

Effects of fire on the distribution and abundance of Sprague's pipit (*Anthus spragueii*) and their invertebrate prey.

By

Janessa Champagne

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Submitted to the Faculty of Graduate Studies
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Abstract

The Sprague's pipit is a small, threatened grassland songbird endemic to the Canadian prairies and to the northern Great Plains of the United States. Between 1968 and 2006, the population of Sprague's pipit in Canada experienced a significant annual decline of 4.5%. The prairie provinces also experienced declines within this reporting period. Pipits are more abundant in native prairie grasslands, however much of their preferred habitat has been lost due to the influence of human activities. Furthermore, management of remaining grasslands has impacted the quality of habitat through suppression of natural disturbances such as fire. Few studies have addressed how fire affects the occurrence and abundance of Sprague's pipit, thus pipit response to fire is poorly understood. This study investigated the effect of fire on the density and distribution of Sprague's pipit in south-western Manitoba by examining the associations between pipit density, invertebrate food resources and vegetation structure with fire history. Surveys to determine pipit abundance, invertebrate resources and vegetation structure were conducted in 2007; in 2008 only pipit abundance and vegetation surveys were conducted. Although there was no significant effect of invertebrate resource abundance on Sprague's pipit density, the abundance of grasshoppers and ground beetles declined with increasing time since last burn, which suggests that longer fire-return intervals may reduce the availability of these prey species for pipits. Fire did not significantly influence the distribution and density of Sprague's pipit in this region. However the response of the vegetation to fire may indicate that the existing fire-return interval is not contributing to the population decline of Sprague's pipit, but that in the

absence of fire, the habitat could regress to a state that does not meet the critical habitat needs of this species.

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Table of Contents

Abstract	i
Acknowledgements.....	iii
List of Tables	vii
List of Figures	viii
1.0 INTRODUCTION	1
1.1 <i>Background</i>	1
1.2 <i>Biology of Sprague’s pipit</i>	4
1.3 <i>Distribution and Population</i>	4
1.4 <i>Habitat Associations</i>	6
1.5 <i>Diet</i>	7
1.6 <i>Project Significance</i>	8
2.0 LITERATURE REVIEW.....	10
2.1 <i>Defining the Mixed-Grass Prairie Community</i>	10
2.2 <i>Approaches to Grassland Management</i>	11
2.3 <i>The Role of Fire in Grasslands</i>	15
2.3.1 <i>Response of Sprague’s pipit to Fire</i>	17
2.3.2 <i>Response of Insects to Fire</i>	18
2.4 <i>Literature Gaps and Research Objectives</i>	21
2.4.1 <i>Research Objectives</i>	23
2.4.2 <i>Hypothesis</i>	24
2.4.3 <i>Implications for Management</i>	24
3.0 METHODS	26
3.1 <i>Study Area</i>	26
3.1.1 <i>Canadian Forces Base Shilo</i>	26
3.1.2 <i>Areas Surrounding Canadian Forces Base Shilo</i>	28
3.2 <i>Point Count Surveys</i>	32
3.2.1 <i>Abundance Surveys of Sprague’s pipit</i>	32
3.2.2 <i>Surveys of Other Species of Conservation Concern</i>	33
3.3 <i>Invertebrate Surveys</i>	33
3.3.1 <i>Grasshopper Surveys</i>	33
3.3.2 <i>Ground Beetle Surveys</i>	35
3.4 <i>Habitat Structure</i>	37
3.4.1 <i>Vegetation Height and Density</i>	37
3.4.2 <i>Litter Depth</i>	38
3.4.3 <i>Percentage of Bare Ground Cover</i>	38
3.5 <i>Data Organization</i>	39
3.6 <i>Data Analysis</i>	40
3.6.1 <i>Fire History, Vegetation Structure and Density of Sprague’s pipit</i>	41
3.6.2 <i>Fire History, Invertebrate Richness and Abundance and Density of Sprague’s pipit</i>	42

4.0 RESULTS.....	44
4.1 Summary Statistics.....	44
4.2 Relationship between fire history and habitat structure	48
4.3 Relationship between fire history and abundance of Sprague’s pipit.....	49
4.4 Relationship between fire history and abundance of invertebrates.....	50
4.5 Relationship between invertebrate resources and density of Sprague’s pipit - 2007	51
4.6 Effects of habitat structure on abundance of Sprague’s pipit.....	52
4.7 Effects of habitat structure on invertebrates	53
5.0 DISCUSSION	55
5.1 Influence of burn history on mixed-grass prairie and the density of Sprague’s pipit.....	56
5.2 Influence of fire on invertebrate resources.....	59
5.3 Influence of vegetation structure on invertebrates	60
5.4 Response of Sprague’s pipit to Invertebrate Resources.....	61
6.0 MANAGEMENT IMPLICATIONS.....	64
6.1 Recommendations for Fire Management at CFB Shilo and Surrounding Habitat	64
6.2 CFB Shilo compared with surrounding grasslands	66
6.3 Recommendations for Conservation Management of Sprague’s pipit in South- Western Manitoba	67
7.0 LITERATURE CITED	69
APPENDICES	77

List of Tables

Table 1. Categories of burns by transect at Canadian Forces Base Shilo, Manitoba in 2007.....	28
Table 2. Categories of burn history for all study sites in prairie surrounding Canadian Forces Base Shilo in 2007.....	30
Table 3. Sample size for variables in CFB Shilo and study sites surrounding CFB Shilo by year.....	40
Table 4. Insect Order richness and abundance data for invertebrate species per 100-m plot data in June and July 2007 in CFB Shilo, south-western Manitoba.....	44
Table 5. Mean and standard deviation (SD) of sampled invertebrates per transect, by time since burn in CFB Shilo 2007.....	45
Table 6. Mean abundance of Sprague’s pipit and mean vegetation structure parameters per 100-m plots in 2007 and 2008 at CFB Shilo, Manitoba.....	46
Table 7. Mean abundance of Sprague’s pipit and mean data for all surveyed vegetation structure parameters per 100-m plots in 2007 and 2008 in study sites surrounding CFB Shilo, south-western Manitoba.....	46
Table 8. Mean abundance of Sprague’s pipit and mean data for all surveyed vegetation structure parameters per 100-m plots in 2007 and 2008 for all study sites (combined data) in south-western Manitoba.....	47
Table 9. Mean and standard deviation (SD) of vegetation parameters per transect by burn history for 2007 and 2008 in all study areas in south-western Manitoba.....	48
Table 10. Model of temporal influence of fire on habitat structure in south-western Manitoba in 2007 and 2008, using generalized linear regression models with Poisson distribution.....	49
Table 11. Model of association between time since burn (in years) and the abundance and richness of invertebrates per plot (3.2 ha) at CFB Shilo study sites in south-western Manitoba, in June and July 2007, using generalized linear regression models with Poisson distribution.....	51
Table 12. Model of relationship between density of Sprague’s pipit per plot (3.2 ha) and the richness and abundance of invertebrates in June and July 2007 at CFB Shilo, in south-western Manitoba, using generalized linear regression models with Poisson distribution.....	52
Table 13. Model of associations between habitat structure and the density of Sprague’s pipit per plot (3.2 ha) in south-western Manitoba, in 2007 and 2008, using generalized linear regression models with Poisson distribution.....	53
Table 14. Model of associations between vegetation composition and abundance of Coleoptera and Orthoptera at CFB Shilo in south-western Manitoba, in June and July 2007.....	54

List of Figures

Figure 1. Location of average density of Sprague’s pipit per plot in all study sites in south-western Manitoba in 2007.....	31
Figure 2. Average density of Sprague’s pipit per point count plot in CFB Shilo in 2007.....	50
Figure 3. Average density of Sprague’s pipit per point count plot in study sites surrounding CFB Shilo in 2007.....	50
Figure 4. Average density of Sprague’s pipit per point count plot in CFB Shilo in 2008.....	50
Figure 5. Average density of Sprague’s pipit per point count plot in study sites surrounding CFB Shilo in 2008.....	50

1.0 Introduction

1.1 Background

Grassland bird populations are declining faster than any other guild in North America, and the conservation of prairie songbird species has become a key conservation issue (Herkert 1994, Helzer and Jelinski 1999, Madden et al. 1999, Winter and Faaborg 1999, Johnson and Igl 2001, McMaster and Davis 2001). Sprague's pipit (*Anthus spragueii*) (*Alauda spragueii*, Audubon 1844) (Grzimek's Animal Life Encyclopedia 2002) is a small grassland songbird experiencing rapid population declines, and is listed as a threatened species (Government of Canada 2010). There are several limiting factors contributing to the decline of grassland songbirds such as Sprague's pipit, including the influence of human activity on the configuration and quality of habitat within prairie landscape (Robbins and Dale 1999, Government of Canada 2010).

Throughout North America, native grasslands have been subjected to the cumulative effects of human influence through conversion of landscapes to cropland by cultivation, draining wetlands, urban developments, fire suppression, poor grazing management, haying and invasion of exotic plant species (Knopf 1994, Prescott 1997, Madden et al. 1999, Davis 2004). Habitat losses in native grasslands were accompanied by significant changes to the natural state of remaining habitat (Samson et al. 2004).

The incidences of ecological drivers such as broad-scale drought, grazing and fire have now significantly decreased (Samson et al. 2004). While fire may have been a natural occurrence as an ecological driver in the mixed-grass prairie as often as every three to five years prior to the European settlement (Unbanhowar 1996), fire events no

longer occur at this frequency (Samson et al. 2004). Changes to the historical fire regimes have been a significant force driving the changing conditions in grassland habitat such as mixed-grass prairie (Askins 2007).

