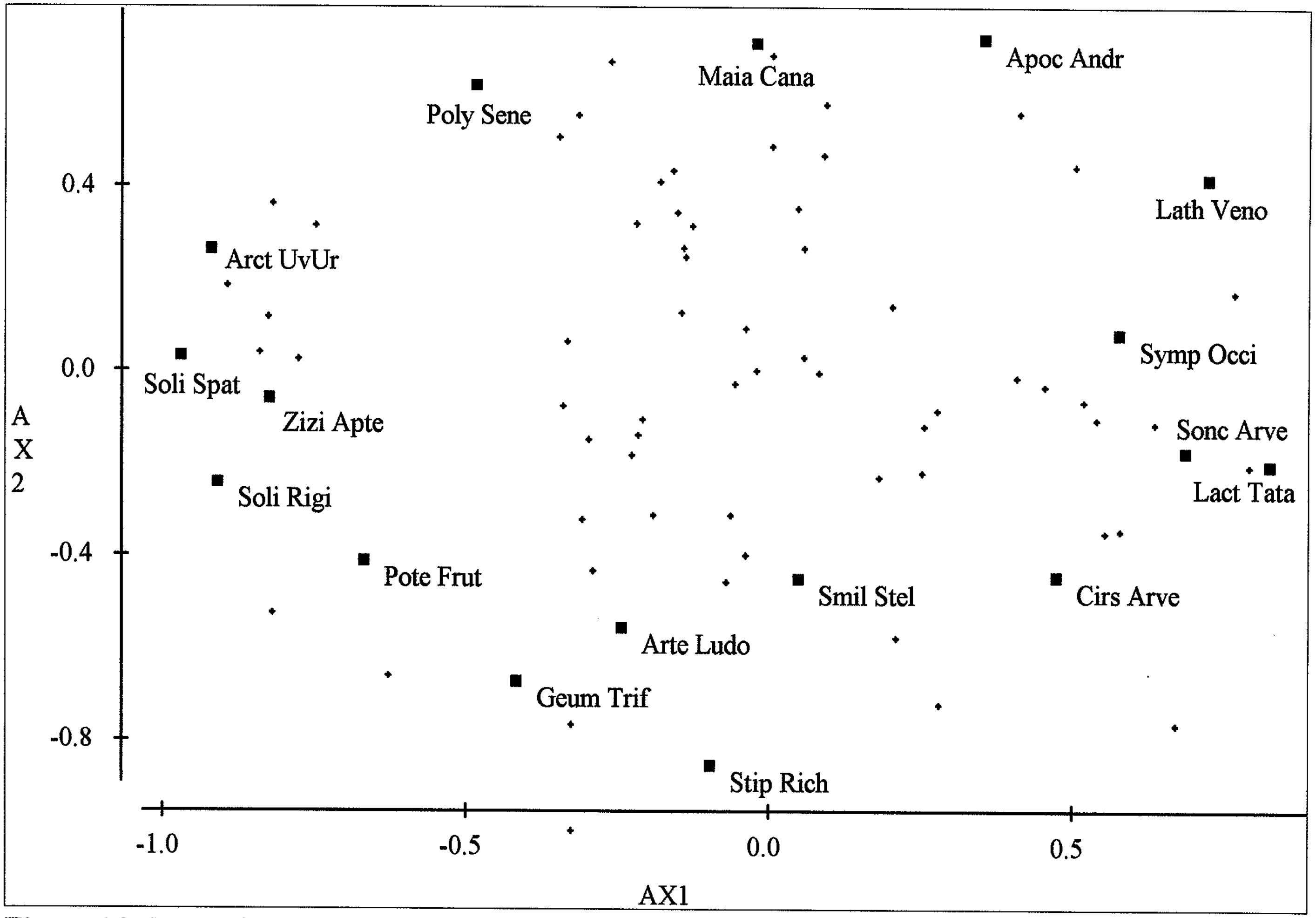


Figure 5.2: Scatterplot of PCA_1 with select plant species.

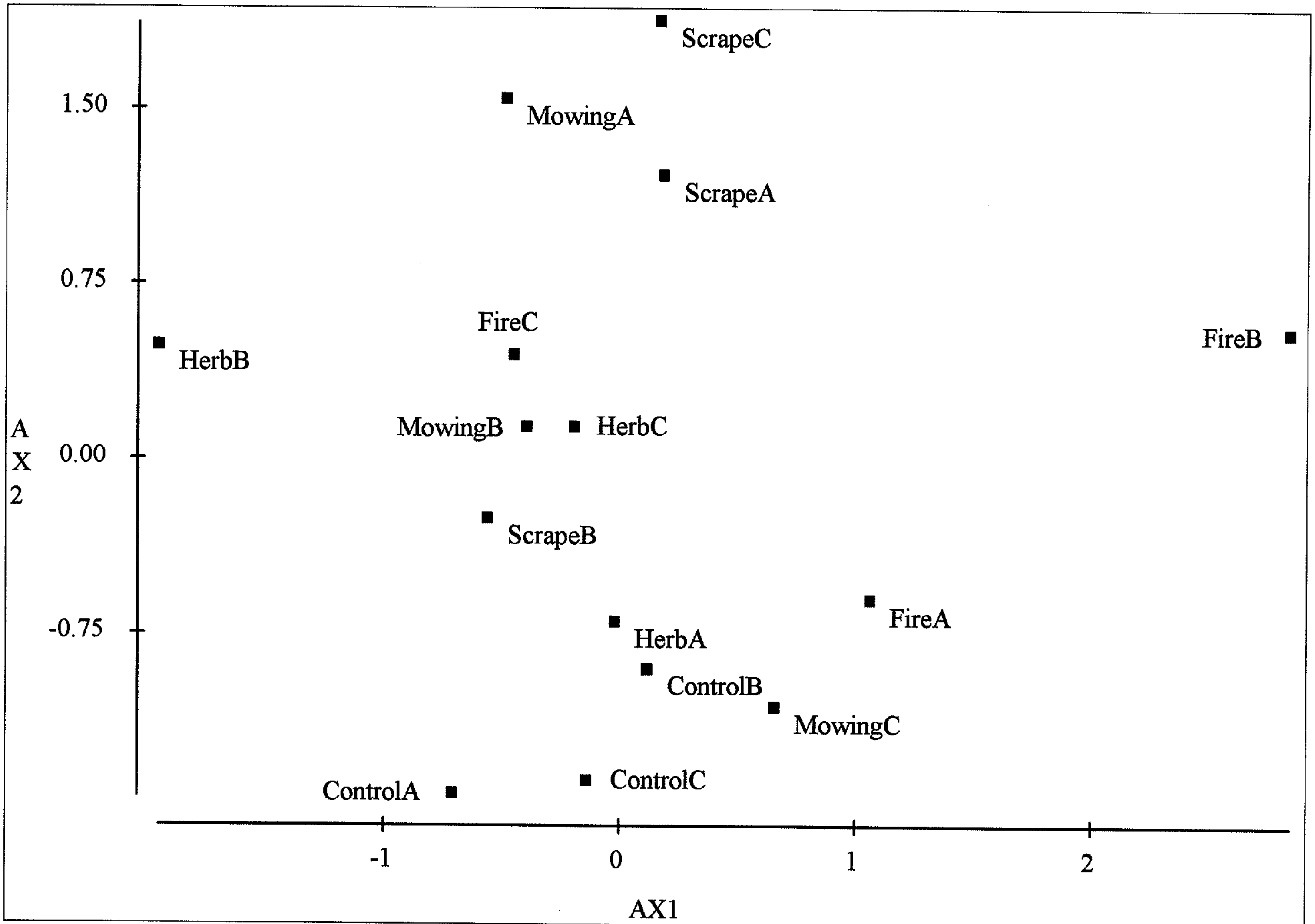


Figure 5.3: Sites for PCA_2 from the 2001 vegetation frequency data.

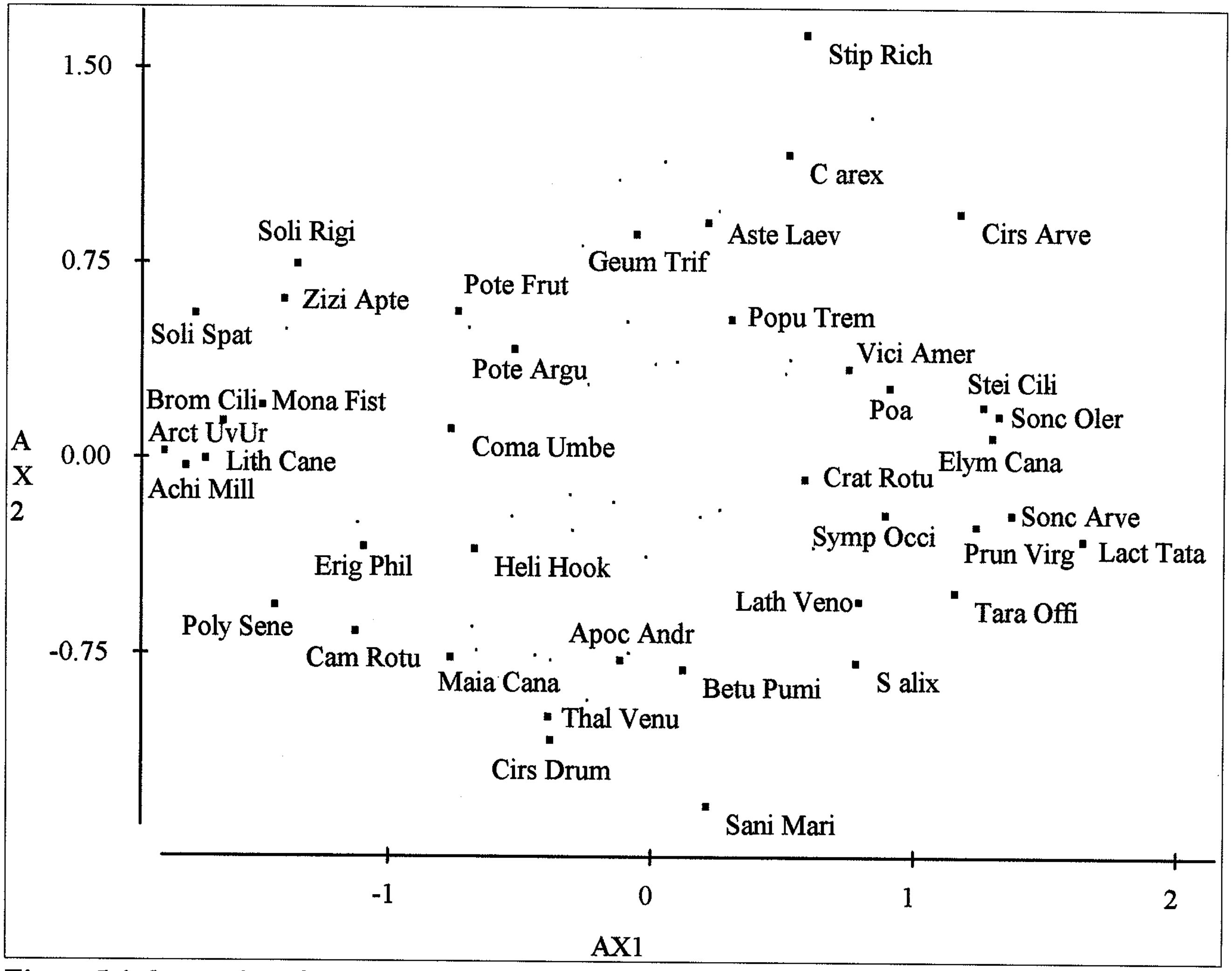


Figure 5.4: Scatterplot of PCA_2 for 2001 vegetation species frequency of occurrence.

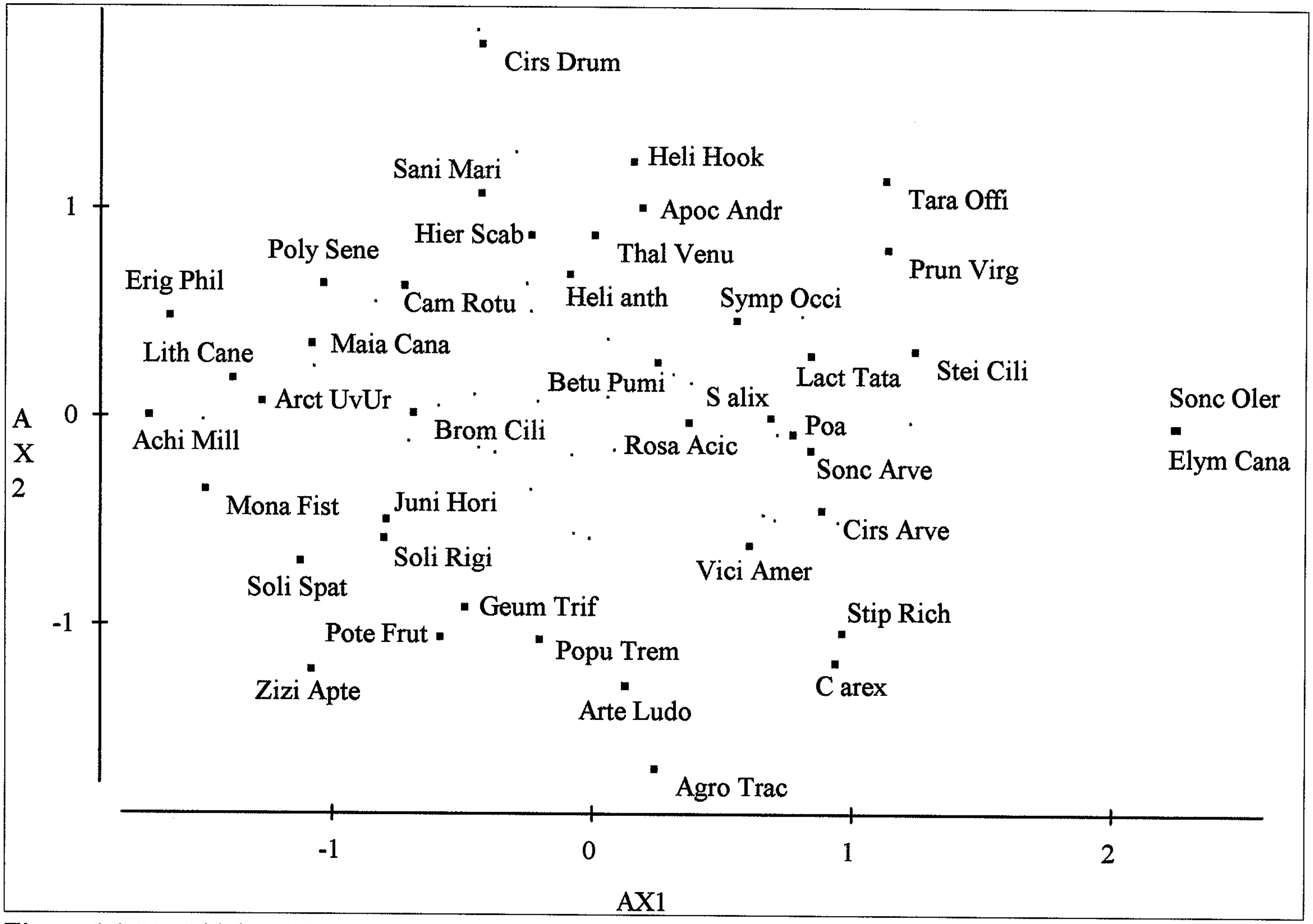


Figure 5.5: RDA biplot with select vegetation species.

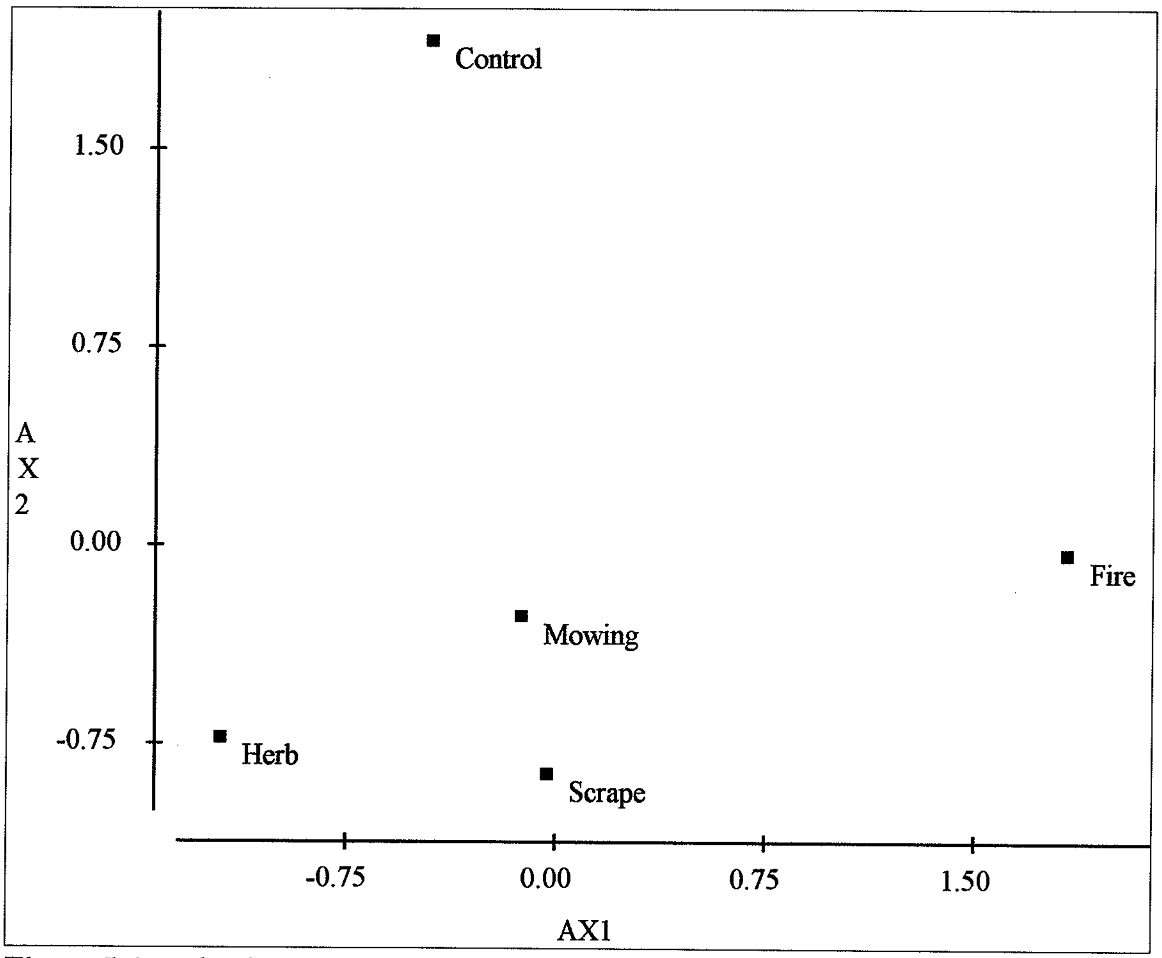


Figure 5.6: Redundancy Analysis biplot of the five treatments.

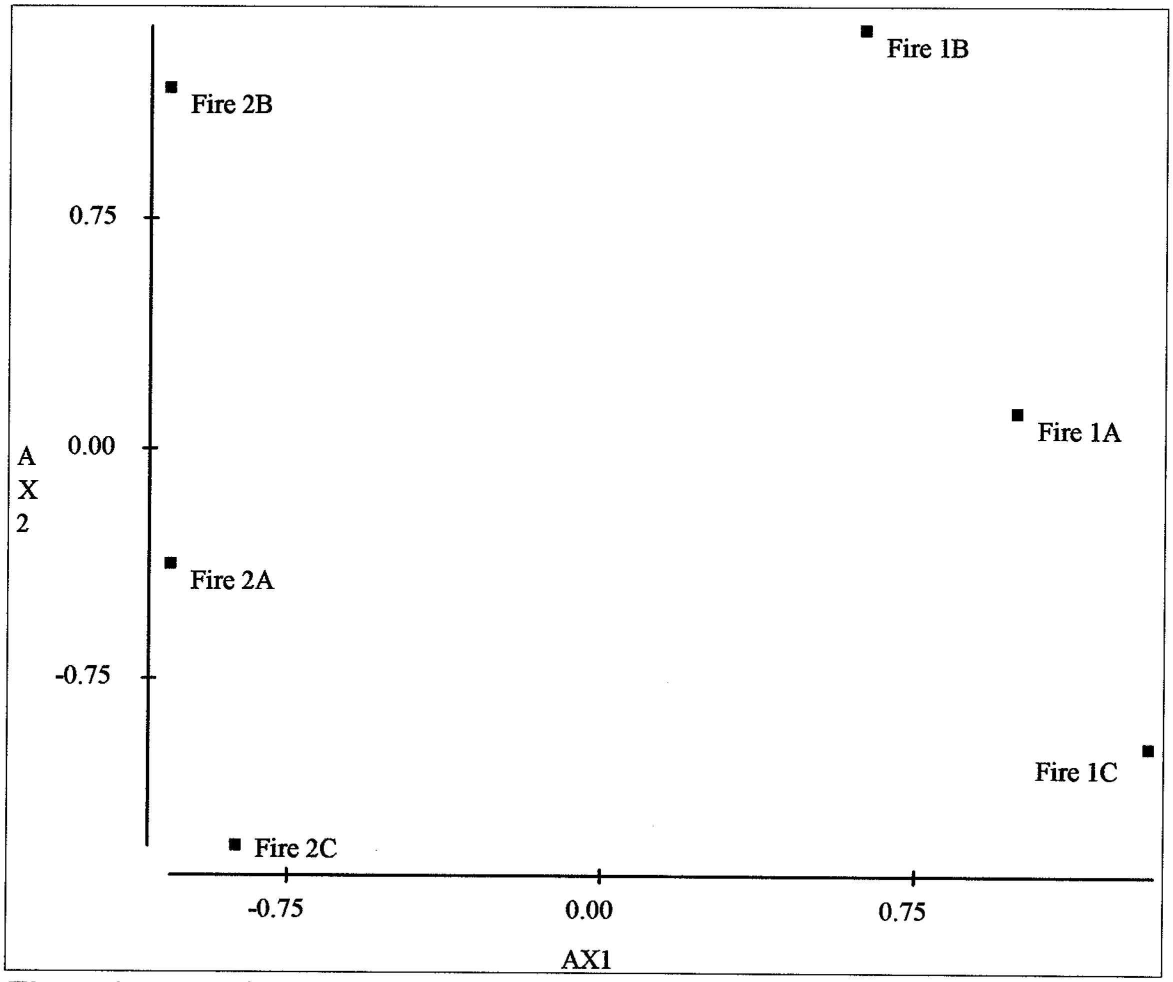


Figure 5.7: PCA_3 biplot of pretreatment vs. post-treatment of the 3 fire blocks. The "1" represents the pretreatment, and "2" represents the post-treatment. The letters represents the particular block the treatment sites were located.

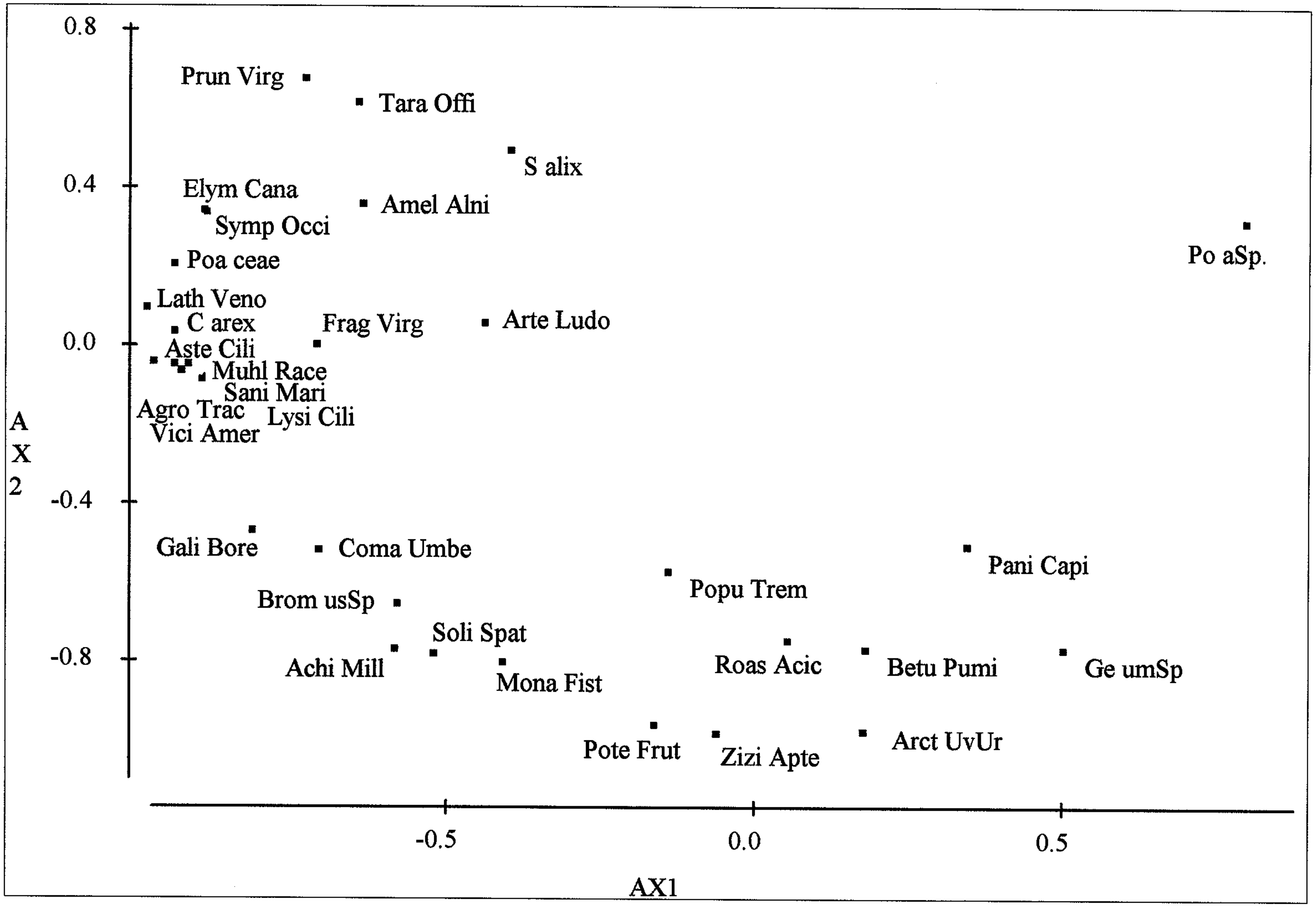


Figure 5.8: PCA_3 biplot based on pretreatment and post-treatment vegetation surveys.

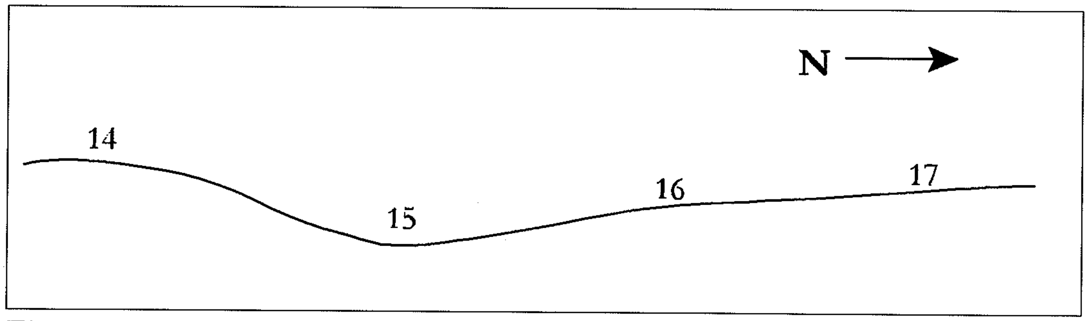


Figure 5.9: Sampling plots along a moisture gradient in the scrape treatment, block A. Plots are 15 m apart from each other.

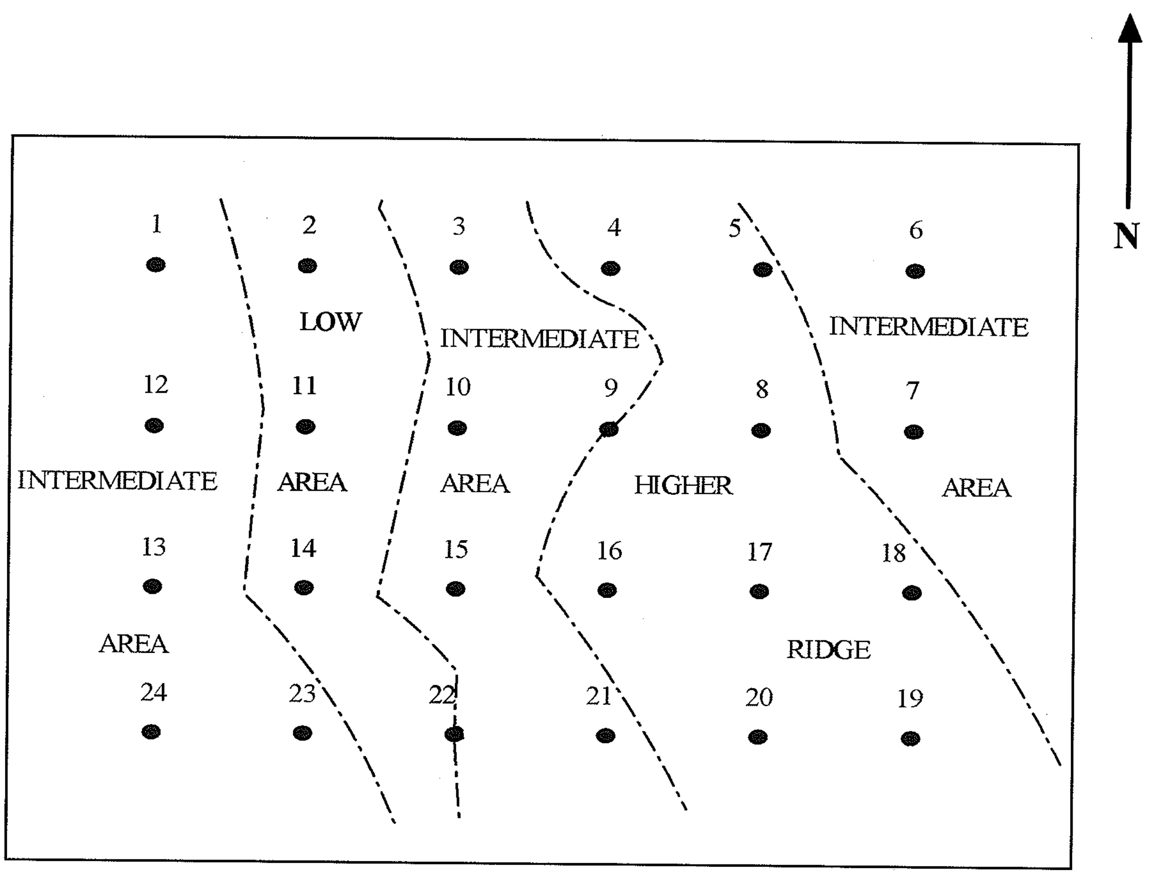
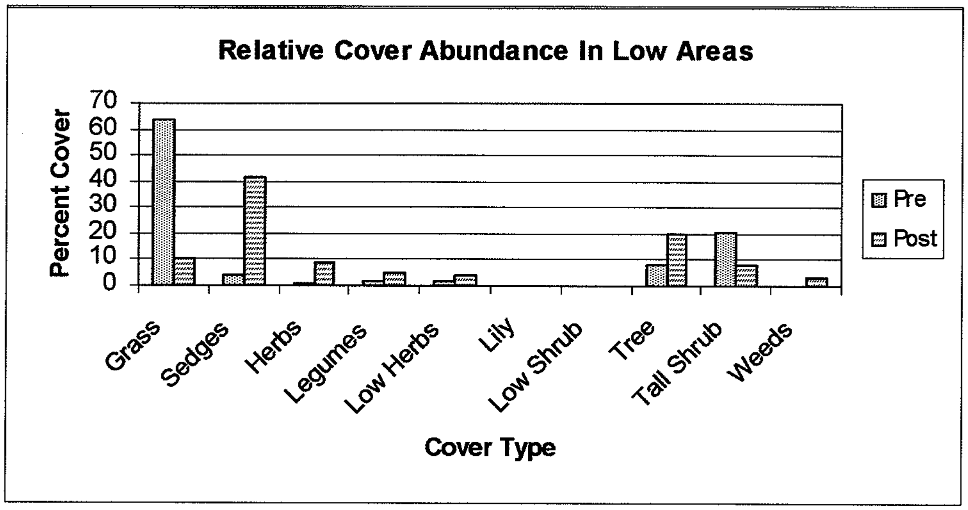
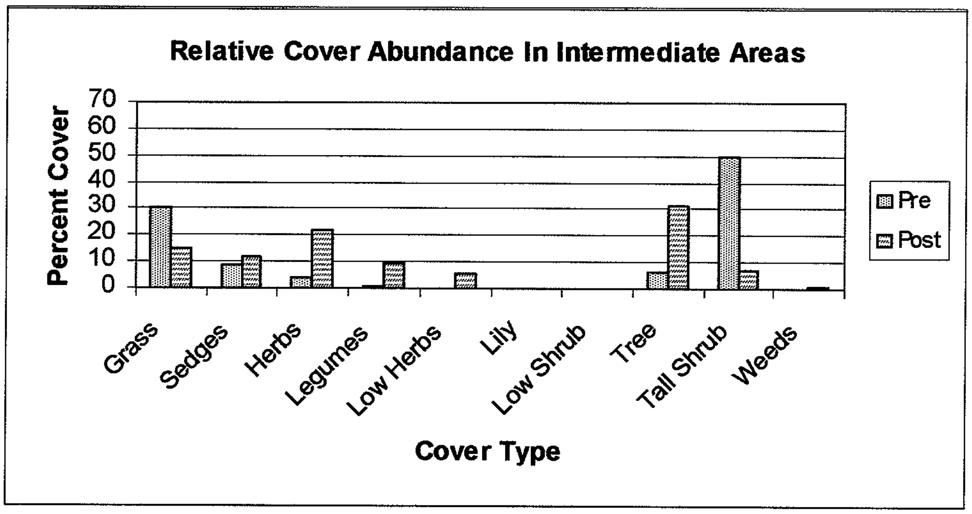


Figure 5.10: Moisture gradient outline for fire block A.





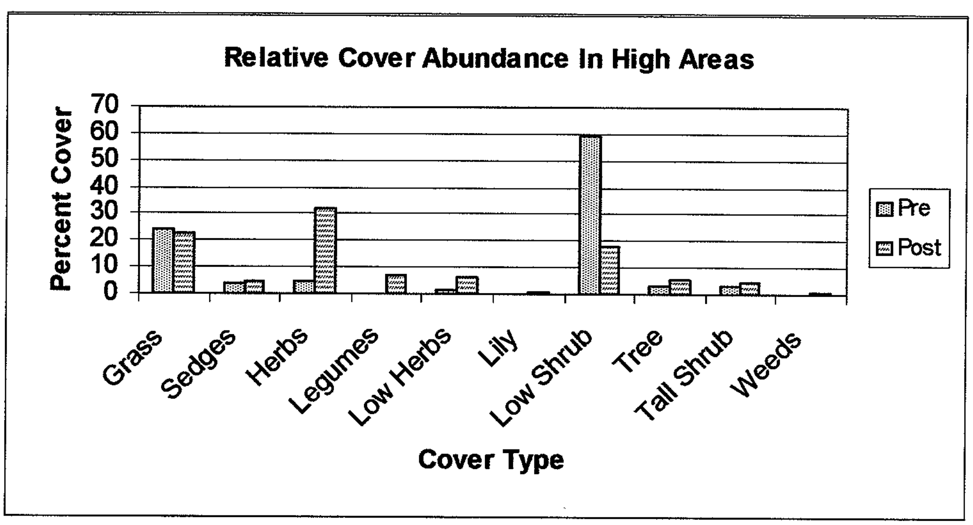


Figure 5.11: Relative cover abundance in low, intermediate, and high areas in fire A before and after burning.