There are numerous grassland species that have an affinity for mixed-grass prairie, yet because of limited studies, the effects of fire on the habitat suitability of these grassland species is poorly understood (Johnson 1997, Madden et al. 1999). Most studies examining fire effects on grassland birds include only single burns and controls (as in Pylypec 1991), or examined only the short-term duration of effects post-fire. Although Johnson (1997) examined long-term effects of a short-term (3-5 year) burn rotation on grassland species abundance, and Madden et al. (1999) examined the long-term (15 year) effects of fire, these studies in the mixed-grass prairie are rare and therefore our comprehensive understanding of the long-term effects of fire on endemic grassland species is poor.

Endemic grassland species such as the Sprague's pipit are experiencing such rapid population declines that conservation of the remaining native grasslands is critical. To successfully conserve these species, restoration of natural ecological drivers, such as fire, is becoming an essential component to management of mixed-grass prairie ecosystems (Brennan and Kuvlesky 2005). However, exactly how the alteration in natural fire regimes affects Sprague's pipit is not clear (Prescott 1997). Existing literature suggests that the effects of burns on pipit abundance vary strongly with time since the last burn event (Pylypec 1991, Madden et al. 1999), but this research is limited and we therefore have a poor understanding of how fire may be affecting pipit habitat selection.

Most previous studies have focused solely on vegetation characteristics in association with pipit abundance and did not examine the influence of fire on the availability of other essential resources. A closer examination of how fire is affecting local microhabitat functions and processes may reveal habitat associations that explain the pattern of pipit response to fire. One factor that may be contributing to the regional response of pipits to fire is the availability of invertebrate prey.

Numerous characteristics influence the effects of fire on arthropods. Time of year of burns, climate and soil conditions, arthropod sampling methods, developmental stage and mobility of arthropods, and the time since previous burns may all potentially alter effects of fire on insects (Warren et al. 1987, Swengel 2001). If the abundance of the prey of pipits varies with pre- or post-fire habitats, then it is possible that resource availability may be influencing habitat selection and the overall response of pipits to fire events. For example, the response of grasshoppers seems to be dependent on the species and their ability to fly and relocate at the onset of fires. Although studies are inconclusive, it appears grasshoppers are more abundant in burned areas from 1 – 12 months following fires (Swengel 2001). Effects of burns on Sprague's pipit may therefore be mitigated by invertebrate resource availability.

Exactly how fires are influencing the invertebrate prey of Sprague's pipit is unknown. The available evidence suggests that the primary food source of the pipit may increase in abundance following the incidence of fires, and this may be a mechanism influencing the habitat selection and pipit response to burning frequency in mixed-grass prairies.

This study addressed the possibility that fire may affect the availability of food resources (invertebrate prey) for Sprague's pipit, and that pipit response to fire may be based on choosing habitats with greater resource abundance. To the best of my knowledge, the longest time sequence that a study has examined effects of fire on Sprague's pipit is 15 years (Madden et al. 1999). My study is unique in that it was the first to examine the post-fire response and abundance of Sprague's pipit in a native mixed-grass prairie habitat in South-western Manitoba in areas with burn histories ranging from 1 year to 40 years.

1.2 Biology of Sprague's pipit

The Sprague's pipit is a small grassland songbird that is endemic to the Canadian prairies and to the northern Great Plains of the United States (Prescott 1997). *A. spragueii* is approximately 10-15 cm in length and weighs 22 - 26 g. The Sprague's pipit resembles a sparrow having nondescript brown plumage and a thin beak (Prescott 1997, Robbins and Dale 1999). As one of the most elusive songbirds, pipits are rarely seen as they seldom sing when on the ground. Audible detection occurs during unique aerial display behavior by the males delivered from high above the nesting grounds in a series of descending notes that may last an average of 12 minutes per singing bout (Robbins 1998).

1.3 Distribution and Population

The breeding range of the Sprague's pipit extends from the foothills of the Rocky Mountains in southern and central Alberta, through central Saskatchewan as far north as Prince Albert, through west-central and southern Manitoba, and to southern Montana, northern South Dakota and northwestern Minnesota (Prescott 1997, Robbins and Dale

1999, Environment Canada 2008). Pipits vary in distribution across the prairie region (Prescott 1997). The Sprague's pipit spend the winter in south central and southeastern Arizona, central and eastern Texas, northwestern Mississippi, and in the northern two-thirds of Mexico (Prescott 1997).

Estimates of historical population sizes have not been determined; however, it has been suggested that it was once the most common grassland songbird throughout the breeding range during the 1900's (Government of Canada 2010). While the Sprague's pipit is still found throughout the distribution range, Breeding Bird Survey (BBS) data indicates that this pipit has experienced rapid population declines over the last 30 years (Sauer et al. 2008).

It has been estimated that 60% of Sprague's pipit's breeding range in North America occurs in Canada (CPPF 2004). Between 1968 and 2006, the Sprague's pipit population in Canada experienced a significant annual decline of 4.5% (Sauer et al. 2008). The prairie provinces also experienced declines within this reporting period; Alberta pipit populations significantly declined by 4.5% per year, Saskatchewan pipit populations declined by 4.3% per year, and although the decline reported in Manitoba was non-significant, there are fewer and more variable Breeding Bird Survey routes ($n=14$ in Manitoba compared with $n=57$ in Alberta and $n=45$ in Saskatchewan; Sauer et al. 2008). The population decline of Sprague's pipit is one of the largest declines experienced by any North American grassland songbird (Davis et al. 1999).

Sprague's pipit was listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2000, and was officially listed under the registry for the Species at Risk Act in June 2003 (Government of Canada 2010). The

status of the Sprague's pipit was re-assessed in April 2010 and it remains on the threatened species list (Government of Canada 2010).

1.4 Habitat Associations

Sprague's pipit is significantly more abundant in native mixed-grass prairie habitat, and tends to avoid areas with introduced grasses and forbs (Wilson and Belcher 1989, Sutter 1997, Dechant et al. 1998, Robbins and Dale 1999, Environment Canada 2008). *Anthus spragueii* is more abundant in habitat consisting of native vegetation of intermediate height and density, with low forb density (Wilson and Belcher 1989, Sutter 1997, Environment Canada 2008). Pipits are typically not found on cultivated lands, or areas with excessive shrub cover (Owens and Myres 1973, Prescott 1997, Davis 2005), being more likely to be found in areas with varying lower levels of bare ground and litter depth (Dechant et al. 1998). The highest density of pipits are found in native ranges that are either ungrazed or moderately grazed (Owens and Myres 1973, Kantrud 1981). Critical habitat for Sprague's pipit has recently been identified based on biophysical characteristics of select habitat in Alberta and Saskatchewan, and include the following: "open areas of upland native prairie \geq 65 ha, native prairie management units in fair to excellent range condition, limited woody vegetation, limited invasion by exotic grasses, flat to gently rolling topography" (Government of Canada 2011).

Some studies have shown pipits to utilize grasslands where prescribed burning or mowing has been done in previous years (Owens and Myres 1973, Prescott 1997, Dechant et al. 1998, Davis et al. 1999, Madden et al. 1999). However, White (2009) examined the relative abundance of Sprague's pipit in burned prairie that was either grazed or ungrazed, as well as in unburned, ungrazed prairie. White (2009) found that in

burned prairie, the relative abundance of Sprague's pipit was lower in pastures that were one and two years post-fire compared with unburned prairie.

In the mixed-grass prairie in Saskatchewan, Sutter (1997) and Davis (1999) reported that pipit nests are more commonly found in areas with higher grass and sedge cover, and where shrubs, bare ground and forb density were minimal. The microhabitat features at nest sites typically included tall vegetation (27 cm) comprised of northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn. (Looman and Best 1987)), and pasture sage (*Artemisa frigida* Willd. (Looman and Best 1987)) (Sutter 1997). However, it is possible that northern wheatgrass was primarily used for the nests simply because it was the dominant vegetation species available at the study site (Sutter 1997).

1.5 Diet

Few quantitative studies exist on the diet of Sprague's pipit. Although their diet may change seasonally, Sprague's pipit feeds almost entirely on arthropods, with less than three percent of their diet consisting of seeds (Prescott 1997, Robbins and Dale 1999). Research conducted in Manitoba on the pipit diet found that females feed nestlings grasshoppers, crickets and moths, with grasshoppers comprising the largest percentage of their diet (Harris 1933). Although the Orders Coleoptera and Orthoptera are the main constituents of the adult diet, pipits also feed on spiders (Class Arachnida: Order Araneae), leafhoppers (Order Hemiptera) and Lepidopteran larvae (Harris 1933, Maher 1974). Based on a study of adult stomach samples from pipits in Saskatchewan, Maher (1974) reported that adults feed primarily on ground beetles (Order Coleoptera) early in the breeding season (May), in addition to grasshoppers (Order Orthoptera: Family Acrididae) and crickets (Order Orthoptera: Family Gryllidae). However, the

percentage of grasshoppers consumed increased from 4% to 47% later in the breeding season (August) and the percentage of ground beetles decreased from 41% to 12% (Maher 1974).

1.6 Project Significance

Project Significance

The incidence of fires in mixed-grass prairie can alter ecosystem functions and processes, and the availability of suitable habitat for breeding birds. Endemic grassland species such as the Sprague's pipit are experiencing such rapid population declines that conservation of the remaining native grasslands is critical. To successfully conserve these species, restoration of natural ecological drivers, such as fire, is becoming an essential component to management of mixed-grass prairie ecosystems (Brennan and Kuvlesky 2005). However, exactly how the alteration in natural fire regimes affects Sprague's pipits is not clear (Prescott 1997). Existing literature suggests that the effects of burns on pipit abundance varies strongly with the time since the last burn event (Pylypec 1991, Madden et al. 1999), but this research is limited and we therefore have a poor understanding of how fire may be affecting pipit habitat selection.

To understand how Sprague's pipit responds to burned habitat, previous studies have focused solely on vegetation characteristics in association with pipit abundance and did not examine the influence of fire on the availability of other essential resources. A closer examination of how fire is affecting local microhabitat functions and processes may reveal habitat associations that explain the pattern of pipit response to fire. One habitat component that may be contributing to the regional response of pipits to fire is the availability of invertebrate prey.

This study addresses the possibility that fire may be negatively affecting the availability of food resources (invertebrate prey) for Sprague's pipit, and that pipit response to fire may be based on choosing habitats with greater resource abundance. A 15 year post-burn period has been the longest time sequence that a study has examined in order to detect an effect of fire on the density of Sprague's pipit (Madden et al. 1999). My study is unique in that it is the first to examine the post-fire response and abundance of Sprague's pipit in areas with burn histories ranging from 1 year to 40 years, in native mixed-grass prairie habitat in South-western Manitoba. Additionally, it is the first to examine whether fire is impacting the resource availability of Sprague's pipit, and if habitat selection following burn events may be driven by invertebrate resource abundance.

2.0 Literature Review

2.1 Defining the Mixed-Grass Prairie Community

The northern Great Plains native grassland type occupies much of the northern United States including Montana, North Dakota, South Dakota and Northeastern Wyoming and parts of Canada including southeastern Alberta, southern Saskatchewan and southwestern Manitoba (Gould 1968, Samson and Knopf 1994, Askins et al. 2007). Prior to European settlement, the northern Great Plains was comprised of approximately 162 million hectares of native grasslands (Samson and Knopf 1994, Davis 2004). Following settlement, the Canadian prairies have experienced a reduction from 35 million hectares to approximately 9.3 million hectares (Askins et al. 2007).

There are three main prairie types within the northern Great Plains grasslands: tallgrass prairie, mixed grass prairie and short grass prairie (Samson and Knopf 1994). Native mixed grass prairie is unbroken land (Wilson and Shay 1990) characterized by Coupland (1950) as a *Stipa-Bouteloua* association (Gould 1968). This association extends from central Canada to the south-central part of Texas and from the western region of Nebraska to the foothills of the Rocky Mountains (Coupland 1950, Gould 1968). In this association, there are six dominant grass species: needle grass (*Hesperostipa comata* (Trin. & Rupr.) Barkworth (Reaume 2009)), porcupine grass (*Hesperostipa spartea* (Trin.) Barkworth (Reaume 2009)), western porcupine grass (*Stipa curtisetata* (Hitchc.) (Looman and Best 1987)), blue grama grass (*Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. (Reaume 2009)), northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn. (Looman and Best 1987)), western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Love (Reaume 2009)), and June grass (*Koeleria*

macrantha (Ledeb.) J.A. Schultes (Reaume 2009)) (Coupland 1950). Bird (1927)

describes the mixed grass prairie to also contain the following species of grasses: little bluestem grass (*Andropogon scoparius* (Mischz.) (Looman and Best 1987)), switch grass (*Panicum virgatum* (L.) (Reaume 2009)), prairie dropseed (*Sporobolus heterolepis* (Gray) Gray (Reaume 2009)), sand grass (*Calamovilfa longifolia* (Hook.) Scribn. (Reaume 2009)), *Bouteloua oligostachya* and Kentucky blue grass (*Poa pratensis* (L.) (Reaume 2009)).

The mixed-grass prairie community, extending from Manitoba to Nebraska, has been reduced by at least 72% of its original size (Madden et al. 1999). In Manitoba the loss of mixed-grass prairie is estimated to be as much as 99%; less than 0.01 % of the remaining prairie is protected (Samson and Knopf 1994).

2.2 Approaches to Grassland Management

Grassland communities have been continuously subjected to human influence through agricultural and urban developments, resulting in habitat loss and fragmentation (Owens and Myres 1973, Herkert 1994, Askins et al. 2007, Brennan and Kuvelsky 2005), and conservation of remaining grasslands has become a considerable challenge. These disturbances have changed the configuration of native grasslands, leaving a landscape mosaic of varying habitats interspersed with cropland, roadsides and urban structures. The intensity of land use by the European settlers influenced remaining ecological drivers that once maintained the Great Plains grasslands (Knopf 1994, Samson et al. 2004) and which historically provided heterogeneous habitats preferred by a diverse group of birds (Brawn et al. 2001).

Human disturbance has resulted in significant changes in frequency and suppression of natural ecological drivers (Evans et al. 1989), and these disturbances may be altering the structure and composition of the remaining prairie landscape. Mixed-grass prairie evolved with natural disturbances such as fire (Samson et al. 2004). Umbanhowar (1996) suggested that fire may historically have occurred every 3-5 years in mixed-grass prairie as a result of lightening or fires started by Native Americans.

Changes to the natural prairie landscape following European settlement could also have been affected by the human-influenced changes to the nomadic behaviour and herd size of grazing American bison (*Bison bison* (Linnaeus) (Grzimek's Animal Life Encyclopedia 2003)). Fire, rainfall and the freely nomadic grazing behaviour of bison herds influenced the vegetation, and this resulted in the creation of a mosaic of plant communities in different seral stages across the Great Plains (Samson et al. 2004, Brennan and Kuvlesky 2005) which would satisfy the habitat requirements of a variety of unique grassland species (Brennan and Kuvlesky 2005). The absence of large scale American bison herd and their nomadic behaviour subsequently impacted the variety of plant communities and their seral or successional stages across the Great Plains.

Over time, humans have also converted large areas of native grasslands into cropland with a shift towards intensive agriculture and monoculture crops (Matson et al. 1997), as well as introducing invasive plant species into natural areas. These agricultural activities have also caused a decrease in the diversity of prairie plant communities. This, in turn, impacted the prairie grassland songbird populations.

Collectively, these factors have resulted in degradation and loss of native prairie grasslands which has had adverse impacts on prairie passerines (Bender et al. 1998,

Helzer and Jelinski 1999, Bergin et al. 2000, McMaster and Davis 2001, McMaster et al. 2005). Because grassland birds are declining faster than any other guild in North America (Herkert 1994, Helzer and Jelinski 1999, Madden et al. 1999, Winter and Faaborg 1999, Johnson and Igl 2001, McMaster and Davis 2001), managing the remaining grasslands to prevent further loss and degradation has become a critical component in the conservation of prairie songbirds.

Conservation of native grasslands is a challenging task as habitats have been subject to the effects of habitat loss and fragmentation. Habitat loss refers to the total reduction in area of habitat; habitat fragmentation can be defined as the destruction or degradation of habitat such that more habitat patches are created that change the spatial configuration of the habitat in the landscape (Fahrig 2003). Fragmentation may have significant impacts on grassland bird species as it can lead to increased isolation of habitat patches, reduced size of remaining patches, and an increase in the amount of habitat edge (Bender et al. 1998, Helzer and Jelinski 1999, Fahrig 2003, Davis et al. 2006). As a result, fragmentation affects habitat occupancy patterns by influencing the spatial distribution and abundance of birds, and dispersal patterns in the landscape (Helzer and Jelinski 1999).

While the effects of habitat edges, patch size and isolation of patches have been examined by numerous studies (Laurance and Yensen 1991, Herkert 1994, Paton 1994, Bender et al. 1998, Fagan et al. 1999, Winter and Faaborg 1999, Johnson and Igl 2001, Chalfoun et al. 2002, Davis et al. 2006), the collective effects of fragmentation and habitat loss can vary in different landscapes. This underlines the importance of understanding the effects of fragmentation, as land managers cannot simply assume

that conserving small remaining tracts of habitat will ensure the conservation of species and maintenance of biodiversity (Harrison and Bruna 1999).

Studies of habitat loss and fragmentation often lead to conclusive statements that recommend the conservation of large, contiguous tracts of grassland areas as this approach is considered beneficial for most grassland species in order to prevent further population declines and reduce the potential for local or regional extinctions of grassland bird populations (Herkert 1994, Helzer and Jelinski 1999, Johnson and Igl 2001, Davis et al. 2006). This management approach may be ideal for bird species that have been deemed as area-sensitive. Area-sensitive species are those species whose densities decline with decreasing patch size, thus indicating a need for larger habitat patches for species success (Davis 2004). Habitat for area-sensitive species must be larger than the normal species territory requirements, and requirements may vary regionally depending on the quality of the habitat (Johnson and Igl 2001, Davis 2004).

Other factors beyond patch size and shape may also influence the demography of grassland passerines (Davis 2004). Further to this, it is essential for studies examining effects of habitat loss, fragmentation and edge effects to examine at the mechanisms responsible for the effects (Johnson 2001). For example, vegetation characteristics such as the height and density of live or residual vegetation, and composition of vegetation, can influence the attractiveness of habitats to grassland birds (Herkert 1994, Winter and Faaborg 1999, Davis 2004). While vegetation structure has been examined relative to patch size in fragmented areas (Helzer and Jelinski 1999), vegetation characteristics such as plant composition may differ within patches between interior core habitat and

exterior habitat edges, and this may also influence the response of some species in habitat patches (Winter and Faaborg 1999, Johnson 2001).

2.3 The Role of Fire in Grasslands

Historically, native prairie grasslands have evolved with fire. Effects of natural fires on grasslands can vary; ecological effects vary relative with frequency, intensity and scale, and by the seasonal and temporal occurrence of fire (Collins and Barber 1986, Biondini et al. 1989, Howe 1994). While some disturbances are disruptive to community stability, and serve as a driver for habitat patch dynamics, these effects vary with the scale of disturbance (Collins 2000).