CHAPTER 6: SHARP-TAILED GROUSE HABITAT MANAGEMENT PLAN

6.1 Introduction

Objectives of Wildlife Management Areas (WMA's) include protection of critical habitats and preservation of ecological integrity, resulting in the enhanced protection of biological diversity. The definition of biological diversity (or biodiversity) is continually evolving. Environment Canada defines biodiversity as "the variability among living organisms from all sources, including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems" (Baydack and Campa III 1999 pg 5). This encompasses the variability in habitat composition and structure, and the ecological processes that take place in that habitat, all of which influence biodiversity.

To maintain biodiversity, it is important to understand the characteristics of any ecosystem, including composition, structure, and function (Baydack and Campa III 1999). Important components are the biotic and abiotic interactions within and between ecosystems, including historical disturbances. Disturbances may cause change in the composition, structure, and functions in an ecosystem, thus creating a natural range of variability. Human induced disturbances that never occurred previously, or the suppression or elimination of disturbances that previously occurred, may cause an ecosystem's composition, structure, and function to change, possibly beyond the natural range of variability.

This change beyond the natural range of variability (*i.e.* a dynamic ecosystem that has become much less dynamic, advancing to a climax state) has occurred in regions such as the Aspen Parkland in Manitoba's Interlake. These habitat changes have impacted biological diversity and wildlife populations, such as the sharp-tailed grouse and the endangered eastern loggerhead shrike. Sharp-tailed grouse require grasslands for dancing grounds, shrublands for nesting, feeding, and daytime resting, and woodlands for winter thermal cover and escape (Gylywoychuk 1993; Johnsgard 1973). Both grassland and shrubland habitats have been negatively impacted by aspen encroachment, and may have resulted in what appears to be a substantial decline in the sharp-tailed grouse population in the NWMA during 2001 (Baydack, pers. comm.). Eastern loggerhead shrike have experienced habitat loss through shrub and tree advancement onto grassland sites (De Smet 1993). Therefore, the impact of habitat change on population decline, and the ongoing threat of species being extirpated from the province, magnifies the importance of effective management of Manitoba's Wildlife Management Areas, to enhance and protect habitat and biological diversity.

Effective management of Manitoba's Wildlife Management Areas, particularly in the Manitoba Interlake, should reflect the historical natural range of variability because it is a dynamic transition zone. The historical range of variability appears to be best described as a 1/3 grassland, 1/3 shrubland, and 1/3 woodland mixture (Sexton, pers. comm.). In order to restore and maintain historic Aspen Parkland conditions, treatments which emulate natural disturbance, effectively kill aspen, restrict aspen spread onto grasslands and shrublands, and increase species richness in the plant community should be employed to maintain the naturally functioning dynamic ecosystem that was historically found in the Manitoba Interlake.

This historically natural functioning ecosystem provided sharp-tailed grouse populations with grassland, shrubland, and woodland habitats. Since sharp-tailed grouse requirements for these various habitats varies both daily and annually, they appear to respond strongly to habitat change. Hence, sharp-tailed grouse may be considered to be a form of indicator species for habitat degradation and biological diversity conditions in the Manitoba Interlake. Therefore, long-term annual monitoring of sharp-tailed grouse population trends should reflect the degree of diversity in existing habitat conditions, and the effectiveness of habitat enhancement projects.

6.2 Management Goals

Sharp-tailed grouse require a diversity of habitat types in order to meet daily and seasonal requirements (Gylywoychuk 1993; Johnsgard 1973). To successfully manage sharp-tailed grouse, a given landscape should possess a balance (*i.e.* 1/3 grassland, 1.3 shrubland, and 1/3 woodland) of quality habitat types possessing grassland and shrubland habitats with little aspen encroachment in order for sharp-tailed grouse to effectively meet their daily and seasonal requirements.

Sufficient dancing ground sites are one important component (Gylywoychuk 1993). The area immediately surrounding the lek site must also have a significant grassland area. Aspen encroachment on grassland areas seems to cause sharp-tailed grouse to abandon dancing grounds (Berger and Baydack 1992). Thus, it is hypothesized that the grouse population is in decline or perhaps has shifted away from the NWMA because of changed habitat conditions. This was evidenced by a sharp population decline observed in 2001 in the Interlake (Baydack, pers. comm.).

In addition, sharp-tailed grouse abandoning leks may also indicate that the quality of the overall habitat is declining (Berger and Baydack 1992). A decrease in habitat quality would result in increased intraspecific competition, lower food quality and abundance, lower average individual fitness, and increased mortality rates.

Hence, it appears that habitat diversity and quality may be the most limiting factors for the sharp-tailed grouse population in the NWMA and the surrounding Manitoba Interlake region. So to effectively manage sharp-tailed grouse and increase the population, one should increase the limiting factors: habitat quality and diversity (*i.e.* decreasing quality and availability of grasslands and shrublands). Aspen forest succession is occurring in the NWMA at an average rate of 1.8% per year, and prairie habitat decreases 1.8% per year (Berger and Baydack 1992). The parkland habitat in and surrounding the NWMA is dynamic, and needs to be actively managed with treatments that emulate natural disturbance. Hence, the goal for the Interlake habitat management plan is to increase habitat quality and diversity for sharp-tailed grouse by increasing grassland and shrubland quality and availability. In addition, the goal is to increase the number of displaying males on dancing grounds. This may provide an indication of the health of the population, and if the management recommendations are effective.

6.3 Management Recommendations

Using principles of adaptive resource management, a set of short-term and long-term strategies are discussed below. These recommendations are experimental, and will need to be monitored. Feedback can be used to modify and improve future decisions.

6.3.1 First Year

Baseline data should be obtained in the NWMA, as well as the surrounding fields, by locating historic and active dancing grounds, and counting the number of males on each active dancing ground.

The following factors should be followed to determine lek site selection: a) the site should be a historical dancing ground or an area known for recent sharp-tailed grouse activity, b) there should be evidence that the site is changing from grassland to tree cover, and c) the site should be within 1.6 to 2.4 km from other active lek sites (Gylywoychuk 1993). A 4th criteria should include the shrub habitat surrounding a historic or known dancing ground has deteriorated to semi-mature woodland.

The treatment site could be limited to no more than 100 acres to keep the application manageable. Prescribed burning in the early spring would be the preferred treatment, as burning facilitates a plant community to change to more of a grassland community. Two out of 3 burned sites should be followed by short, intensive grazing or mowing in mid August of the same year to create a diverse habitat on the treatment site that will fulfill various daily and seasonal requirements. Grazing would be best suited to enhance shrub habitat, while mowing would be acceptable to manage lek sites. One out of 3 burned sites should receive no followup treatments, thus promoting a dynamic ecosystem. Treatments should be implemented such that various habitat types would be a mosaic-like structure to increase edge effects, following the recommended percentage and size of the various habitat types listed in Table 6.1. The 24 ha of grass and shrub habitat should attract breeding males (Gylywoychuk 1993).

Active leks and their surrounding shrublands within a proposed 100 acre treatment area experiencing moderate to heavy aspen advancement should be treated. Historic dancing grounds should also be located and treated, creating where possible lek sites ranging from 3.3 ha to less than 20 ha (Gylywoychuk 1993).

When prescribed burning is not feasible, or a less expensive treatment is desired, bark scraping could be used in conjunction with a grazing followup treatment during mid August. Glyphosate could also be applied with a wiper following full leaf flush. This treatment could initially be conducted as a mini-experiment, to technically evaluate the impact of timing (*i.e.* early July vs. mid August), its effectiveness in killing aspen and the extent of resprout production following treatment application.

Communities of Chatfield, Narcisse, Poplarfield, Sandridge, and the First Nations group near Fisher Branch should be informed of the management goals and proposed recommendations for the NWMA. It would be important to get their feedback, concerns and insights to the problems being addressed, and to invite their involvement in noting wildlife species observed, and in the monitoring and management of sharp-tailed grouse.

6.3.2 Years 2 to 10

During the second year, sharp-tailed grouse surveys should be conducted in the spring to identify which dancing grounds are being used, as well as how many grouse are found on each lek site. This data should be compared with the pretreatment data to determine if the creation of habitat types with the suggested percentages around an active lek resulted in an increase in the number of males on the dancing ground, and if additional dancing grounds were established. If this was not successful, hypotheses will need to be postulated as to why the findings occurred, and a revised plan of action determined, according to the chosen hypothesis (Figure 6.1). Trembling aspen surveys should be conducted on 2 of 3 treated areas during July to determine live stem density and percent cover of aspen, and to determine if the sites require a second grazing or mowing treatment in mid August to reduce aspen to less than 5 percent cover (Bowes 1997a). The target for changing the habitat in and surrounding the NWMA is the historic 1/3 grassland, 1/3 shrub land, and 1/3 woodland mixture (Sexton, pers. comm.). The third treated area should not receive followup treatments in order to promote a dynamic landscape and increase biodiversity. Additional areas needing treatment should be located annually (beginning in year three), and a proportion treated as budget permits. The site selection process should be the same as described in selecting the first year treatment. Each newly treated area should be surveyed for 4 consecutive years to evaluate aspen response and determine if another August treatment is required to reduce aspen to less than 5 percent cover, as well as to monitor lek site usage and numbers. This process should be continued on the treated areas until the ultimate goal of 1/3 grassland, 1/3 shrubland, and 1/3 woodland is reached. All abandoned leks and the regions around them in a 1.0 km radius should be treated.

Lek sites ranging from 3.3 ha to less than 20 ha should be created (Gylywoychuk 1993). These leks need to be monitored each year to determine how lek size directly reflects on the number of males using the lek, and where a plateau is reached. This data could be applied to future treatments.

Sites that were treated with a bark scraper should receive another followup treatment during August of the second year for continued aspen sucker management. Treated sites should be surveyed during the third year to evaluate aspen stem density, and determine if additional followup August treatments are required to reduce aspen percent cover to 5 percent or less.

Mini-experiments should be conducted on selected lek sites during mid August to compare the effectiveness of short intensive grazing, mowing, and herbicide applied with a wiper, for restricting aspen encroachment onto grasslands and shrublands. Managers may also consider burning the lek sites and surrounding shrublands 3 years following the initial burn not only to inflict further damage to the aspen clone, but also to cause the plant community to have a greater shift towards a grassland community. Mowing the lek sites during August, before the second burn, should add to the fuel load to increase burn intensity. The knowledge gained from these mini-experiments can be used to further enhance and refine long-term plans.

6.3.3 Establishing A Bioreserve

The establishment of the Narcisse Bioreserve, with an approximately 10 km wide perimeter around the NWMA, should be considered (Figure 6.2). The habitat surrounding the NWMA is also important for promoting habitat diversity, connectivity, and biological diversity. By working together with local landowners, more benefits will likely be gained by landowners, managers and wildlife.

The Fisher Branch First Nations group, local community members and landowners, should be advised about the successes and failures of the treatments on an ongoing basis. This will keep local groups informed and supportive of the management objectives. One might also gain additional insights from the community regarding other methods or strategies that could be implemented.

Regular meetings should be scheduled with local landowners to identify the extent to which aspen encroachment is a problem, and to discuss available strategies to restore grazing habitat. If some landowners do not feel that aspen encroachment on their land is a problem, it would be important for managers to meet with them to discuss why it is not a problem, what strategies they are employing, and if they would be willing to assist in noting the variety of wildlife species seen on their property, as well as monitoring and evaluating the sharp-tailed grouse population on their land.

6.4 Implementation Strategies

6.4.1 First Year

During April, the active dancing grounds and historic lek sites should be located, to obtain baseline data and confirm the activity of the historic sites. Leks with six or more males are considered stable, and those with 4 or less males are considered sporadic (Caldwell, pers. comm.). During April and May, dancing grounds become active about 30 minutes prior to sunrise (Gylywoychuk 1993). Three or 4 counts should be conducted at each dancing ground, enumerating the displaying males (Caldwell, pers. comm.). These lek counts should be compared with post-treatment counts.

Prescribed burning in the early spring is the preferred treatment applied to the first 100 acre site, because of its effectiveness in killing aspen, and in changing the plant community to better reflect a grassland community, as was shown in my study (Quintilio *et al.* 1991). These plant community changes should make it possible for sharp-tailed grouse to return to historically abandoned leks (Baydack and Hein 1987). Quintilio *et al.* (1991) also suggests that fire of low to medium intensity stimulates aspen suckering. However, frequent fires of low to medium intensity, or a high intensity fire is effective in killing aspen with minimal suckering. Therefore, it is recommended that a prescribed burning treatment be applied in a three-step planning sequence (Irving 2001). The first step is to have a pre-burn plan. Grazing could be used in advance to limit the fuel load if necessary, or grazing may have to be restricted to increase fuel load. Mowing may also be used to increase fuel load. In addition, fire breaks have to be established, and a burning plan developed.

Secondly, the burning operation should be carried out in early May, just before green-up, during the afternoon. Later afternoon would be a better time to burn if it has rained the previous day in order to let the vegetation dry thoroughly, thus promoting a hotter burn. This should ensure that the material on the ground has been dried from the wind, and that there are minimal green leaves, thus resulting in a hotter burn and less aspen suckering. A head fire should be employed as it has a lower impact on grasses and a greater detrimental impact on shrubs (Irving 2001). Conversely, a backfire tends to inflict greater damage on grasses, and less on shrubs. If a high intensity burn is achieved, the clonal root system will be damaged from the heat passed to the root system in the shallow Interlake soils. According to the results obtained in my study, aspen stem density should be lower than the first season following the burn.

Thirdly, there needs to be a post-burn plan, which is often not addressed. (Irving 2001). The purpose of this final plan is to continue treatment application to manage aspen suckers and deplete the carbohydrate reserves in the root system and inflict further damage until the clone dies. It is of utmost importance to apply another treatment during late summer of the same year the burn was conducted, to increase the detrimental effects of decreased carbohydrate reserves of the aspen clone. An adaptive management strategy should be used to monitor and evaluate the aspen response to the fall treatment, to determine if another fall defoliation treatment is required to decrease the percent cover to 5% (Bowes 1997a).

Timing of the post-treatment defoliation, whether grazing or mowing, is critical in order to obtain the most effective results (Fitzgerald and Bailey 1984). For some time, Canada Agriculture has recommended that the best time to treat aspen is in the spring, when the carbohydrate reserves are low (Fitzgerald and Bailey 1984). Conversely, research has shown that the most effective time of year to treat aspen, and eventually nearly kill the clone is in August (Bailey *et al.* 1990; Converse and Echardt 1988; Fitzgerald and Bailey 1984; Irving 2001). Leaf defoliation in August stimulates growth of the shoot primordia, which is too late in the season, thus preventing the development of winter hardiness (Bailey *et al.* 1990). It also prevents shoots that come up earlier in the growing season from going into winter dormancy. The prevention of winter dormancy characteristics makes them much more prone to being killed over the winter (Bailey *et al.* 1990; Fitzgerald and Bailey 1984). Moreover, the same cold winter temperatures may also prevent new primordia from forming on the roots, resulting in no primordia to produce aspen suckers the following spring (Fitzgerald and Bailey 1984).

The prevention of winter dormancy characteristics may be the responsibility of Abscisic Acid (ABA) (Fitzgerald and Bailey 1984). ABA is created in the chloroplasts in leaves, in response to fewer daylight hours. ABA is then transported to the stem and apex, and is associated with bud scales and winter dormancy characteristics with plants. Complete defoliation in August may prevent aspen from entering a winter dormancy state by cutting off the supply of ABA, resulting in a large proportion of the clone dying over the winter.

Therefore, in order to prevent the aspen clone from entering winter dormancy, cattle or sheep could be used as a followup grazing treatment on 2 of 3 recently burned areas during mid to late August. One site would be left ungrazed to promote dynamic habitat conditions, while the other 2 sites would be grazed to enhance and restore grassland and shrubland habitats. Grazing would help replace the historical grazing disturbance that bison used to have on the landscape. Research suggests that cattle will eat large amounts of aspen suckers when they are in leaf from June to September (Bailey and Arthur 1985). A study by Fitzgerald and Bailey (1984) in the Alberta Aspen Parkland showed that mid to late August grazing following a spring burn resulted in a large decline in aspen stem density during the first year, and grazing the following August resulted in an additional smaller decline in aspen density. After two years, prickly rose and snowberry density increased to levels which were greater than the control or grazing in June.

Sheep are presently being used in the Manitoba Interlake to assist in trembling aspen management (Wittenberg, pers. comm.). Sheep appeared to be more effective than cattle in controlling aspen regrowth, as they generally consumed more woody plants. Employing intensive sheep grazing required only 24 hours on a pasture, and they could then be moved to another location. In addition, sheep were easy to manage, and move from one pasture to another. Furthermore, cattle preferred to consume vegetation less than 20 cm in height, as taller vegetation increased energetic costs (Wittenberg, pers. comm.). However, literature suggests that cattle consumed large quantities of aspen suckers provided they were in leaf (Bailey and Arthur 1985). Perhaps a study should be conducted in the Manitoba Interlake evaluating the effectiveness of intensive sheep grazing and intensive cattle grazing in August.

Another study by Bailey *et al.* (1990), also conducted in the Alberta Aspen Parkland, showed that mid August intensive grazing after a spring burn that same year resulted in a near elimination of aspen suckers the following year. Conversely, an early to mid June intensive grazing strategy after burning the same year, which resulted in gradual depletion of carbohydrate reserves, required seven years to bring the aspen stem density down to 7% of the original stem density. In addition, mid August grazing resulted in a higher density of prickly rose over the control, as well as a higher density of snowberry over the control and the early season grazing. Moreover, another experiment in the Aspen Parkland in Saskatchewan showed that as grazing intensity increased from none to moderate to heavy, forb biomass increased, and was positively corelated with Shannon's diversity index (Bai *et al.* 2001). A Manitoba example is provided by Bird (1961), when it was observed that if there were enough elk to winter browse on aspen suckers for two consecutive years, the region would return to a prairie environment. Therefore, a mid August intensive grazing strategy applied a few months following the spring burn should result in a very strong reduction in aspen stem density, by preventing the development of winter dormancy characteristics, and carbohydrate reserves from being replenished before winter (thereby decreasing the vigour of the clonal root system). Intensive grazing should also increase effective richness, and prickly rose and snowberry frequency, both of which being important shrub species for sharp-tailed grouse.