Abiotic disturbances such as fire will normally vary in frequency and intensity, and can interact with biotic disturbances to affect vegetation structure and species diversity in grasslands (Collins and Barber 1986, Collins 1992). Effects of fire on grasslands can vary regionally and temporally, but generally the productivity of grasslands increases after fires (Hulbert 1969). Ehrenreich (1959) reported that vegetation regrowth and maturation occurred earlier in burned areas following fire, and that the reduced litter increased bare ground exposure. This enabled soil temperatures to increase as a result of more surface area exposure to sunlight. In the absence of fire, build-up of litter and dead vegetation blocks sunlight and impedes even moisture distribution following rainfall events, resulting in cool, dark microclimates that impede growth of new vegetation (Askins 2002). Ultimately, there is a decrease in vegetative productivity in prairie that remains unburned; the rate of growth of new vegetation slows and parallels the rate of accumulation of litter and decay of vegetation (Askins 2002).

In tallgrass prairie, fire is considered a critical component in management for maintaining the natural vegetation composition, and is therefore seen as a stabilizing force (Hulbert 1988, Howe 1995, Collins 2000) as it suppresses woody vegetation. Bragg and Hulbert (1976) also found that a lack of fire in tallgrass prairie leads to an accumulation of plant litter, invasion of woody species and the increase of moisture availability, which contributes to a shift in grasslands to woodland vegetation. Additionally, with the division of the landscape into farmland and the resultant establishment of roads, humans have indirectly created multiple firebreaks that have prevented naturally occurring fires from spreading over large areas (Askins et al. 2007).

Generally, plants in mixed-grass prairies have adapted to fires, but effects vary considerably by temporal and spatial scales of fire, and the frequency relative to historical intervals (Biondini et al. 1989, Collins 2000). Madden et al. (1999) found the response of vegetation to repeatedly burned areas in mixed-grass prairie of North Dakota to include reduced litter coupled with a decrease in shrub cover, and vegetation height and density. Additionally, grass cover, and percentage of live vegetation were found to increase in response to repeated fire (Madden et al. 1999). Wilson and Shay (1990) found the response of vegetation to fire in mixed-grass prairie at Canadian Forces Base Shilo included a decrease in litter, standing vegetation and an increase in bare ground. These observations support Hulbert's (1969) assertion that fire is an important component for preserving prairie habitat.

The consumer species such as birds or arthropods that persist within vegetation communities can have varying responses to fire that do not always mirror the dynamics seen in the vegetation composition (Collins 2000). Specifically, prairie passerines exhibit

unique responses to fire such that some species respond positively to vegetation composition in landscapes subjected to human influence through mowing or fire suppression, whereas other species populations will decline under these conditions (Madden et al. 1999). In the latter circumstances, the species requiring periodic burning may suffer from the resultant changes in vegetation composition, thus imposing unique demands on grassland managers. Unfortunately, few studies have assessed the influence of fire on consumer species such as prairie passerines in mixed-grass prairie habitats (Madden et al. 1999).

2.3.1 Response of Sprague's pipit to Fire

Sprague's pipit has shown variable responses to fire. Following a prescribed fall burn in Kernan Prairie (comprised of native fescue grassland) in Saskatchewan, Pylypec (1991) found adverse changes in the density of pipits in one to two years following a fire event; densities in one and two year post-burn sites were lower than in unburned areas. However, three years after the prescribed burn, the pipit population in burned sites was similar to populations in unburned areas. White (2009) also found that the abundance of pipits was lower in burned prairie in one and two years following the incidence of fire in the mixed-grass prairie of Grasslands National Park, Saskatchewan.

In mixed-grass prairie in North Dakota, Madden et al. (1999) observed that pipits were absent from areas that had not been burned, but showed a positive response to repeatedly burned areas. The highest abundance of Sprague's pipit was observed in areas with a fire history that included four burns, with the most recent burn being two years prior (Madden et al. 1999). However, Pylypec's (1991) observation that pipits were found in equal densities in burned and unburned areas at three years post-burn

contradicts Madden et al.'s (1999) findings that pipits were never observed in unburned areas. This warrants further investigation into the response of pipits to fire and what characterizes their sensitivities to fire.

Although burning may reduce the suitability of breeding habitat in the short-term, it appears that Sprague's pipit show a positive response to burning over the long-term. This suggests that suppressing fires across the Canadian prairies may be a factor limiting the success of this native grassland specialist.

2.3.2 Response of Insects to Fire

Research has shown that insects have adapted to burning in ecosystems where historically, periodic burns are prevalent (Anderson et al. 1989). Unfortunately, since fire-suppression is becoming more prevalent in native prairie grasslands, the ability of insects to adapt to habitats with infrequent or largely absent burns remains uncertain.

The response of insects to fire can vary temporally depending on environmental variables and intrinsic fire characteristics; the time of year of the fire, frequency of previous burns, weather, soil and moisture conditions to name a few (Warren et al. 1987). Moreover, the stage of growth of the insect can influence the response to fire (Warren et al. 1987).

The period of fire combustion, or pyrolysis, is the time when the fire is actually occurring; the period following the fire, when combustion ceases and until vegetation regrowth begins, is referred to as the shock phase (Warren et al. 1987). The duration of the shock phase can vary by seasonal and climatic conditions, which can further influence the response of insects to fire. Following a burn, much of the vegetation is removed (depending on the fire characteristics) and this is accompanied by increased

air movement and an increase in soil temperatures as a result of increased soil exposure (Warren et al. 1987).

Generally, invertebrates have demonstrated a strong response to fires with declines in abundance immediately after fires, ranging in temporal response from hours up to two months following fires (Swengel 2001). The decline appears to be influenced by the mobility and life stage of the species in addition to the amount of exposure to flames, as some species below ground may show little or no decline in abundance (Swengel 2001). General declines in insect abundance will result in a reduction of food availability for insectivorous species such as Sprague's pipit. However, other studies have recorded a positive response of insects to fire (Evans 1984, Warren et al. 1987), which might benefit pipits.

The response of beetles to fire has been variable, but some have shown a positive response to prescribed burning depending on seasonal burning regimes (Warren et al. 1987). Swengel (2001) cites that numerous researchers have found that the intermediate-term effects of fire on ground beetles are that they become more abundant in post-fire habitat (ranging from 1 or 2 to 12 months following fire events). In contrast, Dunwiddie (1991) observed that the response of beetle abundance (Order Coleoptera) was not consistent following a spring burn, but that the abundance declined following a fall burn.

The vegetation composition following fire may also be influencing the abundance of beetles, depending on the species and area inhabited (Warren et al. 1987). As fire removes above-ground biomass, this reduces the availability of resources for some species, although the root biomass may still be available for consumption. However, the

challenges to beetle species following fires appears to force beetles to relocate to alternate habitat as a means of survival (Roughley 2001). The response of beetles to fire events has been shown to depend on the time of year of the burn and the species (Warren et al. 1987).

Grasshoppers have also shown varying responses to fire, with one study showing an increase in abundance of grasshoppers following fire treatments (Dunwiddie 1997). Grasshoppers (Orthoptera) assemblages examined by Evans (1984) in tallgrass prairie were found to parallel the burn history of the habitat; the relative abundance of species that were adapted to burns changed very little in burned prairie; the relative abundance of species that were adapted to unburned areas changed very little. By examining the survivorship of grasshopper nymphs in experimentally burned sites, Evans (1984) was able to show that fire does disrupt the grasshopper assemblages. Specifically, of the grasshoppers collected, Evans (1984) categorized the individuals as either forb-feeding or grass-feeding and found that the survivorship of forb-feeding grasshoppers was significantly lower on the burned watershed sites than the forb-feeding grasshoppers. Although the cause of the patterns of survivorship as a result of fire in this study could not be explained, Evans (1984) considers the response of grasshoppers to fire events to be caused by the changes to the microhabitats.

Nagel (1973) examined the effect of a spring burn on arthropod populations in prairie, and found an increase in abundance of all arthropods (including the Orthoptera group) in the burned site. In contrast, Anderson (1989) did not find a significant difference in the abundance of most grasshopper species during their three year post-fire study. Other studies involving spring fires showed very little effect on grasshoppers,

but in some cases, grasshoppers were found to quickly repopulate burned areas (Warren et al. 1987).

The early developmental stages (egg, larvae, pupa) of insects in the Order Lepidoptera would be more likely to be affected by burns than the adults due to their increased mobility (Warren et al. 1987). In Dunwiddie (1991), the abundance of Lepidoptera was higher in burned plots than reference plots, however overall there was no consistent trend in response of Lepidoptera abundance to a spring burn. Warren et al. (1987) cites several studies that observed increases in adult Lepidoptera following burns.

While there are many factors causing short and long term effects in invertebrates following fires, it appears that habitat heterogeneity may play a role the varied response. Fires remove the above-ground biomass, thereby reducing resource availability for invertebrates immediately following fires. However, in the long term following fire events, the resource availability increases and it is likely that the frequency of burning, and vegetation composition, are important factors in determining the distribution and abundance of invertebrates.

2.4 Literature Gaps and Research Objectives

Sprague's pipit has shown varying responses to fire. However, few studies have addressed the effects of fire on prairie passerines (Madden et al. 1999), and consequently, little is known about the mechanism influencing the response of Sprague's pipit to fire (Dechant et al. 1998). As the pipit is more abundant in areas with higher proportions of grass and sedge cover, and minimal bare ground, litter and shrub density (Sutter 1997), it is possible that the influence of fire in mixed-grass prairie is that

it creates more suitable habitat for the pipit in years following burns. Alternatively, the vegetation composition may not be as important as resource availability for pipits in habitat selection. The mechanisms that govern pipit response to fire are unknown.

Studies that evaluate the effects of fire have typically focused on direct effects of fire, and few have examined how other causal factors may work together to influence fire effects (Hulbert 1988). It is important to understand how fire events are linked to vegetation composition and invertebrate prey availability in preferred habitats.

Sprague's pipit has been audibly detected on occasion between 2004 and 2006 in the mixed-grass prairie in the training area of Canadian Forces Base Shilo, Manitoba (Punak – Murphy 2006). As with other areas of native grasslands, the training area has been subject to habitat alterations through the impacts of military training over time. Specifically, fires are a frequent occurrence as a result of both controlled and accidental factors from the impacts of artillery during training exercises in some parts of the training area, whereas other areas do not experience burns or burns occur infrequently.

Military training will continue in Shilo for many years, and is anticipated to increase in frequency and intensity in the range area as a response to the increasing need for highly trained personnel to be deployed overseas. As pipits have been detected audibly in the training area in previous years, this native prairie grassland provides a unique opportunity to determine the density and distribution of pipits and to examine whether invertebrate resource availability may be influencing their habitat selection and their ability to persist in this range.

Because CFB Shilo is surrounded by various mixed-grass prairies under different management regimes, it is possible to compare the appropriateness of habitat

management (both within and outside of CFB Shilo) to improve opportunities for the conservation of Sprague's pipit and prevent further population declines.

2.4.1 Research Objectives

The focus of this research project was to examine the impact of fire on the abundance and spatial distribution of Sprague's pipit in mixed-grass prairie in South-western Manitoba. The specific objectives of this project were:

1. To survey the abundance and distribution of Sprague's pipit within CFB Shilo and in the surrounding mixed-grass prairie habitats with different burn history;
2. To survey and compare the vegetation structure in the habitats where Sprague's pipit occurs in CFB Shilo and in the surrounding habitat;
3. To survey the abundance, richness and distribution of invertebrate prey of pipits in burned and unburned habitats where Sprague's pipit was at CFB Shilo; and
4. To model the linkages between fire history and the abundance, richness and availability of invertebrates to the distribution and abundance of Sprague's pipit, to determine if fire is having an indirect effect on the habitat selection of Sprague's pipit and is therefore a limiting factor in their survival in a mixed-grass prairie habitat. This modeling will provide insight into future habitat management in CFB Shilo and the subsequent effects on the population of Sprague's pipit.

This study will also provide CFB Shilo with baseline data on the density of Sprague's pipit over a two year period, as well as provide baseline data on arthropod diversity and abundance which may support future monitoring on the population.

Finally, the results will provide new insights into the appropriateness of incorporating fire into habitat management regimes to improve landscape management practices for the conservation of Sprague's pipit in mixed-grass prairie in south-western Manitoba.

2.4.2 Hypothesis

The underlying prediction of my hypothesis was that Sprague's pipit select suitable habitats based on resource availability and the structure of the vegetation; if this is true, then I expected that the pipit would be found in higher densities in areas with an abundance of invertebrate prey and appropriate vegetation structure to sustain them through the breeding season. The primary constituents of pipit diet (ground beetles and grasshoppers) tend to increase in abundance in response to burns, although this effect is not universal. Based on this, I expected to find a greater abundance of invertebrate resources available to pipits in burned habitats and, therefore, I predicted that a greater proportion of Sprague's pipit would be detected in more recently burned areas.

2.4.3 Implications for Management

There is minimal literature investigating how natural disturbances such as fire may be contributing to the population decline of Sprague's pipit across the mixed-grass prairie region. The current study will provide additional data on pipit response to habitat characteristics while enabling us to model habitat needs on a local and landscape scale. We will also gain knowledge of the role that fire may have played on pipit populations

historically, and how fire could be used within grassland management plans where pipit populations persist. This information will be a key component to developing improved management practices for the conservation of the remaining mixed-grass prairies and threatened species such as the Sprague's pipit.

3.0 Methods

3.1 Study Area

The study area was located in the mixed-grass prairie in south-western Manitoba, in the rural municipality of Cornwallis and in the rural municipality of South Cypress. The primary study sites were located in Canadian Forces Base (CFB) Shilo, Manitoba, with additional study areas selected in various mixed-grass prairie habitats surrounding CFB Shilo.

3.1.1 Canadian Forces Base Shilo

The primary study site of this project was located at Canadian Forces Base Shilo, Manitoba (49°39'N, 99°30'W), located approximately 30 km southeast of Brandon, Manitoba. CFB Shilo contains the largest remaining tract of mixed-grass prairie in Manitoba (Wilson and Belcher 1989). While this habitat has not been plowed, Wilson and Shay (1990) suggested that it may have been grazed during the 1930s.

The dominant vegetation includes blue grama grass (*Boutelona gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. (Reaume 2009)), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes (Reaume 2009)), Kentucky bluegrass (*Poa pratensis* (L.) (Reaume 2009)), little bluestem (*Andropogon scoparius* (Mischz.) (Looman and Best 1987)), needle grass (*Hesperostipa comata* (Trin. & Rupr.) Barkworth (Reaume 2009)), and porcupine grass (*Hesperostipa spartea* (Trin.) Barkworth (Reaume 2009)). Additional vegetation included forbs such as pasture sage (*Artemisia frigida* (Willd.) (Looman and Best 1987)), prairie sage (*Artemisia ludoviciana* (Nutt. var. *ludoviciana*) (Looman and Best 1987)) and purple prairie clover (*Petalostemon purpureus* (Vent.) Rydb. (Looman and Best 1987)). Leafy spurge (*Euphorbia esula* (L.) (Looman and Best 1987)) was the primary non-native

species in this area. Spurge is a perennial Eurasian forb that has become a noxious, invasive weed (Wilson and Belcher 1989). Common shrubs include western snowberry (*Symphoricarpos occidentalis* (Hook.) (Looman and Best 1987)) and prairie rose (*Rosa acicularis* (Lindl.) (Looman and Best 1987)).

CFB Shilo is divided into 17 areas, based on habitat type and use for military training. A total of seven areas were selected in Shilo (Figure 1), and were stratified by variation in fire frequency, likelihood of ongoing accessibility to the areas between military training, and habitat suitability for Sprague's pipit . Within the selected areas, 14 transects were randomly established, with each transect containing 4 point count plots (with the exception of one transect), for a total of 55 point count plots established at CFB Shilo (Table 1). Transects were grouped into 1 of 4 categories of time since burn (in years), which ranged from 1 year to approximately 40 years (Table 1). A 40 year category was chosen for areas that had no known fire history prior to unofficial and official fire records (Sherry Punak-Murphy, personal communication). Further, this clarifies that we cannot know that there has never been a fire in these habitats. Within each area, a minimum of one and a maximum of three transects were established.

Table 1. Categories of burns by transect at Canadian Forces Base Shilo, Manitoba in 2007.

Surveyed Areas	Transects (Site Name)	Number of Plots <i>n</i> =55	Categories of Burns
			(Time Since Burn in years) <i>n</i> =4
1A	1A	4	40
1B	1B1	4	2
1B	1B21	4	2
2	2A	4	40
2	2B	4	40
2	2C	4	40
3	301	4	7
3	311	4	7
4	411	4	40
4	421	4	40
D	D01	4	40
D	D31	4	2
E	E01	4	40
E	D21	3	1

3.1.2 Areas Surrounding Canadian Forces Base Shilo

The prairie surrounding the southwestern portion of CFB Shilo can be denoted as cultivated agricultural land in some cases, and in others, abandoned agricultural land (Wilson and Belcher 1989). The northeastern portion of CFB Shilo merges with aspen parkland from Spruce Woods Provincial Park, and the vegetation in the mixed-grass prairie in this area has been characterized by Bird (1927).

Areas surrounding CFB Shilo were selected for the study based on habitat type (mixed-grass prairie) and were stratified by fire history; areas included provincial parkland, wildlife management areas and private land. Six mixed-grass prairie sites were selected in the offsite study areas in the Rural Municipality of South Cypress and the

Rural Municipality of Cornwallis (Table 2). In each area, one transect was randomly established with four point count plots, with two exceptions in which one site had only three point count plots along a transect (due to smaller size of habitat patch) and another area had two transects. A total of 7 transects and 26 point count plots were established in areas outside of CFB Shilo (Table 2).

Sites in the Rural Municipality of South Cypress included the entrance to Epinette Creek from Spruce Woods Provincial Park, a Yellow Quill (Nature Conservancy) pasture and two wildlife management areas. The Yellow Quill pasture was an actively grazed pasture during the two years of the study. Two pastures owned by private landowners were selected in the Rural Municipality of Cornwallis, one of which was actively grazed in the two years of the study and the other was grazed in recent years prior to the study.

The Assiniboine Corridor Wildlife Management Areas sampled near the CFB Shilo were characterized by provincial conservation officials as idle mixed-grass prairie with a B/C+ grade in May, 1997 (Manitoba Conservation Data Centre 1997). For a habitat to achieve a B grade there must be “some evidence of negative human impacts (i.e. cultivation, unsound grazing or haying practices, long-term fire suppression) but with relatively little effect on the community’s overall structure and/or composition” (Manitoba Conservation Data Centre 1996). Further, a habitat will be characterized as a B grade if there is “increased abundance of shrubs and/or exotic species as well as decreased abundance of native species” (Manitoba Conservation Data Centre 1996). A C grade habitat will have similar characteristics as a B grade habitat, however distinguishing guidelines for a C grade is that “the community has the potential to improve in quality to

a B grade occurrence over time, or with proper management” (Manitoba Conservation Data Centre 1996).