To follow through with aspen sucker management, cattle or sheep would come from neighbouring ranchers to temporarily graze on the NWMA. A cattle stocking density of 7.70 AU/ha for 5 days should be used to manage aspen regeneration (Irving *et al.* 1995). This grazing period should be monitored and be subject to change, based on the productivity of the area being grazed, the defoliation rate, and grazing uniformity. Research has shown that fields 0.4 km wide and 3.2 km long with one water source at an extreme end of the field were uniformly grazed with 7.70 AU/ha by the end of the fifth day (Irving *et al.* 1995). When grazing is not an option, mowing of grassland habitats should occur after August 10 not only because it appears to be the best time to treat aspen, but also to allow sufficient time for completion of nesting activities, and to ensure that grouse broods are old enough to remove themselves from treatment activities (USGS Northern Prairie Wildlife Research Center 2002). However, grazing would be the preferred choice over mowing, particularly in shrubland habitats, as grazing increases spatial heterogeneity (Hobbs 1996).

When prescribed burning is not possible, bark scraping could be used for aspen management, as long as it has a followup treatment to manage the flush of sucker production. This followup treatment should be applied during the first month of August, after the initial treatment. The treatment could be a short, intensive grazing strategy involving cattle or sheep, or perhaps mowing, or herbicide applied with a wiper.

Community meetings should be held in Chatfield, Poplarfield, Sandridge, and the Fisher Branch First Nations group during the months of April and September, to inform members of management concerns, goals, results, and proposed recommendations for the NWMA. This will allow for public feedback regarding concerns, or perhaps new innovative ideas. By including local communities in the management plan from the beginning, they will know from the start why grazing will be permitted on the NWMA, and that grazing privileges are only temporary.

6.4.2 Years 2 to 10

Each lek should be enumerated 3 or 4 times during late April or May, to determine if the number of displaying males has increased, decreased, or remained the same. The following questions should be addressed. Did displaying males shift over to neighbouring lek sites, or did the number of displaying males actually increase? Were new lek sites established? Is the increase or decrease attributed to other biotic or abiotic factors, such as a change in predators or unusual weather? Information about weather and predators can be obtained from weather records, and by talking with local trappers. The number of displaying males on a lek should provide an indication of the health of the population. Thus, the numbers should reflect upon the effectiveness of the applied treatments. If the treated sites had more displaying males than before they were treated, and the neighbouring lek sites did not experience a decrease in displaying males, then the treatment was most likely a success.

From year 3 to year 10, the 100 acre treatments, (prescribed spring burning followed by cattle or sheep grazing on two-thirds of the burned sites, or mowing in mid August), should continue to be used. Treatment size may depend on available funds for that year, and should be applied until the 1/3, 1/3, 1/3 landscape target has been reached. Applying prescribed burning during the fall can be experimented with as well, to compare the impact of spring burning versus fall burning on reducing aspen suckering. Updated knowledge will be utilized as it becomes available through adaptive management, and strategies modified accordingly. Hence as knowledge increases, the implementation strategies can incorporate the latest findings. Therefore, treatment effectiveness should evolve through the application of the adaptive resource management model: implement, monitor, and evaluate.

The effectiveness of various lek sizes in attracting displaying males should be analysed. Enumeration of displaying males will need to be done in the spring (late April and early May). Comparisons should be made from year to year, and from one dancing ground to another, to determine if the birds are increasing or simply moving about. Ratios should be used to help evaluate the comparisons.

Trembling aspen surveys should be conducted on grassland and shrubland habitats following treatment application, to evaluate stem density and percent cover, and to determine if additional August treatments are required to reduce aspen to 5 percent cover. Once a 5 percent aspen cover has been achieved, followup treatments can be stopped. Ten years following the end of treatment, aspen percent cover would only have increased to approximately 18 percent, and more than 40 years would pass before aspen would reach 80 percent cover (Bowes 1997a). Hence, effective long-term aspen management would be achieved with reduced long-term management costs.

In addition, evaluation of mini-experiments could also be carried out. A transect can be laid out across the lek site in a random direction over the central dancing ground and into the shrub habitat. Sample counts can be taken every 20 metres (depending upon the size of the lek) using a 2m x 2m quadrat, and enumerating the number of aspen shoots. A cone of vulnerability, which measures the openness of the habitat, could be measured along the transect to quantify habitat structure (Harrell *et al.* 2001). A greater description of the sampling methods is provided by Harrell *et al.* (2001).

If bark scraping was implemented, followup treatments should be used during August until aspen percent cover has been reduced to 5 percent. In addition, Glyphosate could also be applied with a wiper to manage aspen, provided the results from the herbicide mini-experiment were positive. Perhaps a mid August herbicide treatment would prove to be more effective than bark scraping. It is possible that Glyphosate applied with a wiper would kill nearly all aspen stems with almost no regeneration (Roberts, pers. comm.). A treatment which is that effective would not require followup treatments, and would therefore reduce management time and costs.

People in and around the communities of Chatfield, Narcisse, Poplarfield, Sandridge, and the First Nations group near Fisher Branch, should be informed about the proposed establishment of the Narcisse Bioreserve approximately 10 km wide around the NWMA. It should be emphasized that no restrictions will be placed on land use activities. Rather, the purpose of the bioreserve is to pool local knowledge with scientific knowledge, to gain a better understanding of the scope of the problem, and to improve local habitat for both cattle grazing and wildlife. They should be informed about a graduate project that was conducted on the NWMA, which evaluated the effectiveness of various techniques for controlling aspen, and have the results made available to them in a condensed format. When more effective techniques have been determined through adaptive management, landowners can decide which treatment(s) they may consider. The manager can then work together with neighbouring ranchers to determine the degree and scope of the problem, which areas should be treated, and assist in the application process. Time will be required to establish relationships and to build trust.

Prior to meeting specifically with local ranchers, managers should first consider attending a community meeting, or an agricultural meeting to initiate contacts. Once contacts have been established, one could hold a community meeting twice a year to update treatment information and findings. Because the aspen forestation event is of significant concern to ranchers surrounding the NWMA, there could be an exchange of knowledge that would benefit all. Ranchers could increase the quantity and quality of grazing land available to their cattle, and managers could learn at a local level, both present and historic management activities on each land unit. Managers could also learn more about the scope of the aspen forestation event in the Interlake, and work together with landowners to implement effective treatments to improve habitat diversity surrounding the NWMA, and improve connectivity of various habitat types.

6.5 Summary

The objective of this management plan is to increase habitat diversity and biological diversity in the NWMA and the surrounding area (*i.e.* the Narcisse Biosphere). The goal is to restore a dynamic state of the 1/3, 1/3, 1/3 habitat complex that probably existed prior to European settlement, which provided optimal conditions for rich diversity in both flora and fauna. Sharp-tailed grouse, a species which has diverse habitat requirements, was historically abundant in the Manitoba Interlake. The decline in the Interlake sharptail population over the years suggests a decline in habitat conditions, and possibly biological diversity. Hence, sharp-tailed grouse could be used as an indicator species for evaluating habitat quality, diversity, and biological diversity. The Narcisse Biosphere would be a tool to share knowledge and resources between managers and landowners, and improve the overall effectiveness of habitat management. Treatments such as burning, cattle or sheep grazing, herbicide, or mowing, should be used to reduce trembling aspen cover and restore the 1/3, 1/3, 1/3 habitat conditions. Followup treatments applied during August are needed for managing aspen shoot production and reducing aspen to 5 percent cover. Reducing aspen percent cover to 5 percent or less should improve long-term habitat quality and diversity, and decrease long-term management costs, thus ending the need for followup treatments for more than a decade. Successful habitat management resulting in restored quality grassland and shrubland habitats will increase species richness and effective richness in the plant community at the landscape level. It should also improve habitat quality for many wildlife species, including sharp-tailed grouse. Improved sharp-tailed grouse habitat should contribute to an increase in the sharp-tailed grouse population, thus reflecting an increase in biological diversity in the Manitoba Interlake.

Table 6.1: Optimum habitat types within 1 and 1.6 km of a lek (Gylywoychuk 1993; Berger and Baydack 1992).

Habitat Types	Within 1km	Within 1.6km
Max closed aspen forest	44%	
Max open aspen forest	15%	
Optimum prairie habitat	23%	
Optimum shrub habitat	15 - 17%	
Minimum grass & shrub habitat		24 ha

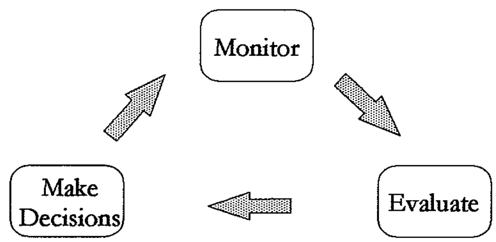


Figure 6.1: A flowchart of the Adaptive Resource Management model.

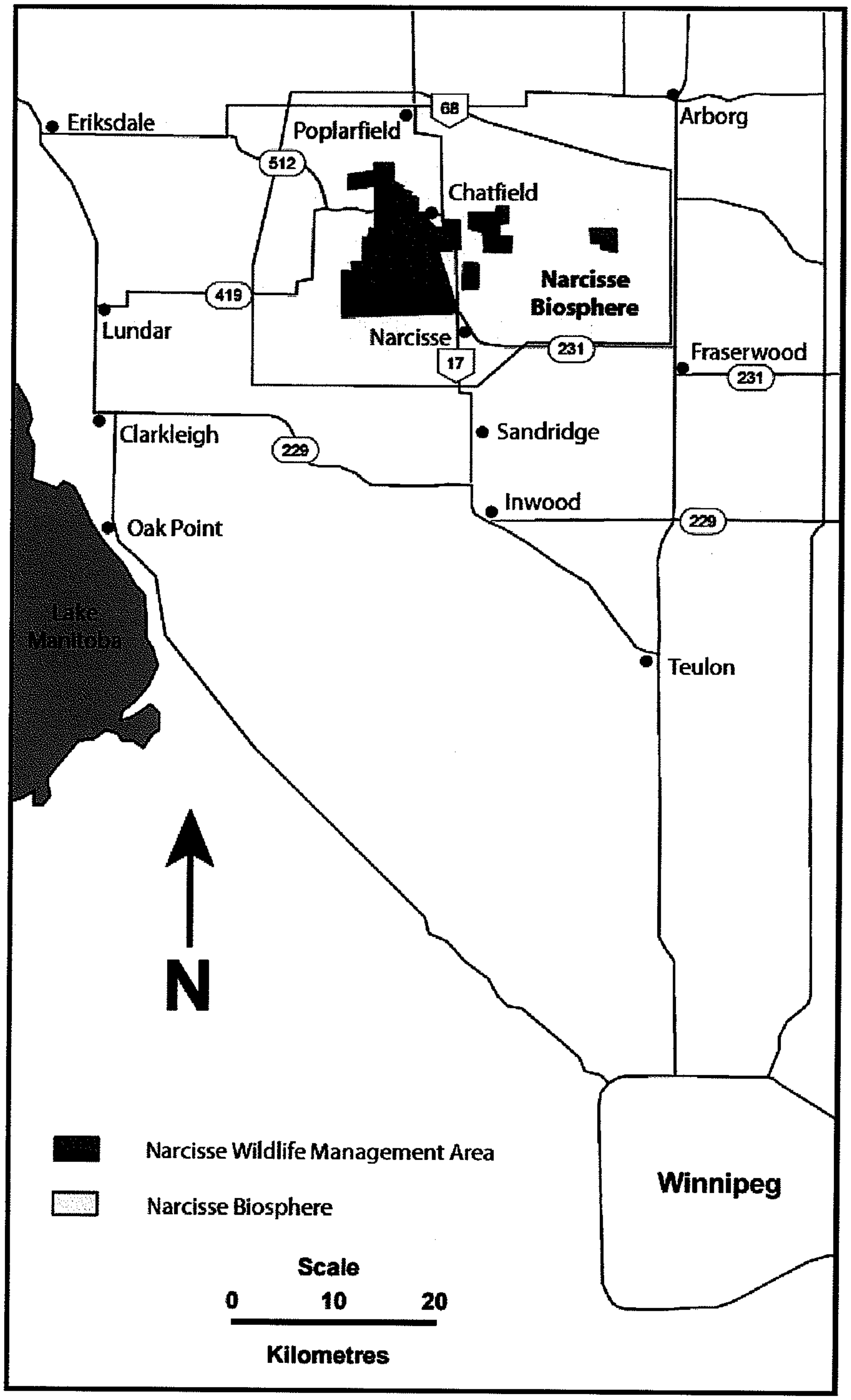


Figure 6.2: An artist's rendition of the Narcisse Wildlife Management Area with the proposed Narcisse Biosphere (After Gylywoychuk 1993).

CHAPTER 7: SUMMARY AND CONCLUSION

7.1 Summary and Conclusion

Aspen encroachment onto grassland and shrubland habitats results in a loss of grazing pasture for landowners, dancing and nesting grounds for sharp-tailed grouse, and lower plant species diversity in the plant community (Gylywoychuk 1993). The information obtained from this research will give landowners and management agencies a better understanding of how trembling aspen responds to various treatments, and which secondary treatment would be the most effective in killing aspen and restricting aspen spread onto grasslands in the Manitoba Interlake.

Treatment costs, based on 100 acres, ranged from approximately \$10 to \$22/acre. Bark scraping was the cheapest at \$10.71/acre, followed by prescribed burning at \$16/acre. Rolling was about \$22.50/acre, herbicide with the wiper and skidder as applied at Narcisse was \$33.33/acre, and finally mowing was the most expensive at \$62.67/acre. Treatment costs were based on 2002 pricing, and do not include taxes or equipment transportation costs where applicable.

All treatments, including the control which was rolled, were observed to have lower aspen biomass than the unrolled bush. However, any attempt to eliminate trembling aspen, whether by rolling, burning, herbicide, mowing, or bark scraping, will result in a substantial flush of shoots from the shallow root system and an increase in live stem density. Shoot production varied appreciably between treatments, as well as between blocks with the same treatments, and therefore did not appear to be entirely treatment dependent. In addition, shoot production appeared to be influenced by the proportion of woody stems killed within the clone. Finally, shoot production appeared to vary depending upon the age of the aspen clone. A younger aspen clone resulted in greater shoot production than a more mature aspen clone.

There was a wide range in shoot density following the prescribed burn in this study. Shoot production in prescribed burn treatments vary depending upon the intensity of the burn (Peterson and Peterson 1992; Quintilio *et al.* 1991). High intensity burns will transfer more heat to the lateral root system resulting in tissue damage and lower shoot density the following season. Based on observations made while the burns were conducted, as well as the plant community response, I feel that the range in shoot densities found in my study may be attributed to various burn intensities. The greatest shoot density was found in the site that appeared to have the lowest burn intensity, whereas the lowest shoot density was found in the site that appeared to have the highest burn intensity. Moreover, the high intensity burn plot was the only burn site where shoot density decreased from 2000 to 2001. This was probably from a greater heat transfer to the shallow root system. Therefore, I feel that the most effective treatment to kill preexisting woody stems with minimal regeneration appears to be an intense burn.

Bark scrape was the second most effective treatment for managing aspen. It had a lower live stem density than the herbicide or mowing treatments, and was more successful in killing the woody stems than herbicide. However, the bark scrape and herbicide treatments were not nearly as effective in actually killing the preexisting woody stems as prescribed burning. Finally, mowing was the least effective treatment in managing trembling aspen. Mowing resulted in highest live stem density, and did not kill the preexisting woody stems. Mowing simply altered the vertical structure of the stem, resulting in shoots (resprouts) sprouting off the chopped woody stems. Perhaps mowing during mid August for 2 consecutive years would greatly reduce aspen stem density and future management costs.

All treatments, including the control (*i.e.* rolling), significantly ($p<0.05$) improved species richness compared to the unrolled bush, a habitat which has become increasingly dominant in the Manitoba Interlake. Therefore, the initial rolling treatment enhanced plant diversity, as the most limiting factor was probably light availability. Yet there was little impact observed on the plant community between the applied treatments and the control. Rather, diversity was primarily determined by a complex arrangement of microtopic variations inherent in the landscape. Low areas contained the greatest moisture and had the lowest species richness and effective richness. Intermediate areas had substantially greater species richness and the highest effective richness. Finally, higher areas with limited moisture had the greatest species richness, and effective richness that was slightly less than intermediate areas. Therefore, it is the rolling topography inherent in the landscape with its varying degree of soil moisture availability that primarily shapes a plant community and its diversity.

Of all the treatments employed, prescribed burning was the most invasive on the plant community. Fire was the only treatment that significantly increased the effective richness of the plant community over that of the unrolled bush. Moreover, prescribed burning was shown to maintain or increase 2 important wildlife shrub species. Western snowberry density increased following a burn, while there was little impact from the burn on prickly rose density. Finally, prescribed burning caused the plant community to change to become more of a grassland community, including the shrubby intermediate microtopic sites.

Results from this study have shown that trembling aspen cannot be managed with only one followup treatment 3 years after the initial treatment. Followup treatments that manage sucker production are critical for effective long-term management. Various literature sources suggest that mid August is an appropriate time for aspen sucker management (Bailey *et al.* 1990; Converse and Echardt 1988; Fitzgerald and Bailey 1984; Irving 2001). According to these sources, I suggest that followup treatments for aspen shoot management be implemented during August. One such treatment could incorporate a short intensive grazing strategy. If grazing is carried out during August to defoliate the aspen shoots just prior to leaf fall, shoot density should be substantially lower the following year, and may not even require additional treatment for several more years (Bailey *et al.* 1990). Future areas of research should compare the effectiveness of cattle and sheep grazing in the Interlake during August, utilizing a short intensive grazing strategy. In addition, if removing the leaves just prior to leaf fall is important in preventing winter dormancy characteristics, mowing during mid August should also be evaluated for its effectiveness in reducing live stem density. Finally, herbicide applied with a wiper following full leaf flush in early July should be compared to mid August application to determine if timing impacts kill effectiveness and aspen regeneration.

In conclusion, the overriding management goal was to increase habitat and biological diversity by effectively controlling aspen regrowth, resulting in a heterogeneous balance of quality grassland and shrubland habitats with little aspen encroachment, and woodland habitats, all maintained in a dynamic state in Manitoba's Interlake. The most effective treatment used to emulate natural disturbance was prescribed burning. Burning was the most effective treatment for killing preexisting woody stems, and it had the lowest overall live stem density of the 4 applied treatments. In addition, burning resulted in greater species richness and effective richness in the plant community compared to the dominating mature woodlands. Finally, burning caused the plant community to change to better reflect a grassland community, and maintained or increased shrub species important to a variety of wildlife species. Hence, fire appeared to be the most effective treatment for enhancing habitat quality, diversity, and plant community diversity, and therefore biological diversity in Manitoba's Interlake.

Appendix A

Wildlife species commonly found in the Narcisse Wildlife Management Area

Common Name	Latin Name
ruffed grouse	*Bonasa umbellus*
sharp-tailed grouse	*Tympanuchus phasianellus*
goshawk	*Accipiter gentilis*
northern harrier	*Circus hudsonius*
red-tailed hawk	*Buteo jamaicensis*
rough-legged hawk	*Buteo lagopus*
broad-winged hawk	*Buteo platypterus*
bald eagle	*Haliaeetus leucocephalus*
great horned owl	*Bubo virginianus*
snowy owl	*Nyctea scandiaca*
crow	*Corvus brachyrhynchos*
black-billed magpie	*Pica pica*
elk	*Cervus canadensis*
white-tailed deer	*Odocoileus virginianus*
coyote	*Canis latrans*
red fox	*Vulpes vulpes*
short-tailed weasel	*Mustela erminea*
mink	*Mustela vison*
badger	*Taxidea taxus*
striped skunk	*Mephitis mephitis*
thirteen-lined ground squirrel	*Spermophilis tridecemlineatus*
snowshoe hare	*Lepus americanus*
red-sided garter snake	*Thamnophis sirtalis*

Sources: (Gylywoychuk 1993; Sexton 1979).

Appendix B

Plant species found in the Narcisse Wildlife Management Area

Common Name	Latin Name	Family
Manitoba maple	*Acer negundo*	Aceraceae
Red-footed pigweed	*Amaranthus retroflexus**	Amaranthaceae
Poison-ivy	*Rhus radicans var. rydbergii*	Anacardiaceae
Caraway	*Carum carvi**	Apiaceae
Cow-parsnip	*Heracleum lanatum*	Apiaceae
Snakeroot	*Sanicula marilandica*	Apiaceae
Heart-leaved alexanders	*Zizia aptera*	Apiaceae
Golden alexanders	*Zizia aurea*	Apiaceae
Spreading dogbane	*Apocynum androsaemifolium*	Apocynaceae
Indian-hemp	*Apocynum cannabinum*	Apocynaceae
Wild sarsaparilla	*Aralia nudicaulis*	Araliaceae
Dwarf milkweed	*Asclepias ovalifolia*	Asclepiadaceae
Showy milkweed	*Asclepias speciosa*	Asclepiadaceae
Woolly yarrow	*Achillea millefolium var. lanulosa*	Asteraceae
Common yarrow	*Achillea millefolium var. millefolium**	Asteraceae
False dandelion	*Agoseris glauca*	Asteraceae
Field cat's-foot	*Antennaria neglecta*	Asteraceae
Common pussy-toes	*Antennaria neodioica*	Asteraceae
Small-leaved everlasting	*Antennaria parvifolia*	Asteraceae
Common burdock	*Arctium minus**	Asteraceae
Absinthe	*Artemesia absinthium**	Asteraceae
Plains wormwood	*Artemesia campestris ssp. caudata*	Asteraceae
Western mugwort	*Artemesia ludoviciana*	Asteraceae
Northern aster	*Aster borealis*	Asteraceae
Lindley's aster	*Aster ciliolatus*	Asteraceae
Heath aster	*Aster ericoides*	Asteraceae
Willow aster	*Aster hesperis*	Asteraceae
Smooth aster	*Aster laevis*	Asteraceae
Wood aster	*Aster lateriflorus*	Asteraceae
New England aster	*Aster novae-angliae*	Asteraceae
White upland aster	*Aster ptarmicoides*	Asteraceae
Purple-stemmed aster	*Aster puniceus*	Asteraceae
Small blue aster	*Aster simplex*	Asteraceae
Flat-topped white aster	*Aster umbellatus*	Asteraceae
Smooth beggarticks	*Bidens cernua*	Asteraceae
Ox-eye daisy	*Chrysanthemum leucanthemum**	Asteraceae
Canada thistle	*Cirsium arvense**	Asteraceae
Short-stemmed thistle	*Cirsium drummondii*	Asteraceae
Flodman's thistle	*Cirsium flodmanii*	Asteraceae
Bull thistle	*Cirsium vulgare**	Asteraceae
Scapose hawks-beard	*Crepis runcinata*	Asteraceae
Narrow-leaved hawks-beard	*Crepis tectorum**	Asteraceae
Northern daisy fleabane	*Erigeron acris var. elatus*	Asteraceae
Rough fleabane	*Erigeron asper*	Asteraceae
Canada fleabane	*Erigeron canadensis*	Asteraceae
Smooth fleabane	*Erigeron glabellus*	Asteraceae
Philadelphia fleabane	*Erigeron philadelphicus*	Asteraceae
Daisy fleabane	*Erigeron strigosus*	Asteraceae
Great-flowered gaillardia	*Gaillardia aristata*	Asteraceae

* exotic species

Plant species found in the Narcisse Wildlife Management Area in grasslands, deciduous woods, scrubland, and disturbed or farmed areas (Greenall, pers. comm.).

Appendix B, Continued

Common Name	Latin Name	Family
Curly-cup gumweed	*Grindelia squarrosa*	Asteraceae
Large sunflower	*Helianthus giganteus*	Asteraceae
Beautiful sunflower	*Helianthus laetiflorus var. subrhomboideus*	Asteraceae
Narrow-leaved sunflower	*Helianthus maximiliani*	Asteraceae
	Hieracium sp.	Asteraceae
Wild lettuce	*Lactuca tartarica*	Asteraceae
Meadow blazingstar	*Liatris ligulistylus*	Asteraceae
Pineapple weed	*Matricaria matricarioides**	Asteraceae
Arrow-leaved colt's-foot	*Petasites sagittatus*	Asteraceae
White lettuce	*Prenanthes alba*	Asteraceae
Black-eyed susan	*Rudbeckia hirta*	Asteraceae
Entire-leaved groundsel	*Senecio integerrimus**	Asteraceae
Balsam groundsel	*Senecio pauperculus*	Asteraceae
Canada goldenrod	*Solidago canadensis*	Asteraceae
Late goldenrod	*Solidago gigantea*	Asteraceae
Flat-topped goldenrod	*Solidago graminifolia*	Asteraceae
Flat-topped goldenrod	*Solidago graminifolia var. major*	Asteraceae
Hairy goldenrod	*Solidago hispida*	Asteraceae
Low goldenrod	*Solidago missouriensis*	Asteraceae
Stiff goldenrod	*Solidago rigida*	Asteraceae
Field sow-thistle	*Sonchus arvensis**	Asteraceae
Spiny-leaved sow-thistle	*Sonchus asper**	Asteraceae
Common tansy	*Tanacetum vulgare**	Asteraceae
Red-seeded dandelion	*Taraxacum laevigatum**	Asteraceae
Common dandelion	*Taraxacum officinale*	Asteraceae
Goat's-beard	*Tragopogon dubius**	Asteraceae
Goat's-beard	*Tragopogon pratensis**	Asteraceae
River birch	*Betula occidentalis*	Betulaceae
Swamp birch	*Betula pumila var. glandulifera*	Betulaceae
American hazelnut	*Corylus americana*	Betulaceae
Beaked hazelnut	*Corylus cornuta*	Betulaceae
Common hound's tongue	*Cynoglossum officinale**	Boraginaceae
Bristly stickseed	*Lappula squarrosa**	Boraginaceae
Hoary puccoon	*Lithospermum canescens*	Boraginaceae
Purple rock cress	*Arabis divaricarpa*	Brassicaceae
Drummond's rock cress	*Arabis drummondii*	Brassicaceae
Tower mustard	*Arabis glabra**	Brassicaceae
Hirsute rock cress	*Arabis hirsuta*	Brassicaceae
Charlock	*Brassica kaber**	Brassicaceae
Shepherd's purse	*Capsella bursa-pastoris**	Brassicaceae
Tansy mustard	*Descurainia pinnata*	Brassicaceae
Western wallflower	*Erysmium asperum*	Brassicaceae
Wormseed mustard	*Erysmium cheiranthoides**	Brassicaceae
Small-flowered prairie rocket	*Erysmium inconspicuum*	Brassicaceae
Dame's violet	*Hesperis matronalis**	Brassicaceae
Common pepper grass	*Lepidium densiflorum*	Brassicaceae
Field pennycress	*Thlaspi arvense**	Brassicaceae
Creeping bluebell	*Campanula rapunculoides**	Campanulaceae
Harebell	*Campanula rotundifolia*	Campanulaceae

Appendix B, Continued

Common Name	Latin Name	Family
Twining honeysuckle	*Lonicera dioica var. glaucescens*	Caprifoliaceae
Swamp-fly-honeysuckle	*Lonicera oblongifolia*	Caprifoliaceae
Western snowberry	*Symphoricarpos occidentalis*	Caprifoliaceae
Nannyberry	*Viburnum lentago*	Caprifoliaceae
Highbush-cranberry	*Viburnum opulus var. americanum*	Caprifoliaceae
Downy arrow-wood	*Viburnum rafinesquianum*	Caprifoliaceae
Grove sandwort	*Arenaria lateriflora*	Caryophyllaceae
Sandwort	*Arenaria stricta var. dawsonensis*	Caryophyllaceae
Field chickweed	*Cerastium arvense*	Caryophyllaceae
Bouncing bet	*Saponaria officinalis*	Caryophyllaceae
Sleepy catchfly	*Silene antirrhina*	Caryophyllaceae
Night-flowered catchfly	*Silene noctiflora**	Caryophyllaceae
Lamb's-quarters	*Chenopodium album**	Chenopodiaceae
Strawberry-blite	*Chenopodium capitatum*	Chenopodiaceae
Maple-leaved goosefoot	*Chenopodium hybridum*	Chenopodiaceae
Hedge bindweed	*Convolvulus sepium*	Convolvulaceae
Red-osier dogwood	*Cornus stolonifera*	Cornaceae
Common juniper	*Juniperus communis*	Cupressaceae
Creeping juniper	*Juniperus horizontalis*	Cupressaceae
Golden sedge	*Carex aurea*	Cyperaceae
A sedge	*Carex tenera*	Cyperaceae
A sedge	*Carex tenera*	Cyperaceae
Rigid sedge	*Carex tetanica*	Cyperaceae
Rigid sedge	*Carex tetanica*	Cyperaceae
Wolf-willow	*Elaeagnus commutata*	Eleagnaceae
Canada buffaloberry	*Shepherdia canadensis*	Eleagnaceae
Common horsetail	*Equisetum arvense*	Equisetaceae
Smooth scouring rush	*Equisetum laevigatum*	Equisetaceae
Common bearberry	*Arctostaphylos uva-ursi*	Ericaceae
Ascending milkvetch	*Astragalus adsurgens*	Fabaceae
Milkvetch	*Astragalus agrestis*	Fabaceae
Canadian milkvetch	*Astragalus canadensis*	Fabaceae
Ground-plum	*Astragalus crassicarpus*	Fabaceae
Slender milkvetch	*Astragalus flexuosus*	Fabaceae
Common caragana	*Caragana arborescens**	Fabaceae
White prairie-clover	*Dalea candida*	Fabaceae
Purple prairie-clover	*Dalea purpurea*	Fabaceae
Wild Licorice	*Glycyrrhiza lepidota*	Fabaceae
Pale vetchling	*Lathyrus ochroleucus*	Fabaceae
Marsh vetchling	*Lathyrus palustris*	Fabaceae
Wild peavine	*Lathyrus venosus*	Fabaceae
Bird's-foot trefoil	*Lotus corniculatus**	Fabaceae
Black medick	*Medicago lupulina**	Fabaceae
Alfalfa	*Medicago sativa**	Fabaceae
White sweet clover	*Melilotus alba*	Fabaceae
Yellow sweet clover	*Melilotus officinalis**	Fabaceae
Purple locoweed	*Oxytropis lambertii*	Fabaceae
Alsike clover	*Trifolium hybridum**	Fabaceae
Red clover	*Trifolium pratense**	Fabaceae

Appendix B, Continued

Common Name	Latin Name	Family
White clover	*Trifolium repens**	Fabaceae
Common vetch	*Vicia americana ssp. americana*	Fabaceae
Tufted vetch	*Vicia cracca**	Fabaceae
Bur oak	*Quercus macrocarpa*	Fagaceae
Felwort	*Gentianella amarella*	Gentianaceae
Fringed gentian	*Gentianella crinita*	Gentianaceae
Fringed gentian	*Gentianella crinita ssp. macounii*	Gentianaceae
Bicknell's geranium	*Geranium bicknellii*	Geraniaceae
Carolina wild geranium	*Geranium carolinianum*	Geraniaceae
Bristly wild gooseberry	*Ribes oxyacanthoides*	Grossulariaceae
Wild red currant	*Ribes triste*	Grossulariaceae
Common blue-eyed grass	*Sisyrinchium montanum*	Iridaceae
Seaside arrow-grass	*Triglochin maritima*	Juncaginaceae
American dragon head	*Dracocephalum parviflorum*	Lamiaceae
American dragon head	*Dracocephalum parviflorum*	Lamiaceae
Wild bergamot	*Monarda fistulosa*	Lamiaceae
Pink-flowered onion	*Allium stellatum*	Liliaceae
Wood Lily	*Lilium philadelphicum var. andinum*	Liliaceae
Two-leaved Solomon's seal	*Maianthemum canadense*	Liliaceae
Star-flowered Solomon's seal	*Smilacina stellata*	Liliaceae
White camas	*Zigadenus elegans*	Liliaceae
Large-flowered yellow flax	*Linum perenne*	Linaceae
Indian-pipe	*Monotropa uniflora*	Monotropaceae
Fireweed	*Epilobium angustifolium*	Onagraceae
Willow-herb	*Epilobium leptophyllum*	Onagraceae
Marsh willow-herb	*Epilobium palustre*	Onagraceae
Evening-primrose	*Oenothera biennis*	Onagraceae
Evening-primrose	*Oenothera biennis*	Onagraceae
Evening-primrose	*Oenothera parviflora*	Onagraceae
Evening-primrose	*Oenothera parviflora*	Onagraceae
Rattlesnake fern	*Botrychium virginianum*	Ophioglossaceae
	(Habenaria viridis)	Orchidaceae
Striped coral-root	*Corallorrhiza striata*	Orchidaceae
Early coral-root	*Corallorrhiza trifida*	Orchidaceae
Small yellow lady's slipper	*Cypripedium calceolus var. parviflorum*	Orchidaceae
Large yellow lady's slipper	*Cypripedium calceolus var. pubescens*	Orchidaceae
White spruce	*Picea glauca*	Pinaceae
Jack pine	*Pinus banksiana*	Pinaceae
Common plantain	*Plantago major**	Plantaginaceae
Common plantain	*Plantago major**	Plantaginaceae
Quack grass	*Agropyron repens**	Poaceae
Western wheat grass	*Agropyron smithii*	Poaceae
Slender wheat grass	*Agropyron trachycaulum*	Poaceae
Tickle-grass	*Agrostis hyemalis var. tenuis*	Poaceae
Redtop	*Agrostis stolonifera**	Poaceae
Short-awned foxtail	*Alopecurus aequalis*	Poaceae
Big bluestem	*Andropogon gerardii*	Poaceae
Little bluestem	*Andropogon scoparius*	Poaceae
Wild oats	*Avena fatua**	Poaceae

Appendix B, Continued

Common Name	Latin Name	Family
Fringed brome	*Bromus ciliatus*	Poaceae
Smooth brome	*Bromus inermis**	Poaceae
Porter's chess	*Bromus porteri*	Poaceae
Marsh reed grass	*Calamagrostis canadensis*	Poaceae
Northern reed grass	*Calamagrostis inexpansa*	Poaceae
Reed grass	*Calamagrostis neglecta*	Poaceae
Orchard grass	*Dactylis glomerata**	Poaceae
Poverty oatgrass	*Danthonia spicata*	Poaceae
Tufted hair grass	*Deschampsia caespitosa*	Poaceae
Barnyard grass	*Echinochloa crus-galli**	Poaceae
Canada wild-rye	*Elymus canadensis*	Poaceae
Fowl manna grass	*Glyceria striata*	Poaceae
Hooker's oat grass	*Helicotrichon hookeri*	Poaceae
Sweet grass	*Hierochloe odorata*	Poaceae
Foxtail barley	*Hordeum jubatum*	Poaceae
June grass	*Koeleria cristata*	Poaceae
Scratch grass	*Muhlenbergia asperifolia*	Poaceae
White-grained mountain rice-grass	*Oryzopsis asperifolia*	Poaceae
Canada rice grass	*Oryzopsis canadensis*	Poaceae
Witch grass	*Panicum capillare*	Poaceae
Common timothy	*Phleum pratense*	Poaceae
Mutton grass	*Poa cusickii*	Poaceae
Kentucky blue grass	*Poa pratensis*	Poaceae
Purple oat grass	*Schizachne purpurascens*	Poaceae
Green foxtail	*Setaria viridis**	Poaceae
Richardson needle grass	*Stipa richardsonii*	Poaceae
Porcupine grass	*Stipa spartea*	Poaceae
Fringed polygala	*Polygala paucifolia*	Polygalaceae
Seneca snakeroot	*Polygala senega*	Polygalaceae
A knotweed	*Polygonum arenastrum**	Polygonaceae
Black bindweed	*Polygonum convolvulus**	Polygonaceae
Bushy knotweed	*Polygonum ramosissimum*	Polygonaceae
Curled dock	*Rumex crispus**	Polygonaceae
Pygmyflower	*Androsace septentrionalis var. puberulenta*	Primulaceae
Fringed loosestrife	*Lysimachia ciliata*	Primulaceae
Lance-leaf loosestrife	*Lysimachia lanceolata*	Primulaceae
Tufted loosestrife	*Lysimachia thyrsiflora*	Primulaceae
Mealy primrose	*Primula incana*	Primulaceae
Pink pyrola	*Pyrola asarifolia*	Pyrolaceae
Shinleaf	*Pyrola elliptica*	Pyrolaceae
One-sided pyrola	*Pyrola secunda*	Pyrolaceae
Red baneberry	*Actaea rubra*	Ranunculaceae
Canada anemone	*Anemone canadensis*	Ranunculaceae
Thimbleweed	*Anemone cylindrica*	Ranunculaceae
Cut-leaved anemone	*Anemone multifida*	Ranunculaceae
Prairie crocus	*Anemone patens*	Ranunculaceae
Small-flowered buttercup	*Ranunculus abortivus*	Ranunculaceae
Macoun's buttercup	*Ranunculus macounii*	Ranunculaceae
Cursed crowfoot	*Ranunculus sceleratus*	Ranunculaceae