All study sites surrounding CFB Shilo could be grouped into one of three categories of burn, categorized by years since burn, which ranged from one year to approximately forty years. For locations where there was no known fire history (at least within the last 40 years), then the category chosen for those sites was 40 years, in order to be consistent with the methods applied to categorizing fire history for the CFB Shilo sites. At each offsite location, one transect was randomly established for point-count surveys, with the exception of one larger wildlife management area, which had two transects. A total of 26 point-count plots were established in the offsite study areas.

Table 2. Categories of burn history for all study sites in prairie surrounding Canadian Forces Base Shilo in 2007.

Area	Transects (Site Name)	Number of Plots <i>n</i> =26	Categories of Burns <i>n</i> =3 (Time Since Burn in years)
Assiniboine Corridor	ACA1	4	40
Wildlife Management Area			
Assiniboine Corridor	ACB1	4	40
Wildlife Management Area			
Assiniboine Corridor	SM	3	40
Wildlife Management Area			
Private Pasture	GB	4	40
Private Pasture	WH	3	40
Yellow Quill Pasture	YQ	4	1
Nature Conservancy Land			
Epinette Creek	SP	4	10
Spruce Woods Provincial Park			

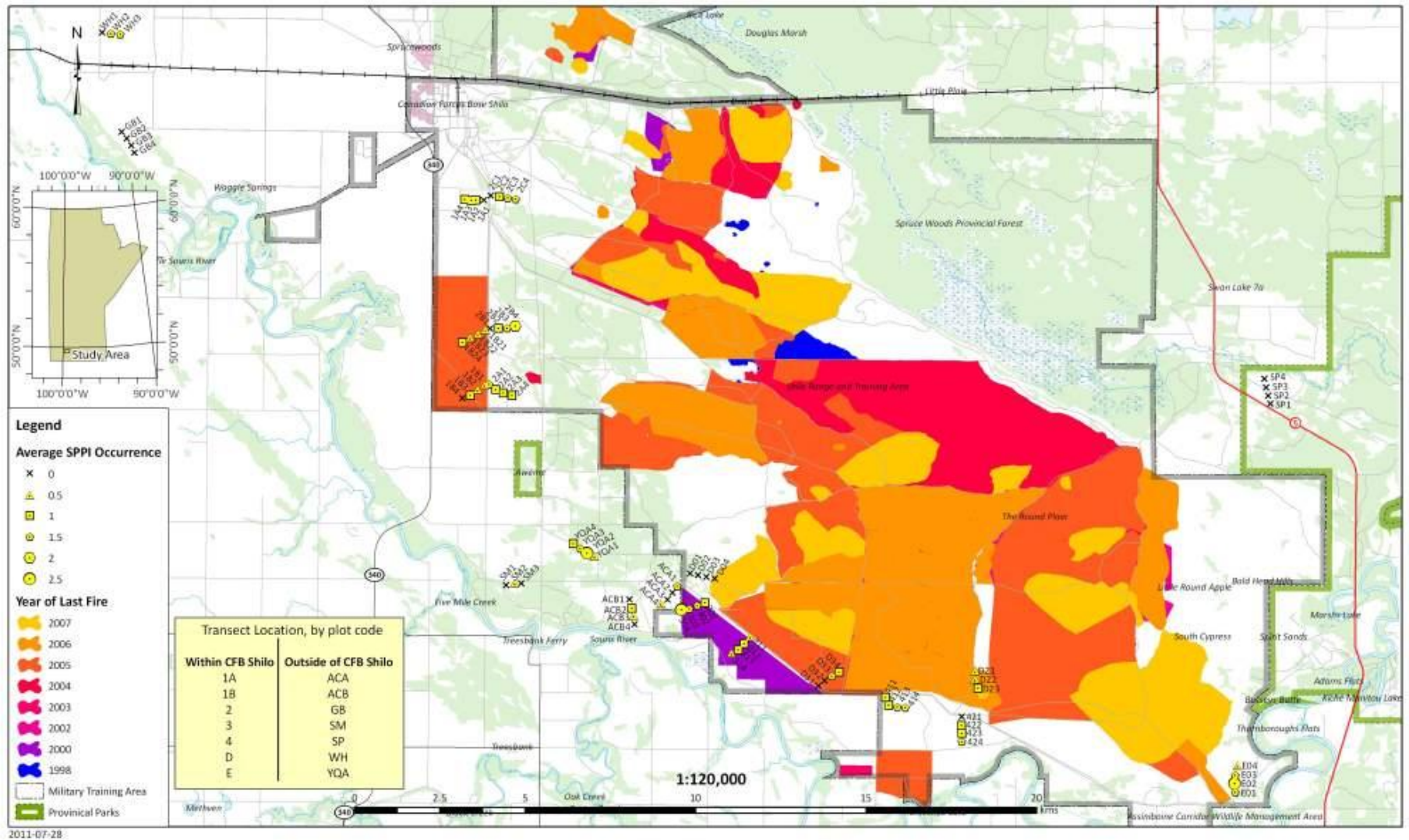


Figure 1. Location of average density of Sprague's pipit per plot in all study sites in south-western Manitoba in 2007. CFB Shilo is outlined by a grey border. Year of most recent fire identified in CFB Shilo only. Map courtesy of Rob Shearer, GIS Technician, Department of National Defence, CFB Shilo, Manitoba.

3.2 Point Count Surveys

3.2.1. *Abundance Surveys of Sprague's pipit*

To evaluate the distribution and abundance of Sprague's pipit in the CFB Shilo training area and surrounding land, 100-m fixed radius point count plots were used for the aural detection of pipits (Hutto et al. 1986). Most species and individuals of birds are detected within the first three to five minutes (Ralph et al. 1995). In each point count control, and observer listened for six minutes for the presence of pipits. If the sound was within 100-m of the observer's position, the approximate distance and direction to the sound of the pipit was recorded a one detection, however all detections outside of the 100-m fixed radius were also recorded to maximize data collection for each site. This study only utilized data from detections within the 100-m fixed-radius point count plot. Point count plots were established at least 250 m apart in order to ensure statistical independence of data compiled from within each plot (Hutto et al. 1986).

The point-count surveys were conducted between 21 May and 24 June 2007 and between 18 May and 24 June 2008 during the regular breeding season (Government of Canada 2008, Prescott 1997, Sauer et al. 2008), and included two rounds of surveys at each of the 55 point-count locations in CFB Shilo, and in each of the 26 point count plots surrounding Shilo with a minimum of 10 days between the surveys at each site. Point counts were conducted between sunrise and 1000 hrs. Point counts were conducted when there was no heavy rain and wind speeds did not exceed 20 km/hr in order to maximize detection of songbird activity.

3.2.2 Surveys of Other Species of Conservation Concern

The focus of this research project was the Sprague's pipit. However, the survey methods also enabled the monitoring of other avian species. Although the intent was to conduct monitoring on the loggerhead shrike, the chimney swift, the common nighthawk, Baird's sparrows, chestnut-collared longspurs and any other species listed by the Federal Species at Risk Act or the Manitoba Species at Risk Act, not all species were detected at the study sites.

3.3 Invertebrate Surveys

The association between available invertebrate resources and the density of Sprague's pipit was only assessed in CFB Shilo habitat due to limited time and resources available to conduct the invertebrate surveys. To determine the richness and density of the invertebrate prey of the pipit, three methods were employed to sample the existing arthropods in the study sites: T-bar counts, sweep netting and pit-fall traps. Two plots per transect were randomly selected for the arthropod sampling, and in one case where there was only three point count plots per transect, one plot was randomly selected for the sampling. Two rounds of surveys were conducted between June and July 2007 for each method employed, to survey the potential food resources for the nesting pipits (June surveys) and the juvenile pipits (July surveys).

3.3.1 Grasshopper Surveys

T-Bar Surveys

The T-bar count method was used to evaluate grasshopper (Order Orthoptera) abundance. This method was described by Roughley (personal communication, 2007), and consisted of a one-metre long aluminum rod attached perpendicular to a long

aluminum handle. At a random location 50-m from the centre of the randomly selected point-count plot, I held the T-bar and began walking from east to west across the point-count plot while pushing through the tops of the vegetation to disturb the grasshoppers. As the T-bar skimmed the vegetation, each grasshopper that was seen jumping was counted using a hand-held counter. One, 100-m T-bar survey was conducted per plot. The abundance of the grasshoppers was the total number of individuals counted per 100 m survey at each point count plot using the T-bar method. Two rounds of T-bar surveys were conducted at each point count plot: June 15-17 and July 19-22, 2007.

Sweep Net Surveys

Surveys of grasshopper Family richness were conducted using an 18-inch triangular-hoop sweep net. These surveys were conducted after the T-bar surveys to ensure the removal of individuals would not influence the results of the T-bar surveys. While Evans et al. (1983) found that sweep net sampling did not provide good abundance data for grasshoppers when compared between burned and unburned sites, Collins (2000) and others have used the sweep net method for surveying grasshopper abundance and richness.

At 50-m from the centre of the point count plot, a random location and direction were chosen and sweep netting was conducted along a 100-m transect through the centre of the selected point-count plot. The sweep-net transect was chosen at a location at least 20 m from the T-bar transect to minimize movement from the t-bar surveys to the area where the sweep net survey would be conducted. At each step, a transverse sweep was taken through the top layer of the vegetation at a 180° arc in one direction, and then on the next step the sweep was taken in the same manner in the opposite direction

(Evans 1984). In order to maintain consistent sampling along all sweep-net transects (Dunwiddie 1991), 50 sweeps were conducted along each transect. One sweep-net transect was completed at each point-count plot.