Appendix B, Continued

Common Name	Latin Name	Family
Tall meadow-rue	*Thalictrum dasycarpum*	Ranunculaceae
Veiny meadow-rue	*Thalictrum venulosum*	Ranunculaceae
Saskatoon	*Amelanchier alnifolia*	Rosaceae
Round-leaved hawthorn	*Crataegus chrysocarpa*	Rosaceae
Woodland strawberry	*Fragaria vesca*	Rosaceae
Smooth wild strawberry	*Fragaria virginiana*	Rosaceae
Yellow avens	*Geum aleppicum*	Rosaceae
Three-flowered avens	*Geum triflorum*	Rosaceae
Silverweed	*Potentilla anserina*	Rosaceae
Silvery cinquefoil	*Potentilla argentea**	Rosaceae
Tall cinquefoil	*Potentilla arguta*	Rosaceae
Shrubby cinquefoil	*Potentilla fruticosa*	Rosaceae
Rough cinquefoil	*Potentilla norvegica*	Rosaceae
Cinquefoil	*Potentilla pensylvanica*	Rosaceae
Pin cherry	*Prunus pensylvanica*	Rosaceae
Sand cherry	*Prunus pumila*	Rosaceae
Choke cherry	*Prunus virginiana*	Rosaceae
Prickly rose	*Rosa acicularis*	Rosaceae
Low prairie rose	*Rosa arkansana*	Rosaceae
Wood's rose	*Rosa woodsii*	Rosaceae
Wild red raspberry	*Rubus idaeus ssp. strigosus*	Rosaceae
Dewberry	*Rubus pubescens*	Rosaceae
Meadowsweet	*Spirea alba*	Rosaceae
Northern bedstraw	*Galium boreale*	Rubiaceae
Long-leaved bluets	*Houstonia longifolia*	Rubiaceae
Balsam poplar	*Populus balsamifera*	Salicaceae
Trembling aspen	*Populus tremuloides*	Salicaceae
Beaked willow	*Salix bebbiana*	Salicaceae
Hoary willow	*Salix candida*	Salicaceae
Sandbar willow	*Salix exigua*	Salicaceae
Yellow willow	*Salix lutea*	Salicaceae
Bastard toadflax	*Comandra umbellata*	Santalaceae
Pale bastard toadflax	*Comandra umbellata ssp. pallida*	Santalaceae
Alumroot	*Heuchera richardsonii*	Saxifragaceae
Scarlet paintbrush	*Castilleja coccinea*	Scrophulariaceae
Red painted-cup	*Castilleja miniata*	Scrophulariaceae
Butter-and-eggs	*Linaria vulgaris**	Scrophulariaceae
Eyebright	*Odontites verna**	Scrophulariaceae
Owl's-clover	*Orthocarpus luteus*	Scrophulariaceae
Wood-betony	*Pedicularis canadensis*	Scrophulariaceae
Lilac-flowered beard-tongue	*Penstemon gracilis*	Scrophulariaceae
Carrion-flower	*Smilax lasioneura*	Smilacaceae
Stinging nettle	*Urtica dioica*	Urticaceae
Early blue violet	*Viola adunca*	Violaceae
Dog violet	*Viola conspersa*	Violaceae
Northern bog violet	*Viola nephrophylla*	Violaceae
Purple prairie violet	*Viola pedatifida*	Violaceae
Virginia creeper	*Parthenocissus quinquefolia*	Vitaceae

Appendix C

Mean temperature and precipitation for Fisher Branch, Manitoba

Month	Mean Temperature (Celcius)		
	1999	2000	2001
March	-	1.2	-
April	-	5.9	7.1
May	12.6	13.5	14.7
June	18.5	16.7	18.4
July	22.3	22.8	23.5
August	20.7	21.5	23.9
September	14.8	14.5	17.7

Source: (Manitoba Conservation 2002)

Month	Total Preciptiation (mm)		
	1999	2000	2001
March	-	10	-
April	-	0	0
May	48	32	83
June	67	100	100
July	64	26	37
August	43	46	50
September	65	72	14

Source: (Manitoba Conservation 2002)

Appendix D

Study site GPS data points for each treatment in Blocks A, B, and C

Study Site GPS Data Points For Block A						
Block A Treatments	**Area**	**Waypoint**	**UTM Easting**	**UTM Northing**	**Plot type**	**Plot Corner or Number**
Herbicide	**Acres:** 2.9687 **Hectares:** 1.2014	1	598460	5628450	treatment	NE
		2	598455	5628452	study	24
		3	598379	5628451	study	19
		4	598340	5628454	treatment	NW
		5	598374	5628406	study	6
		6	598336	5628349	treatment	SW
		11	598461	5628360	treatment	SE
		12	598450	5628405	study	1
Mowing	**Acres:** 2.9230 **Hectares:** 1.1829	7	598335	5628315	treatment	NW
		8	598371	5628304	study	19
		9	598445	5628303	study	24
		10	598460	5628331	treatment	NE
		13	598442	5628261	study	1
		14	598460	5628231	treatment	SE
		18	598369	5628261	study	6
		19	598332	5628226	treatment	SW
Bark Scrape	**Acres:** 3.3876 **Hectares:** 1.3709	15	598459	5628200	treatment	NE
		16	598438	5628199	study	1
		17	598393	5628202	study	24
		20	598331	5628204	treatment	NW
		21	598398	5628128	study	19
		22	598325	5628094	treatment	SW
		23	598456	5628098	treatment	SE
		24	598441	5628125	study	6
Burn	**Acres:** 3.0398 **Hectares:** 1.2302	25	597932	5627867	treatment	SE
		26	597900	5627890	study	19
		27	597900	5627934	study	6
		28	597939	5627965	treatment	NE
		29	597808	5627960	treatment	NW
		30	597826	5627931	study	1
		31	597829	5627888	study	24
		32	597808	5627865	treatment	SW
Control	**Acres:** 3.4797 **Hectares:** 1.4082	41	597921	5628391	treatment	SE
		42	597889	5628393	study	1
		43	597846	5628408	study	24
		44	597826	5628375	treatment	SW
		57	597824	5628518	treatment	NW
		58	597861	5628481	study	19
		59	597905	5628468	study	6
		60	597916	5628547	treatment	NE

Appendix D, Continued

Study Site GPS Data Points For Block B						
Block B Treatments	**Area**	**Waypoint**	**UTM Easting**	**UTM Northing**	**Plot type**	**Plot Corner or Number**
Burn	Acres: 4.2289 Hectares: 1.7114	33	597702	5628326	treatment	SE
		34	597719	5628246	study	6
		35	597721	5628171	study	1
		36	597709	5628147	treatment	SW
		37	597766	5628169	study	24
		38	597805	5628158	treatment	SE
		39	597764	5628247	study	19
		40	597795	5628335	treatment	NE
Mowing	Acres: 3.1878 Hectares: 1.2901	45	597795	5628370	treatment	SE
		46	597779	5628379	study	1
		47	597735	5628373	study	24
		48	597700	5628354	treatment	SW
		49	597717	5628448	study	19
		50	597695	5628479	treatment	NW
		55	597797	5628507	treatment	NE
		56	597759	5628455	study	6
Herbicide	Acres: 2.7610 Hectares: 1.1174	51	597695	5628513	treatment	SW
		52	597711	5628545	study	24
		53	597754	5628540	study	1
		54	597795	5628530	treatment	SE
		61	597788	5628639	treatment	NE
		62	597752	5628620	study	6
		63	597709	5628617	study	19
		64	597694	5628631	treatment	NW
Bark Scrape	Acres: 3.0062 Hectares: 1.2166	65	597660	5628628	treatment	NE
		66	597629	5628613	study	6
		67	597585	5628619	study	19
		68	597566	5628627	treatment	NW
		69	597578	5628546	study	24
		70	597578	5628492	treatment	SW
		74	597623	5628541	study	1
		75	597673	5628512	treatment	SE
Control	Acres: 2.6669 Hectares: 1.0793	71	597597	5628467	treatment	NW
		72	597615	5628456	study	24
		73*	597630	5628456	study	23
		76	597673	5628478	treatment	NE
		77*	597661	5628456	study	11
		78	597671	5628440	study	1
		79*	597663	5628382	study	5
		80*	597618	5628381	study	18
		81	597587	5628339	treatment	SW
		82	597680	5628354	treatment	SE

* Note: end plots off set

Appendix D, Continued

Study Site GPS Data Points For Block C						
Block C Treatments	**Area**	**Waypoint**	**UTM Easting**	**UTM Northing**	**Plot type**	**Plot Corner or Number**
Control	**Acres:** 2.6172 **Hectares:** 1.0592	89	597497	5627794	treatment	SE
		90	597465	5627803	study	24
		91	597468	5627846	study	1
		92	597490	5627882	treatment	NE
		93	597372	5627878	treatment	NW
		94	597388	5627852	study	6
		95	597388	5627805	study	19
		96	597371	5627795	treatment	SW
Mowing	**Acres:** 2.6656 **Hectares:** 1.0788	99	597199	5627799	treatment	SE
		100	597161	5627839	study	1
		101	597171	5627909	study	6
		102	597201	5627949	treatment	NE
		103	597127	5627917	study	19
		104	597108	5627946	treatment	NW
		130	597096	5627801	study	24
		131	597119	5627845	treatment	SW
Herbicide	**Acres:** 3.3898 **Hectares:** 1.3719	105	597081	5627949	treatment	NE
		106	597065	5627903	study	19
		107	597021	5627903	study	6
		108	596987	5627954	treatment	NW
		126	596988	5627809	treatment	SW
		127	597025	5627827	study	1
		128	597072	5627829	study	24
		129	597083	5627807	treatment	SE
Bark Scrape	**Acres:** 2.7415 **Hectares:** 1.1095	111	596958	5627986	treatment	SE
		112	596922	5627995	study	24
		113	596920	5628071	study	19
		114	596957	5628106	treatment	NE
		115	596864	5628093	treatment	NW
		116	596873	5628066	study	6
		117	596876	5627993	study	1
		118	596865	5627978	treatment	SW
Burn	**Acres:** 3.7961 **Hectares:** 1.5363	109	596960	5627954	treatment	NE
		110	596932	5627929	study	19
		123*	596850	5627954	treatment	NW
		120	596889	5627936	study	6
		121	596887	5627860	study	1
		122	596854	5627817	treatment	SW
		124	596931	5627854	study	24
		125	596958	5627806	treatment	SE
* Note: correction for waypoint 119, wrong location						
Note: waypoint 132 is a repeat of waypoint 99						

Appendix E

Vegetation species list from pretreatment, 2000, and 2001 surveys

Family	Common Name	Latin Name	Native vs. Introduced
Adoxaceae	Harebell	*Campanula rotundifolia* L.	Native
Apiaceae	Snakeroot	*Sanicula marilandica* L.	Native
Apiaceae	Heart-leaved Alexanders	*Zizia aptera* (Gray) Fern.	Native
Apocynaceae	Spreading Dogbane	*Apocynum androsaemifolium* L.	Native
Asteraceae	Common Yarrow	*Achillea millefolium* L.	Native
Asteraceae	Prairie Sage	*Artemisia ludoviciana* Nutt.	Native
Asteraceae	Marsh Aster	*Aster borealis* (T. & G.) Provancher	Native
Asteraceae	Fringed Aster	*Aster ciliolatus* Lindl.	Native
Asteraceae	Sunflower Family	*Aster* Dum.	
Asteraceae	Smooth Aster	*Aster laevis* L.	Native
Asteraceae	White Upland Aster	*Aster ptarmicoides* (Nees) T. & G.	Native
Asteraceae	Canada Thistle	*Cirsium arvense* (L.) Scop.	Introduced Weed / Eurasian
Asteraceae	Short-stemmed Thistle	*Cirsium drummondii* T. & G.	Native
Asteraceae	Philadelphia Fleabane	*Erigeron philadelphicus* L.	Native
Asteraceae	Sunflower	*Helianthus* L.	Native to N.A.
Asteraceae	Rhombic-leaved Sunflower	*Helianthus laetiflorus* Pers. var. *subrhomboideus* (Rydb.) Fern.	Native
Asteraceae	Narrow-leaved Hawkweed	*Hieracium scabriusculum* Schwein.	Native
Asteraceae	Blue lettuce	*Lactuca tatarica* (L.) Meyer var. *pulchella* (Pursh)	Native Weed
Asteraceae	Meadow blazingstar	*Liatris ligulistylis* (Nels.) Schum.	Native
Asteraceae	White Lettuce	*Prenanthes alba* L.	Native
Asteraceae	Canada Goldenrod	*Solidago canadensis* L.	Native
Asteraceae	Goldenrod	*Solidago* L.	Native
Asteraceae	Stiff Goldenrod	*Solidago rigida* L.	Native
Asteraceae	Spike-like Goldenrod	*Solidago spathulata* DC.	Native

Appendix E, Continued

Family	Common Name	Latin Name	Native vs. Introduced
Asteraceae	Field-Sow-Thistle (perennial)	*Sonchus arvensis* L.	Introduced / Eurasian
Asteraceae	Sow-Thistle	*Sonchus* L.	Introduced / Eurasian
Asteraceae	Common-Sow-Thistle (annual)	*Sonchus oleraceus* L.	Introcuded / Eurasian
Asteraceae	Common Dandelion	*Taraxacum officinale* Weber	Introduced Weed / European
Asteraceae	Goat's-beard	*Tragopogon dubius* Scop.	Introduced / European
Betulaceae	Low Birch	*Betula pumila L. var. glandulifera* Regel	Native
Boraginaceae	Puccoon	*Lithospermum canescens* (Michx.) Lehm.	Native
Brassicaceae	Wormseed-Mustard	*Erysimum cheiranthoides* L.	Introduced / Eurasian
Bryophyta	Moss	*Brachythecium*	Native
Bryophyta	Copper wire moss	*Pohlia nutans*	Native
Caprifoliaceae	Western Snowberry	*Symphoricarpos occidentalis* Hook.	Native
Caryophyllaceae	Chickweed	*Stellaria* L.	
Cupressaceae	Creeping Juniper	*Juniperus horizontalis* Moench	Native
Cyperaceae	Sedge	*Carex* L.	
Diapensiaceae	Fringed Loosestrife	*Steironema ciliatum* (L.) Raf.	Native
Elaeagnaceae	Soapberry	*Shepherdia canadensis* (L.) Nutt.	Native
Ericaceae	Common Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.	Native
Fabaceae	Canadian Milk-vetch	*Astragalus canadensis* L.	Native
Fabaceae	Hedysarum	*Hedysarum alpinum* L.	Native
Fabaceae	Creamy Peavine	*Lathyrus ochroleucus* Hook.	Native
Fabaceae	Purple Peavine	*Lathyrus venosus* Muhl.	Native
Fabaceae	White sweet-clover	*Melilotus alba* Desr.	Introduced Weed / Eurasian
Fabaceae	Clover sp.	*Trifolium* L.	Introduced / Eurasian
Fabaceae	Red Clover	*Trifolium pratense* L.	Introduced / Eurasian
Fabaceae	Wild Vetch	*Vicia americana* Muhl.	Native

Appendix E, Continued

Family	Common Name	Latin Name	Native vs. Introduced
Fagaceae	Bur oak	*Quercus macrocarpa* Michx.	Native
Gentianaceae	Felwort	*Gentianella amarella* (L.) Borner	Native
Geraniaceae	Bicknell's Geranium	*Geranium bicknellii* Britt.	Native
Lamiaceae	Blue Giant Hyssop	*Agastache foeniculum* (Pursh) Ktze.	Native
Lamiaceae	Wild Bergamot	*Monarda fistulosa* L.	Native
Liliaceae	Nodding onion	*Allium cernuum* Roth	Native
Liliaceae	Wild Lily of the Valley	*Maianthemum canadense* Desf.	Native
Liliaceae	Star False Solomon's-seal	*Smilacina stellata* (L.) Desf.	Native
Liliaceae	Carrion-flower	*Smilax herbacea* L.	Native
Mycomycota	Lichen	*Peltigera*	
Ophioglossaceae	Leathery Grape-Fern	*Botrychium multifidum* (Gmel.) Rupr.	Native
Poaceae	Wheatgrass	*Agropyron* Gaertn.	
Poaceae	Slender Wheat Grass	*Agropyron trachycaulum* (Link) Malte	Native
Poaceae	Hairgrass	*Agrostis hyemalis* (Walt.) BSP.	Native
Poaceae	Fringed Brome	*Bromus ciliatus* L.	Native
Poaceae	Brome Grass	*Bromus* L.	
Poaceae	Timber Oat-Grass	*Danthonia intermedia* Vasey	Native
Poaceae	Canadian Wild Rye	*Elymus canadensis* L.	Native
Poaceae	Spike Oat	*Helictotrichon hookeri* (Scribn.) Henrard	Native
Poaceae	June-Grass	*Koeleria cristata* (L.) Pers.	Native
Poaceae	Green Muhly	*Muhlenbergia racemosa* (Michx.) BSP.	Native
Poaceae	Rough-Leaved Rice Grass	*Oryzopsis asperifolia* Michx.	Native
Poaceae	Old-witch Grass	*Panicum capillare* L.	Native
Poaceae	Common Timothy	*Phleum pratense* L.	Introduced / Eurasian
Poaceae	Bluegrass	*Poa* L.	

Appendix E, Continued

Family	Common Name	Latin Name	Native vs. Introduced
Poaceae	Kentucky Bluegrass	*Poa pratensis* L.	Native
Poaceae	Grass Family	*Poaceae* Barnh.	
Poaceae	Speargrass	*Stipa comata* Trin. & Rupr.	Native
Poaceae	Needlegrass	*Stipa* L.	Native
Poaceae	Richardson's Needle Grass	*Stipa richardsonii* Link	Native
Polygalaceae	Seneca Root	*Polygala senega* L.	Native
Ranunculaceae	Canada Anemone	*Anemone canadensis* L.	Native
Ranunculaceae	Wind Flower	*Anemone* L.	
Ranunculaceae	Veiny Meadow Rue	*Thalictrum venulosum* Trel.	Native
Rosaceae	Saskatoon	*Amelanchier alnifolia* Nutt.	Native
Rosaceae	Hawthorn	*Crataegus rotundifolia* Moench	Native
Rosaceae	Strawberry	*Fragaria* L.	Native
Rosaceae	Smooth Wild Strawberry	*Fragaria virginiana* Dcne.	Native
Rosaceae	Avens	*Geum* L.	
Rosaceae	Three-flowered avens	*Geum triflorum* Pursh	Native
Rosaceae	Tall Cinquefoil	*Potentilla arguta* Pursh	Native
Rosaceae	Shrubby Cinquefoil	*Potentilla fruticosa* L.	Native
Rosaceae	Choke-Cherry	*Prunus virginiana* L.	Native
Rosaceae	Prickly Rose	*Rosa acicularis* Lindl.	Native
Rubiaceae	Northern Bedstraw	*Galium boreale* L.	Native
Salicaceae	Trembling Aspen	*Populus tremuloides* Michx.	Native
Salicaceae	Willow	*Salix* L.	
Santalaceae	Pale Comandra	*Comandra umbellata* (L.) Nutt. var. *pallida* (DC.) Jones	Native
Saxifragaceae	Alumroot	*Heuchera richardsonii* R. Br.	Native
Scrophulariaceae	Lousewort	*Pedicularis* L.	Native

Source of Latin and common names: Flora of the Great Plains (Great Plains Flora Association 1986).

Appendix F

2001 Vegetation Species Frequency of Occurrence In Percent

2001 Plant Species	Control A	Control B	Control C	Fire A	Fire B	Fire C	Herbicide A	Herbicide B	Herbicide C	Mowing A	Mowing B	Mowing C	Scrape A	Scrape B	Scrape C
Poaceae	100.00	100.00	100.00	100.00	100.00	100.00	87.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Galium boreale	100.00	95.83	100.00	95.83	83.33	95.83	95.83	100.00	100.00	100.00	100.00	100.00	100.00	95.83	100.00
Lithospermum canescens	95.83	70.83	66.67	37.50	0.00	79.17	54.17	79.17	79.17	91.67	54.17	58.33	66.67	66.67	83.33
Aster ciliolatus	87.50	95.83	91.67	75.00	70.83	95.83	87.50	100.00	100.00	33.33	95.83	95.83	87.50	100.00	91.67
Carex sp.	87.50	95.83	79.17	100.00	100.00	91.67	87.50	100.00	87.50	95.83	95.83	95.83	100.00	91.67	100.00
Achillea millefolium	87.50	70.83	83.33	58.33	50.00	75.00	75.00	100.00	79.17	91.67	70.83	79.17	79.17	83.33	70.83
Lathyrus venosus	83.33	100.00	70.83	83.33	100.00	75.00	83.33	79.17	83.33	75.00	91.67	87.50	70.83	95.83	79.17
Populus tremuloides	83.33	95.83	75.00	87.50	87.50	91.67	100.00	79.17	100.00	100.00	83.33	100.00	87.50	95.83	100.00
Comandra umbellata	79.17	79.17	50.00	45.83	58.33	70.83	62.50	87.50	33.33	75.00	70.83	62.50	54.17	50.00	62.50
Amelanchier alnifolia	79.17	75.00	91.67	62.50	62.50	66.67	58.33	75.00	87.50	83.33	91.67	83.33	83.33	87.50	45.83
Arctostaphylos uva-ursi	79.17	54.17	58.33	37.50	0.00	87.50	66.67	95.83	66.67	91.67	54.17	25.00	54.17	58.33	45.83
Monarda fistulosa	75.00	45.83	87.50	41.67	37.50	79.17	79.17	91.67	83.33	95.83	70.83	75.00	75.00	62.50	62.50
Bromus ciliatus	70.83	41.67	50.00	37.50	29.17	75.00	41.67	91.67	50.00	70.83	41.67	50.00	41.67	58.33	45.83
Thalictrum venulosum	66.67	70.83	79.17	58.33	58.33	75.00	70.83	66.67	50.00	41.67	70.83	50.00	16.67	83.33	58.33
Rosa acicularis	58.33	87.50	75.00	75.00	75.00	91.67	83.33	75.00	75.00	50.00	79.17	70.83	58.33	70.83	87.50
Vicia americana	58.33	79.17	37.50	87.50	83.33	41.67	50.00	62.50	58.33	83.33	66.67	83.33	66.67	87.50	66.67
Polygala senega	58.33	16.67	16.67	8.33	0.00	8.33	8.33	54.17	4.17	41.67	25.00	16.67	16.67	29.17	0.00
Agropyron trachycaulum	54.17	0.00	41.67	75.00	0.00	91.67	95.83	0.00	95.83	79.17	0.00	75.00	75.00	0.00	83.33
Helictotrichon hookeri	50.00	45.83	54.17	41.67	12.50	33.33	16.67	20.83	16.67	37.50	29.17	4.17	25.00	58.33	29.17
Artemisia ludoviciana	45.83	37.50	66.67	54.17	70.83	66.67	50.00	70.83	83.33	75.00	45.83	62.50	62.50	62.50	75.00
Symphoricarpos occidentalis	41.67	83.33	70.83	45.83	91.67	62.50	37.50	54.17	62.50	58.33	66.67	95.83	62.50	58.33	45.83
Solidago canadensis	41.67	50.00	29.17	41.67	54.17	16.67	54.17	29.17	20.83	33.33	29.17	29.17	29.17	75.00	12.50
Steironema ciliatum	41.67	29.17	33.33	79.17	45.83	29.17	25.00	0.00	33.33	41.67	16.67	29.17	54.17	16.67	62.50
Hieracium umbellatum	33.33	29.17	16.67	16.67	4.17	8.33	0.00	29.17	12.50	0.00	16.67	8.33	8.33	37.50	12.50
Solidago spathulata	33.33	16.67	33.33	25.00	0.00	58.33	45.83	75.00	41.67	66.67	37.50	20.83	37.50	33.33	50.00
Solidago rigida	33.33	8.33	25.00	29.17	0.00	33.33	16.67	50.00	37.50	54.17	12.50	16.67	45.83	16.67	50.00
Apocynum androsaemifolium	29.17	62.50	4.17	4.17	16.67	16.67	8.33	12.50	0.00	0.00	37.50	4.17	16.67	29.17	0.00
Poa	29.17	33.33	29.17	41.67	54.17	20.83	12.50	29.17	33.33	25.00	66.67	45.83	37.50	25.00	41.67
Phleum pratense	25.00	4.17	16.67	20.83	0.00	41.67	16.67	25.00	16.67	25.00	20.83	0.00	20.83	25.00	20.83
Sanicula marilandica	20.83	79.17	79.17	41.67	33.33	16.67	50.00	29.17	29.17	8.33	58.33	41.67	8.33	45.83	25.00
Campanula rotundifolia	20.83	16.67	29.17	8.33	4.17	16.67	4.17	45.83	16.67	4.17	16.67	12.50	0.00	29.17	16.67
Erigeron philadelphicus	20.83	8.33	8.33	0.00	0.00	0.00	8.33	16.67	4.17	0.00	16.67	0.00	16.67	4.17	4.17
Prunus virginiana	16.67	16.67	29.17	16.67	50.00	8.33	16.67	0.00	0.00	16.67	33.33	12.50	25.00	12.50	8.33
Muhlenbergia racemosa	16.67	4.17	4.17	16.67	8.33	16.67	12.50	16.67	8.33	4.17	8.33	0.00	4.17	0.00	12.50
Tragopogon dubius	12.50	4.17	4.17	4.17	4.17	0.00	4.17	12.50	12.50	4.17	4.17	0.00	12.50	4.17	0.00
Aster laevis	12.50	0.00	8.33	12.50	4.17	16.67	0.00	0.00	12.50	50.00	0.00	4.17	25.00	0.00	16.67
Cirsium drummondii	12.50	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potentilla fruticosa	12.50	0.00	4.17	16.67	0.00	25.00	37.50	20.83	29.17	12.50	12.50	8.33	16.67	0.00	29.17
Fragaria virginiana	8.33	58.33	37.50	37.50	50.00	58.33	37.50	37.50	41.67	12.50	16.67	25.00	37.50	50.00	54.17

Appendix F, Continued

2001 Plant Species	Control A	Control B	Control C	Fire A	Fire B	Fire C	Herbicide A	Herbicide B	Herbicide C	Mowing A	Mowing B	Mowing C	Scrape A	Scrape B	Scrape C
Potentilla arguta	8.33	12.50	0.00	0.00	0.00	12.50	8.33	0.00	4.17	8.33	4.17	4.17	4.17	8.33	16.67
Salix sp.	8.33	8.33	0.00	29.17	16.67	4.17	4.17	4.17	16.67	4.17	0.00	33.33	0.00	8.33	0.00
Zizia aptera	8.33	4.17	16.67	8.33	0.00	25.00	29.17	29.17	16.67	16.67	12.50	12.50	25.00	25.00	33.33
Taraxacum officinale	4.17	20.83	0.00	12.50	20.83	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00
Lactuca tatarica	4.17	12.50	12.50	20.83	45.83	0.00	12.50	0.00	4.17	0.00	4.17	4.17	12.50	8.33	12.50
Geranium bicknellii	4.17	4.17	8.33	4.17	8.33	4.17	8.33	4.17	4.17	0.00	0.00	8.33	12.50	8.33	8.33
Prenanthes alba L.	4.17	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Betula pumila	4.17	0.00	16.67	29.17	0.00	16.67	12.50	0.00	29.17	4.17	0.00	12.50	0.00	0.00	0.00
Panicum capillare	4.17	0.00	4.17	4.17	0.00	0.00	16.67	0.00	0.00	8.33	4.17	0.00	8.33	0.00	0.00
Stipa comata	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anemone canadensis	4.17	0.00	0.00	0.00	0.00	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crataegus	4.17	0.00	0.00	0.00	4.17	0.00	4.17	0.00	4.17	0.00	0.00	0.00	4.17	0.00	0.00
Botrychium multifidum	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	4.17
Maianthemum canadense	0.00	37.50	4.17	0.00	0.00	4.17	4.17	20.83	8.33	0.00	4.17	12.50	0.00	12.50	0.00
Smilacina stellata	0.00	12.50	12.50	16.67	4.17	29.17	12.50	0.00	4.17	12.50	12.50	25.00	8.33	12.50	33.33
Trifolium pratense	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17
Helianthus sp.	0.00	0.00	12.50	0.00	0.00	4.17	4.17	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00
Heuchera richardsonii	0.00	0.00	4.17	4.17	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	4.17	0.00	0.00
Astragalus canadensis	0.00	0.00	4.17	0.00	0.00	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	0.00	8.33
Geum triflorum	0.00	0.00	4.17	0.00	0.00	8.33	8.33	0.00	20.83	8.33	0.00	8.33	4.17	0.00	37.50
Aster ptarmicoides	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elymus canadensis	0.00	0.00	0.00	8.33	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stipa richardsonii	0.00	0.00	0.00	8.33	12.50	12.50	0.00	0.00	8.33	25.00	0.00	0.00	41.67	0.00	37.50
Agrostis hyemalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00
Gentianella amarella	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00
Quercus macrocarpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cirsium arvense	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17
Smilax herbacea var. *lasioneur*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Juniperus horizontalis	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agastache foeniculum	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	4.17
Pedicularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aster borealis	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liatris ligulistylis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	4.17	0.00	0.00
Allium cernuum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	4.17	0.00	0.00
Shepherdia canadensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00
Sonchus oleraceus L.	0.00	0.00	0.00	4.17	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sonchus arvensis L.	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00

Appendix G

Photographs of unrolled bush sites in blocks A, B, and C

Figure G-1: Unrolled bush in block A, quadrat 23.

Figure G-2: Unrolled bush in block B, quadrat 9.

Figure G-3: Unrolled bush in block C.

Appendix H

Chapter5: Vegetation Data

Table H-1: Percent frequency of occurrence of plant species in fire blocks A, B, and C in 2001.

Latin Name	Common Name	Fire A	Fire B	Fire C
Geranium bicknellii	Bicknell's Geranium	4.17	8.33	4.17
Agastache foeniculum	Blue Giant Hyssop	0.00	4.17	0.00
Lactuca tatarica	Blue lettuce	20.83	45.83	0.00
Poa	Bluegrass	41.67	54.17	20.83
Solidago canadensis	Canada Goldenrod	41.67	54.17	16.67
Cirsium arvense	Canada Thistle	0.00	4.17	0.00
Prunus virginiana	Choke-Cherry	16.67	50.00	8.33
Arctostaphylos uva-ursi	Common Bearberry	37.50	0.00	87.50
Taraxacum officinale	Common Dandelion	12.50	20.83	0.00
Phleum pratense	Common Timothy	20.83	0.00	41.67
Achillea millefolium	Common Yarrow	58.33	50.00	75.00
Sonchus oleraceus	Common-Sow-Thistle (annual)	4.17	8.33	4.17
Sonchus arvensis	Field-Sow-Thistle (perennial)	0.00	4.17	0.00
Aster ciliolatus	Fringed Aster	75.00	70.83	95.83
Bromus ciliatus	Fringed Brome	37.50	29.17	75.00
Steironema ciliatum	Fringed Loosestrife	79.17	45.83	29.17
Tragopogon dubius	Goat's-beard	4.17	4.17	0.00
Muhlenbergia racemosa	Green Muhly	16.67	8.33	16.67
Campanula rotundifolia	Harebell	8.33	4.17	16.67
Crataegus rotundifolia	Hawthorn	0.00	4.17	0.00
Zizia aptera	Heart-leaved Alexanders	8.33	0.00	25.00
Betula pumila L. var. glandulifera	Low Birch	29.17	0.00	16.67
Hieracium scabriusculum	Narrow-leaved Hawkweed	16.67	4.17	8.33
Galium boreale	Northern Bedstraw	95.83	83.33	95.83
Comandra umbellata	Pale Comandra	45.83	58.33	70.83
Artemisia ludoviciana	Prairie Sage	54.17	70.83	66.67
Rosa acicularis	Prickly Rose	75.00	75.00	91.67
Lithospermum canescens	Puccoon	37.50	0.00	79.17
Lathyrus venosus	Purple Peavine	83.33	100.00	75.00
Amelanchier alnifolia	Saskatoon	62.50	62.50	66.67
Carex	Sedge	100.00	100.00	91.67
Polygala senega	Seneca Root	8.33	0.00	8.33
Potentilla fruticosa	Shrubby Cinquefoil	16.67	0.00	25.00
Agropyron trachycaulum	Slender Wheat Grass	75.00	75.00	91.67
Aster laevis	Smooth Aster	12.50	4.17	16.67
Sanicula marilandica	Snakeroot	41.67	33.33	16.67
Helictotrichon hookeri	Spike Oat	41.67	12.50	33.33
Solidago spathulata	Spike-like Goldenrod	25.00	0.00	58.33
Apocynum androsaemifolium	Spreading Dogbane	4.17	16.67	16.67
Smilacina stellata	Star False Solomon's-seal	16.67	4.17	29.17
Solidago rigida	Stiff Goldenrod	29.17	0.00	33.33
Potentilla arguta	Tall Cinquefoil	0.00	0.00	12.50
Geum triflorum	Three-flowered avens	0.00	0.00	8.33
Populus tremuloides	Trembling Aspen	87.50	87.50	91.67
Symphoricarpos occidentalis	Western Snowberry	45.83	91.67	62.50
Monarda fistulosa	Wild Bergamot	41.67	37.50	79.17
Vicia americana	Wild Vetch	87.50	83.33	41.67
Salix	Willow	29.17	16.67	4.17

Table H-2: Relative abundance of cover types with respect to treatments for 2001.

Treatment	Relative Abundance of Cover Types for 2001									
	Grass	Sedges	Herbs	Legumes	Low Herbs	Lily	Low Shrub	Tree	Tall Shrub	Weeds
Control A	25.85	3.69	29.71	4.13	6.73	0.00	14.27	5.96	9.28	0.37
Control B	24.08	5.59	28.47	6.30	7.58	0.99	7.15	6.68	12.37	0.79
Control C	25.85	5.17	27.84	2.62	5.91	0.22	10.78	6.83	14.38	0.40
Fire A	16.88	13.22	23.17	7.44	5.45	0.18	6.29	6.11	20.56	0.70
Fire B	20.82	13.67	24.16	7.24	8.24	0.07	0.00	6.98	16.64	2.18
Fire C	22.70	3.06	28.75	2.39	6.37	0.65	13.76	7.93	14.29	0.09
Herbicide A	25.48	4.22	29.45	5.32	6.93	0.59	6.44	10.25	10.50	0.82
Herbicide B	20.53	3.97	27.95	4.29	9.17	0.29	18.48	5.83	9.15	0.34
Herbicide C	19.49	6.86	28.50	3.35	4.56	0.28	12.99	8.67	14.94	0.36
Mowing A	17.85	4.71	27.64	4.47	6.46	0.18	16.71	13.29	8.60	0.09
Mowing B	29.75	4.44	27.49	5.08	6.43	0.30	8.69	6.84	10.77	0.21
Mowing C	25.00	10.38	25.41	5.23	5.42	0.63	3.86	8.44	15.35	0.28
Scrape A	25.24	7.04	28.74	4.28	6.23	0.13	10.41	5.35	11.79	0.79
Scrape B	22.90	3.06	34.54	6.19	7.00	0.35	8.05	6.57	10.98	0.37
Scrape C	20.85	7.17	32.89	3.90	6.29	0.72	6.30	8.67	12.71	0.51
Bush A	17.79	10.42	20.87	4.10	4.40	1.65	4.46	20.67	14.88	0.76
Bush B	16.32	13.03	18.21	6.14	4.34	1.92	0.00	17.97	21.62	0.45
Bush C	12.29	20.13	16.10	6.90	5.29	3.40	0.53	21.00	14.04	0.35

Table H-3: Site descriptions for each treatment plot.