After completing the sweep net sampling along a transect, contents of the net were emptied into a labeled plastic bag and stored on ice in a cooler. The samples were later placed in a freezer then transported back to the University of Winnipeg for identification. The first sampling period was from June 15-17th and the second sampling period was from July 19-22nd, 2007. All Orthoptera specimens collected were sorted and identified to the Family level (Dunwiddie 1991, Swengel 2001).

3.3.2 Ground Beetle Surveys

Pit-fall Trap Surveys

The pit-fall traps were established at two randomly selected point-count plots along each transect at CFB Shilo, with a total of 10 traps installed per point-count plot. The exception was on one transect that only had 3 point count plots, and at this location, only one point count plot was randomly selected for the pit-fall traps.

A hole auger was used to dig a hole for each of the ten traps in a 50-m radius circle from the centre of the point-count plot. Similar to methods described by Roughley et al. (2006), two, 1-litre plastic containers were placed in the hole (one to retain the shape of the hole while the other could be removed for invertebrate sampling), with a plastic lid secured on top to prevent unwanted collections between sampling dates. The containers were flush with ground level to facilitate access by invertebrates. Wooden shelters were also used over each pit-fall trap, to protect the trap from wild animals and the elements. The wooden shelters were approximately 240 cm², with holes drilled into

each corner to allow wooden dowels to be inserted. The dowels were pushed into the ground until the wooden lid was approximately half an inch above the trap. Trap lids were numbered and a pin-flag was used to mark the location of the trap. There were a total of 270 pit-fall traps established in 2007.

Over a three-day period in June (8-10th) 2007, each of the traps were set up by removing the plastic lid and pouring in 130 ml of diluted antifreeze into the trap. The antifreeze served as an attractant to invertebrates and a preservative during the seven-day sampling period. The plastic lids were retained and the wooden lid was placed over the traps. The start date was the first day the liquid was poured into the trap, and the collection date was seven days later. Collection involved removing the inner plastic container and pouring all contents into a labeled, small plastic jar and transporting the jars in coolers back to the lab for storage and further segregation. The plastic lids were placed back on the containers at the time of collection, and the wooden lids were used once again to protect the plastic traps.

A second sampling of each trap was conducted in July 2007, in order to sample the population available to juvenile pipits. The traps were set-up in each study site from July 19-22, 2007 and the contents were collected 7 days later (July 26-29). Upon completion of the second round of sampling, the traps were removed and the excavated soil was returned to the holes to minimize possible safety risks to future habitat users and to minimized disturbance to the habitat.

The arthropods were temporarily stored in the plastic containers and later sorted into small glass vials. All arthropods stored in glass vials contained ethanol as a preservative. Samples were sorted and identified to the family level.

3.4 Habitat Structure

To assess how Sprague's pipit may select their territories based on their perception of their environment following fire events, habitat structure was measured. Habitat structure is a key parameter to consider as it is an important measure of determining how an animal is responding to its environment (Vinton and Collins 1997). Koper and Schmiegelow (2006) reported that patterns in Sprague's pipit abundance were explained more by local habitat parameters such as vegetation height, density, litter depth, and percentage of bare ground than broader landscape factors. In this study, these vegetation parameters were measured and used to determine whether the habitat structure and quality could explain the abundance of Sprague's pipits and their invertebrate prey in burned and unburned prairie habitat. The vegetation parameters were measured using methods developed by Wiens (1969).

At each point count location at all CFB Shilo and offsite study sites, vegetation surveys were conducted in each cardinal direction at a distance of 50 -m from the centre of the point count plot. At each sampling location, a Wien's pole support structure was pushed into the ground, the Wiens pole was dropped through the support, and two crossed metre sticks were placed at the end of the Wiens pole. Vegetation surveys were conducted in 2007 and 2008, with the following vegetation measurements taken at each point count plot: vegetation height and density, litter depth and percentage of bare ground cover.

3.4.1 Vegetation Height and Density

Using the Wiens pole, the height of each live and dead piece of vegetation touching the pole was counted and measured for vertical length (in cm), using a 30-cm

ruler. The number of pieces of live vegetation touching the pole represented the vertical density of the vegetation (Koper and Schmiegelow 2006). Each piece of vegetation was differentiated as being a grass or a forb, but this data was not used in the analysis within this thesis. In 2007, the vegetation was sampled for height and density at one end of the crossed metre sticks, in each of the four cardinal directions, resulting in four vegetation height and density samples per point count plot. In 2008, the vegetation was sampled for height and density at each end of the crossed metre sticks, in each of the four cardinal directions, resulting in 16 vegetation height samples per point count plot. In 2007 and in 2008, the samples were averaged per point count plot.

3.4.2 Litter Depth

The litter depth was defined as the dead, mat-like layer of vegetation from previous years (Madden et al. 2000). If standing vegetation from previous years was bent- over, it was included in the litter depth layer for sampling. The litter depth measurement (in mm) was made where the Wien's pole was located in the plot (Koper and Schmiegelow 2006). In 2007, the litter depth sample was measured at one end of the crossed metre sticks, in each of the four cardinal directions, resulting in four vegetation height samples per point count plot. In 2008, the vegetation was sampled for height and density at each end of the crossed metre sticks, in each of the 4 cardinal directions, resulting in 16 vegetation height samples per point count plot. In 2007 and in 2008, the samples were averaged per point count plot.

3.4.3 Percentage of Bare Ground Cover

Within each quadrant of the crossed metre sticks, a visual estimation of the percentage area of cover of litter, shrubs, moss or lichens and bare ground was taken

(Koper and Schmiegelow 2006). The percentage of bare ground was estimated based on the actual amount of soil exposed, and based on the amount of bare ground in the quadrant. In both years, a survey of the percentage of bare ground cover was estimated in each cardinal direction, resulting in 16 bare ground observations in each point count plot.

The vegetation surveys were conducted at the CFB Shilo and off-site study areas between 10 August and 24 August 2007 and between 15 August and 06 September 2008. During each sampling period, the area from within CFB Shilo and from the surrounding study sites were sampled concurrently to eliminate bias between results due to possible extended growth periods.

3.5 Data Organization

For the analyses, the mean abundance of Sprague's pipit was calculated based on the total number of individuals of Sprague's pipit per point count plot averaged over two rounds of point count surveys, for each year of the study. This mean pipit abundance data was defined as the density of Sprague's pipits in the point count plots; the terms density and abundance are used interchangeably throughout this thesis. The point count plots were used as the units of replication for all models.

The abundance data from the pit-fall traps were pooled for each point-count plot and used for a total invertebrate count. A count of the insect Orders within each point count plot was used to describe overall invertebrate Order richness. Ground beetle abundance and beetle Family richness were determined from the pit-fall trap data. Total count of grasshoppers from the T-bar method was used for the grasshopper abundance

data at each point-count location. Grasshopper Family richness was calculated using a total count of Families from the sweep-net data.

The observations from each vegetation variable were averaged over each of the four subplots per point count plot in 2007 and over the 16 subplots per point count plot in 2008. The means were used to qualitatively assess the vegetation structure at the point count plots. The sample sizes for vegetation surveys were inconsistent between 2007 and 2008, and were therefore analyzed separately between years.

3.6 Data Analysis

Vegetation, burn history and Sprague’s pipit abundance data from the study sites in Shilo were analyzed in the same models as the data from study sites in the surrounding areas to allow comparison of Sprague’s pipit response to different burn histories in mixed-grass prairie habitat in south-western Manitoba (Table 3). Sample sizes for the habitat structure variables and abundance data for Sprague’s pipit are shown in Table 3 for 2007 and 2008.

Table 3. Sample size for variables in CFB Shilo and study sites surrounding CFB Shilo by year. Bracketed numbers indicated sample size once observations were pooled

Variable	CFB Shilo 2007	CFB Shilo 2008	Surrounding Sites 2007	Surrounding Sites 2008
Count of Sprague’s pipit	110	110	52	52
Vegetation Height	220 (110)	880 (110)	104 (52)	416 (52)
Vegetation Density	220 (110)	880 (110)	104 (52)	416 (52)
Litter Depth	220 (110)	880 (110)	104 (52)	416 (52)
Bare Ground Cover	880 (110)	880 (110)	416 (52)	416 (52)
Beetle Abundance	270 (110)	-	-	-
Beetle Richness	270 (110)	-	-	-
Grasshopper Abundance	54	-	-	-
Grasshopper Richness	54	-	-	-

3.6.1 Fire History, Vegetation Structure and Density of Sprague's pipit

To assess the effects of fire on vegetation structure and the density of Sprague's pipit and the effects of vegetation structure on the density of pipits, generalized linear models were used with a Poisson distribution, using S-Plus 2000 (MathSoft 1999). Poisson distribution was used because initial diagnostics showed that the data distributions were not normal, and because response variables were count data, which generally follow a Poisson distribution. The models used were: 1) Fire Effects Models, which included effects of fire on Sprague's pipit and effects of fire on vegetation structure, and 2) a Habitat Structure Model.

The predictor (independent) variable in the Fire Effects Model was the time since the last burn event (in years), and the response (dependent) variable was the density of Sprague's pipit. Sample sizes for the count of Sprague's pipit are shown in Table 3. The density of Sprague's pipit was based on the mean pipit abundance data for each point count plot. To assess the effects of fire on habitat structure, I used time since the last burn event (in years) as the predictor variable, and the following response variables of vegetation structure: vegetation height, vegetation density, litter depth, and bare ground cover.

The effects of vegetation structure on the density of Sprague's pipit were analyzed in the Habitat Structure Model. In this model, the density of Sprague's pipit was the response variable, and the predictor variables included vegetation structure: vegetation height, vegetation density, litter depth, and bare ground cover. Sample sizes for each predictor variable are shown in Table 3. Each year of the study (2007 and 2008) was analyzed separately in all models.