Treatment	Block	Description
Control	A	High and dry; quite flat;
	B	More topographic variations; Q14 was high, dry, and had no trees
	C	Slight topographic variations; ranges from shrubby area to grassland with very few trees; Q17 was an open, grassy area
Fire	A	Pronounced topographic variations; clear low, intermediate and high areas; Q2, 11 & 14 had a dense sedge cover (75 - 100%), found in the low area
	B	Intermediate and a low area (a draw where the single *Aster borealis* was found); Q23 & 24 were in low sites; had little high ground (Q5 was a drier site); less overall relief than Fire A; possibly had the hottest burn of the three blocks
	C	very flat, unlike the other fire blocks; appeared to have had the coolest burn;
Herbicide	A	Fairly flat ground
	B	Somewhat rolling; lots of high ground
	C	Fairly flat ground; has a grassy area
Mowing	A	Very high aspen stem density; quite flat;
	B	Fairly flat, with a slight rise to the north; Q21 was a drier site with limited vertical structure; Q24 was also dry
	C	Quite flat; Q22 & 23 were open, dry sites
Scrape	A	Relatively flat, a drop in elevation was noted from Q14 to 15, and then climbed from Q15 through 17
	B	High up in block B, probably drier ground
	C	Fairly flat; some plots near mature aspen; Q10 was a dry site with low vertical structure
Unrolled Bush	A	Youngest forest; recently burned?
	B	Plots 9-11 were thick, difficult to walk through
	C	most mature forest

Table H-4: Mean frequency of occurrence in percent for the 2001 vegetation.

2001 Plant Species	Control A	Control B	Control C	Fire A	Fire B	Fire C	Herbicide A	Herbicide B	Herbicide C	Mowing A	Mowing B	Mowing C	Scrape A	Scrape B	Scrape C
Apocynum androsaemifolium	29.17	62.50	4.17	4.17	16.67	16.67	8.33	12.50	0.00	0.00	37.50	4.17	16.67	29.17	0.00
Arctostaphylos uva-ursi	79.17	54.17	58.33	37.50	0.00	87.50	66.67	95.83	66.67	91.67	54.17	25.00	54.17	58.33	45.83
Betula pumila	4.17	0.00	16.67	29.17	0.00	16.67	12.50	0.00	29.17	4.17	0.00	12.50	0.00	0.00	0.00
Bromus ciliatus	70.83	41.67	50.00	37.50	29.17	75.00	41.67	91.67	50.00	70.83	41.67	50.00	41.67	58.33	45.83
Campanula rotundifolia	20.83	16.67	29.17	8.33	4.17	16.67	4.17	45.83	16.67	4.17	16.67	12.50	0.00	29.17	16.67
Cirsium arvense	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17
Cirsium drummondii	12.50	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elymus canadensis	0.00	0.00	0.00	8.33	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Erigeron philadelphicus	20.83	8.33	8.33	0.00	0.00	0.00	8.33	16.67	4.17	0.00	16.67	0.00	16.67	4.17	4.17
Geum triflorum	0.00	0.00	4.17	0.00	0.00	8.33	8.33	0.00	20.83	8.33	0.00	8.33	4.17	0.00	37.50
Lactuca tatarica	4.17	12.50	12.50	20.83	45.83	0.00	12.50	0.00	4.17	0.00	4.17	4.17	12.50	8.33	12.50
Lathyrus venosus	83.33	100.00	70.83	83.33	100.00	75.00	83.33	79.17	83.33	75.00	91.67	87.50	70.83	95.83	79.17
Maianthemum canadense	0.00	37.50	4.17	0.00	0.00	4.17	4.17	20.83	8.33	0.00	4.17	12.50	0.00	12.50	0.00
Monarda fistulosa	75.00	45.83	87.50	41.67	37.50	79.17	79.17	91.67	83.33	95.83	70.83	75.00	75.00	62.50	62.50
Polygala senega	58.33	16.67	16.67	8.33	0.00	8.33	8.33	54.17	4.17	41.67	25.00	16.67	16.67	29.17	0.00
Potentilla fruticosa	12.50	0.00	4.17	16.67	0.00	25.00	37.50	20.83	29.17	12.50	12.50	8.33	16.67	0.00	29.17
Prunus virginiana	16.67	16.67	29.17	16.67	50.00	8.33	16.67	0.00	0.00	16.67	33.33	12.50	25.00	12.50	8.33
Salix sp.	8.33	8.33	0.00	29.17	16.67	4.17	4.17	4.17	16.67	4.17	0.00	33.33	0.00	8.33	0.00
Sanicula marilandica	20.83	79.17	79.17	41.67	33.33	16.67	50.00	29.17	29.17	8.33	58.33	41.67	8.33	45.83	25.00
Solidago rigida	33.33	8.33	25.00	29.17	0.00	33.33	16.67	50.00	37.50	54.17	12.50	16.67	45.83	16.67	50.00
Solidago spathulata	33.33	16.67	33.33	25.00	0.00	58.33	45.83	75.00	41.67	66.67	37.50	20.83	37.50	33.33	50.00
Sonchus arvensis L.	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00
Sonchus oleraceus L.	0.00	0.00	0.00	4.17	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Steironema ciliatum	41.67	29.17	33.33	79.17	45.83	29.17	25.00	0.00	33.33	41.67	16.67	29.17	54.17	16.67	62.50
Stipa richardsonii	0.00	0.00	0.00	8.33	12.50	12.50	0.00	0.00	8.33	25.00	0.00	0.00	41.67	0.00	37.50
Symphoricarpos occidentalis	41.67	83.33	70.83	45.83	91.67	62.50	37.50	54.17	62.50	58.33	66.67	95.83	62.50	58.33	45.83
Taraxacum officinale	4.17	20.83	0.00	12.50	20.83	0.00	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00
Thalictrum venulosum	66.67	70.83	79.17	58.33	58.33	75.00	70.83	66.67	50.00	41.67	70.83	50.00	16.67	83.33	58.33
Zizia aptera	8.33	4.17	16.67	8.33	0.00	25.00	29.17	29.17	16.67	16.67	12.50	12.50	25.00	25.00	33.33

Table H-5: Mean percent frequency of occurrence for 2001 plant species in respective treatments.

2001 Plant Species	Mean Percent Frequency For Each Treatment					
Latin Name	Fire	Herbicide	Mowing	Scrape	Control	Bush
Achillea millefolium	61.11	84.72%	80.56%	77.78%	80.56	**20.83%**
Apocynum androsaemifolium	12.50	6.94%	13.89%	15.28%	31.94	**41.67%**
Arctostaphylos uva-ursi	41.67	76.39%	56.94%	52.78%	63.89	**25.00%**
Betula pumila var. glandulifera	15.28	13.89%	5.56%	0.00%	6.94	4.17%
Bromus ciliatus	47.22	61.11%	54.17%	48.61%	54.17	**29.17%**
Campanula rotundifolia	9.72	22.22%	11.11%	15.28%	22.22	**0.00%**
Cirsium arvense	1.39	0.00%	0.00%	1.39%	0.00	0.00%
Cirsium drummondii	0.00	0.00%	0.00%	0.00%	5.56	0.00%
Elymus canadensis	6.94	0.00%	0.00%	0.00%	0.00	8.33%
Erigeron philadelphicus	0.00	9.72%	5.56%	8.33%	12.50	4.17%
Geum triflorum	2.78	9.72%	5.56%	13.89%	1.39	0.00%
Helianthus sp.	1.39	1.39%	1.39%	0.00%	4.17	0.00%
Helictotrichon hookeri	29.17	18.06%	23.61%	37.50%	50.00	**70.83%**
Hieracium umbellatum	9.72	13.89%	8.33%	19.44%	26.39	20.83%
Lactuca tatarica	22.22	5.56%	2.78%	11.11%	9.72	25.00%
Maianthemum canadense	1.39	11.11%	5.56%	4.17%	13.89	**66.67%**
Monarda fistulosa	52.78	84.72%	80.56%	66.67%	69.44	**25.00%**
Poa	38.89	25.00%	45.83%	34.72%	30.56	25.00%
Polygala senega	5.56	22.22%	27.78%	15.28%	30.56	4.17%
Populus tremuloides	88.89	93.06%	94.44%	94.44%	84.72	100.00%
Potentilla fruticosa	13.89	29.17%	11.11%	15.28%	5.56	4.17%
Prunus virginiana	25.00	5.56%	20.83%	15.28%	20.83	25.00%
Rosa acicularis	80.56	77.78%	66.67%	72.22%	73.61	87.50%
Salix sp.	16.67	8.33%	12.50%	2.78%	5.56	8.33%
Sanicula marilandica	30.56	36.11%	36.11%	26.39%	59.72	**91.67%**
Solidago rigida	20.83	34.72%	27.78%	37.50%	22.22	**0.00%**
Solidago spathulata	27.78	54.17%	41.67%	40.28%	27.78	**8.33%**
Sonchus arvensis	1.39	0.00%	1.39%	0.00%	0.00	0.00%
Sonchus oleraceus	5.56	0.00%	0.00%	0.00%	0.00	0.00%
Steironema ciliatum	51.39	19.44%	29.17%	44.44%	34.72	45.83%
Stipa richardsonii Link	11.11	2.78%	8.33%	26.39%	0.00	0.00%
Symphoricarpos occidentalis	66.67	51.39%	73.61%	55.56%	65.28	70.83%
Taraxacum officinale	11.11	0.00%	1.39%	0.00%	8.33	4.17%
Thalictrum venulosum	63.89	62.50%	54.17%	52.78%	72.22	**95.83%**
Zizia aptera	11.11	25.00%	13.89%	27.78%	9.72	**4.17%**

Table H-6: Plant species that remained constant or decreased in observed frequency (percent).

Plant Species		Fire A		Fire B		Fire C	
Latin Name	**Common Name**	**PreTreat**	**2001**	**PreTreat**	**2001**	**PreTreat**	**2001**
Betula pumila L. var. *glandulifera*	Low Birch	33.33	29.17	0.00	0.00	20.83	16.67
Arctostaphylos uva-ursi	Common Bearberry	37.50	37.50	0.00	0.00	91.67	87.50
Panicum capillare	Old-witch Grass	0.00	4.17	0.00	0.00	16.67	0.00
Poa sp.	Bluegrass Sp.	62.50	41.67	75.00	54.17	100.00	20.83
Amelanchier alnifolia	Saskatoon	58.33	62.50	66.67	62.50	50.00	66.67
Geum sp.	Geum Sp.	4.17	0.00	0.00	0.00	16.67	8.33
Rosa acicularis	Prickly Rose	70.83	75.00	75.00	75.00	91.67	91.67
Populus tremuloides	Trembling Aspen	83.33	87.50	87.50	87.50	91.67	91.67
Salix sp.	Willow	25.00	29.17	12.50	16.67	0.00	4.17

Table H-7: Plant species that increased in observed frequency (percent).

Plant Species		Fire A		Fire B		Fire C	
Latin Name	**Common Name**	**PreTreat**	**2001**	**PreTreat**	**2001**	**PreTreat**	**2001**
Sanicula marilandica	Snakeroot	4.17	41.67	0.00	33.33	0.00	16.67
Zizia aptera	Heart-leaved Alexanders	4.17	8.33	0.00	0.00	12.50	25.00
Achillea millefolium	Common Yarrow	37.50	58.33	33.33	50.00	54.17	75.00
Artemisia ludoviciana	Prairie Sage	37.50	54.17	62.50	70.83	62.50	66.67
Aster ciliolatus	Fringed Aster	8.33	75.00	12.50	70.83	0.00	95.83
Solidago spathulata	Spike-like Goldenrod	0.00	25.00	0.00	0.00	4.17	58.33
Taraxacum officinale	Common Dandelion	0.00	12.50	4.17	20.83	0.00	0.00
Symphoricarpos occidentalis	Western Snowberry	20.83	45.83	37.50	91.67	8.33	62.50
Carex	Sedge	66.67	100.00	79.17	100.00	75.00	91.67
Steironema ciliatum	Fringed Loosestrife	12.50	79.17	4.17	45.83	4.17	29.17
Lathyrus venosus	Purple Peavine	16.67	83.33	33.33	100.00	16.67	75.00
Vicia americana	Wild Vetch	12.50	87.50	4.17	83.33	12.50	41.67
Monarda fistulosa	Wild Bergamot	20.83	41.67	16.67	37.50	54.17	79.17
Agropyron trachycaulum	Slender Wheat Grass	45.83	75.00	54.17	75.00	33.33	91.67
Bromus sp.	Brome Sp.	12.50	37.50	20.83	29.17	33.33	75.00
Elymus canadensis	Canadian Wild Rye	0.00	8.33	4.17	8.33	0.00	4.17
Muhlenbergia racemosa	Green Muhly	0.00	16.67	4.17	8.33	0.00	16.67
Poaceae	Grass Sp.	20.83	100.00	62.50	100.00	8.33	100.00
Fragaria virginiana	Smooth Wild Strawberry	12.50	37.50	41.67	50.00	29.17	58.33
Potentilla fruticosa	Shrubby Cinquefoil	4.17	16.67	0.00	0.00	12.50	25.00
Prunus virginiana	Choke-Cherry	4.17	16.67	16.67	50.00	0.00	8.33
Galium boreale	Northern Bedstraw	25.00	95.83	20.83	83.33	54.17	95.83
Comandra umbellata	Pale Comandra	8.33	45.83	4.17	58.33	37.50	70.83

Table H-8: Relative abundance of plant species found in low, intermediate, and high microtopic relief areas in fire block A.

Plant Species		Ground Type		
Latin Name	Common Name	Low	Intermediate	High
Carex sp.	Sedges	40.98%	11.71%	4.98%
Rosa acicularis	Prickly rose	14.16%	5.40%	0.95%
Populus tremuloides	Trembling aspen	8.20%	6.82%	4.36%
Agropyron trachycaulum	Slender wheat grass	4.47%	2.38%	1.18%
Amelanchier alnifolia	Saskatoon	3.73%	4.54%	2.70%
Steironema ciliatum	Fringed loosestrife	3.43%	1.88%	1.66%
Thalictrum venulosum	Veiny meadow rue	3.28%	1.49%	1.18%
Poaceae	Grass sp.	2.98%	9.66%	15.17%
Vicia americana	Wild vetch	2.68%	4.72%	3.74%
Poa	Blue Grass	2.53%	0.46%	0.95%
Salix sp.	Salix	2.24%	4.44%	0.00%
Lathyrus venosus	Purple peavine	2.24%	4.26%	2.89%
Fragaria virginiana	Smooth wild strawberry	2.24%	1.49%	0.24%
Galium boreale	Northern bedstraw	1.79%	3.16%	2.99%
Lactuca tatarica	Blue lettuce	1.64%	0.11%	0.00%
Taraxacum officinale	Common dandelion	1.19%	0.11%	0.00%
Artemisia ludoviciana	Prairie sage	1.04%	1.42%	1.33%
Achillea millefolium	Yarrow	0.75%	0.82%	2.89%
Muhlenbergia racemosa	Green muhly	0.45%	0.00%	0.38%
Betula glandulosa	Scrub birch	0.00%	11.71%	0.00%
Aster ciliolatus	Fringed aster	0.00%	8.34%	11.23%
Solidago canadensis	Canada goldenrod	0.00%	3.16%	1.90%
Symphoricarpos occidentalis	Western snowberry	0.00%	2.27%	0.62%
Sanicula marilandica	Snakeroot	0.00%	1.74%	1.00%
Potentilla fruticosa	Shrubby cinquefoil	0.00%	1.35%	0.95%
Monarda fistulosa	Western wild bergamot	0.00%	1.06%	1.52%
Prunus virginiana	Choke cherry	0.00%	1.06%	0.00%
Helictotrichon hookeri	Hooker's oat grass	0.00%	0.99%	0.43%
Bromus ciliatus	Fringed brome	0.00%	0.71%	2.13%
Solidago spathulata	Spike-like goldenrod	0.00%	0.71%	1.75%
Comandra umbellata	Pale comandra	0.00%	0.64%	1.80%
Lithospermum canescens	Hoary puccoon	0.00%	0.28%	2.13%
Zizia aptera	Heart-leaved alexanders	0.00%	0.28%	0.24%
Elymus canadensis	Canadian Wild Rye	0.00%	0.28%	0.00%
Apocynum androsaemifolium	Spreading dogbane	0.00%	0.18%	0.00%
Sonchus oleraceus	Sow-thistle (annual)	0.00%	0.18%	0.00%
Solidago rigida	Stiff goldenrod	0.00%	0.11%	2.65%
Smilacina stellata	Star-flowered false solomon's seal	0.00%	0.07%	0.43%
Arctostaphylos uva-ursi	Bearberry	0.00%	0.00%	17.77%
Hieracium scabriusculum	Narrow-leaved hawkweed	0.00%	0.00%	1.23%
Phleum pratense	Timothy grass	0.00%	0.00%	1.04%
Stipa richardsonii	Richardson's needle grass	0.00%	0.00%	1.04%
Aster laevis	Smooth aster	0.00%	0.00%	0.76%
Campanula rotundifolia	Harebell	0.00%	0.00%	0.47%
Polygala senega	Seneca root	0.00%	0.00%	0.47%
Geranium bicknellii	Bicknell's geranium	0.00%	0.00%	0.24%
Panicum capillare	Witchgrass	0.00%	0.00%	0.24%
Tragopogon dubius	Goat's-beard	0.00%	0.00%	0.24%
Heuchera richardsonii	Alumroot	0.00%	0.00%	0.14%

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