3.6.2 Fire History, Invertebrate Richness and Abundance and Density of Sprague's pipit

The influence of fire on invertebrates was analyzed using generalized linear regression models with a Poisson distribution, using S-Plus 2000 (MathSoft 1999). The plots were the units of replication for the analysis, and the models I used were: 1) Fire Effects Model, and 2) Invertebrate Models.

The Fire Effects Model included the time since the last burn event (in years) as the predictor (independent) variable, and the following response variables: total invertebrate Order richness and abundance, grasshopper Family richness and abundance and ground beetle Family richness and abundance.

To evaluate the effects of invertebrate abundance and richness on densities of Sprague's pipit, the density of Sprague's pipit was the response variable, and the predictor variables included: total invertebrate Order richness and abundance, grasshopper Family richness and abundance, as well as ground beetle Family richness and abundance. All predictor variables were included in the invertebrate model to determine the effect on Sprague's pipit density, and the models were run independently for the data from June and July of 2007. As invertebrate data were only collected for CFB Shilo, these models excluded the Sprague's pipit abundance data from the surrounding study sites.

In models for evaluating effects of habitat structure on invertebrate richness, the predictor variables included percentage of bare ground, average litter depth, average height and average density of the vegetation. The response variables included grasshopper Family richness and abundance and ground beetle Family richness and

abundance. Each response variable was analyzed with all of the predictor variables in one model, but the June and July 2007 data were analyzed independently.

4.0 Results

4.1 Summary Statistics

Invertebrates were more numerous in July than in June (Table 4). Further, the total invertebrate species Order richness was greater in July than in June 2007 (Table 4). The mean total invertebrate species abundance and Order richness by transect and by burn history in June and July, 2007 can be found in Appendix I and II.

Table 4. Insect Order richness and abundance data for invertebrate species per 100-m plot data in June and July 2007 in CFB Shilo, south-western Manitoba. Mean values, standard deviation and minimum and maximum data ranges are shown for all focal prey species of Sprague's pipit.

<i>Sampled Parameter</i> ¹	June 2007				July 2007			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Total Order Richness	6.19	0.786	4	7	112.11	50.35	70	301
Total Invertebrate Abundance	768.81	311.75	281	1652	1149.81	928.21	439	4830
Total Grasshopper Family Richness	7	7.67	0	35	33.63	37.19	0	139
Total Grasshopper Abundance	27	23.97	3	93	78.81	42.67	23	192
Total Ground Beetle Family Richness	6.78	1.25	4	9	146.19	122.64	29	498
Total Ground Beetle Abundance	164.48	120.93	16	442	146.19	122.64	29	498

¹ The total sum of each invertebrate parameter was per point count plot.

The distribution of the total invertebrate abundance and Order richness as well as the Family richness and abundance of grasshoppers and ground beetles within the areas of different burn histories can be seen in Table 5.

Table 5. Mean and standard deviation (SD) of sampled invertebrates per transect, by time since burn in CFB Shilo 2007. June and July 2007 data were pooled. Time since burn significantly influenced total grasshopper and beetle abundance and grasshopper family richness ($p=0.05$), as indicated by *.

Transect	Burn History (years)	Total Invertebrate Abundance ^a		Total Invertebrate Order Richness ^a		Total Grasshopper Abundance ^{*b}		Total Grasshopper Family Richness ^{*b}		Total Beetle Abundance ^{*a}		Total Beetle Family Richness ^a	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
		D21	1	1253.50	304.76	42.5	51.62	78	82.02	28.5	40.31	268.5	245.36
1B1	2	2053.75	2033.47	109.25	139.13	72	22.64	35.25	39.5	184.5	202.42	165	220.05
1B21	2	1208	700.75	81.25	99.95	68	56.49	38.5	39.26	203.25	205.91	175.5	232.19
D31	2	1414.25	800.52	56	59.36	48.5	10.97	70.25	62.33	257.5	158.33	133.5	171.97
301	7	655.5	156.52	46.25	46.01	47.5	39.37	13	10.83	216.5	167.49	41.25	41.89
311	7	997.25	230.76	58	63.01	27.5	18.27	4.75	2.63	191.75	89.71	85.25	109.84
1A	40	444.75	106.84	70.5	80.97	38.5	38.23	2.25	1.26	77.75	67.86	64	79.04
2A	40	785.25	292.86	64	66.85	65.5	27.25	9	6.32	139.50	46.11	66.75	75.81
2B	40	561	138.09	59.25	70.60	39	14.58	4.5	1.29	113.75	69.08	35	41.91
2C	40	580.75	128.88	49.25	48.78	47.5	36.37	34.25	24.39	148	104.97	66.75	89.21
411	40	1136.50	402.13	47.5	48.54	32.75	28.11	4.25	5.06	153.5	50.33	70	72.43
421	40	693.50	171.67	45	45.76	24.25	16.84	11	8.04	98.5	52.11	31.5	38.21
D01	40	733	46.53	45.5	45.73	46.25	45.18	25.5	29.58	120.75	58.19	40.5	39.87
E01	40	1060.50	375.38	45.5	44.64	134.25	59.39	7.5	4.04	57.5	3.51	32	29.59

^a For surveys in CFB Shilo, $n = 220$ in 2007.

^b For surveys in CFB Shilo, $n = 54$ in 2007.

The mean density of Sprague's pipit of 3.2. per hectare point count plot for CFB Shilo was greater in 2007 than in 2008 (Table 6). In contrast, in the study sites surrounding CFB Shilo, the mean density of pipits was greater in 2008 (Table 7), although there was no significant difference when combined and statistically analyzed for the region (Table 8).

The average vegetation height was higher in the second year of the study than the first for the sites in CFB Shilo (Table 6); however, the vegetation height in the surrounding study sites was greater in 2007 than in 2008 (Table 7). When the vegetation height for the region (combined sites) was summarized, the vegetation height was higher in 2008 (Table 8). Similarly, the average litter depth for the region was greater in

2008 (Table 8). Vegetation density and the percentage of bare ground were higher in the first year of the study for the regional analysis (Table 8), which is consistent with the observations made in CFB Shilo (Table 6) and in the surrounding study sites (Table 7) for these habitat features.

Table 6. Mean abundance of Sprague's pipit and mean vegetation structure parameters per 100-m plots in 2007 and 2008 at CFB Shilo, Manitoba. Minimum and maximum data ranges are also shown.

<i>Sampled Parameter</i>	2007				2008			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Total density of Sprague's pipits ¹	0.94	0.71	0	3	0.89	0.63	0	2.5
Average vegetation density ²	5.99	3.79	2	24.25	5.61	1.97	0.94	10.69
Average vegetation height (cm) ³	34.27	10.12	13.38	61.00	35.50	9.84	3.69	55.88
Average Litter Depth (mm) ⁴	20.44	15.04	0.00	57.50	19.38	14.30	1.88	77.19
Average Bare Ground ⁵	13.89	14.78	0.00	60.31	5.15	8.46	0.00	41.88

¹ The abundance of Sprague's pipit was averaged per point count plot over two rounds of surveys.

^{2,3,4,5} The density and height of the vegetation, litter depth and percentage of bare ground was averaged per point count plot in each year.

Table 7. Mean abundance of Sprague's pipit and mean data for all surveyed vegetation structure parameters per 100-m plots in 2007 and 2008 in study sites surrounding CFB Shilo, south-western Manitoba. Minimum and maximum data ranges are also shown.

<i>Sampled Parameter</i>	2007				2008			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Total density of Sprague's pipit ¹	0.48	0.70	0	2.5	0.62	0.77	0	2.5
Average vegetation density ²	6.46	3.27	1.75	12.75	5.75	1.97	3.00	10.13
Average vegetation height (cm) ³	33.42	9.87	11.25	54.36	31.94	10.62	14.41	51.31
Average Litter Depth (mm) ⁴	23.56	16.60	0.00	53.75	25.23	17.69	2.81	64.38
Average Bare Ground ⁵	9.70	17.51	0.00	81.25	5.53	7.23	0.00	20.00

¹ The abundance of Sprague's pipit was averaged per point count plot over two rounds of surveys.

^{2,3,4,5} The density and height of the vegetation, litter depth and percentage of bare ground was averaged per point count plot in each year.

Table 8. Mean abundance of Sprague's pipit and mean data for all surveyed vegetation structure parameters per 100-m plots in 2007 and 2008 for all study sites (combined data) in south-western Manitoba. Minimum and maximum data ranges are also shown.

<i>Sampled Parameter</i>	2007				2008			
	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Total density of Sprague's pipit ¹	0.80	0.73	0	3	0.80	0.68	0	2.5
Average vegetation density ²	6.14	3.62	1.75	24.25	5.65	1.96	0.94	10.69
Average vegetation height (cm) ³	34.00	9.99	11.25	61.00	34.36	10.17	3.69	55.88
Average Litter Depth (mm) ⁴	21.45	15.53	0.00	57.50	36.86	15.60	1.88	77.19
Average Bare Ground ⁵	12.53	15.73	0.00	81.25	5.27	8.04	0.00	41.88

¹ The abundance of Sprague's pipit was averaged per point count plot over two rounds of surveys.

^{2,3,4,5} The density and height of the vegetation, litter depth and percentage of bare ground was averaged per point count plot in each year.

The mean of the vegetation variables by transect and by year of burn in Table 9 show the disparity between recently burned sites and sites that have had longer fire return intervals in CFB Shilo and in the surrounding study areas.

Table 9. Mean and standard deviation (SD) of vegetation parameters per transect by burn history for 2007 and 2008 in all study areas in south-western Manitoba. All vegetation parameters were initially averaged per point count plot. In the combined sites analysis, all vegetation variables were significantly influenced by time since burn between 2007 and 2008 ($p=0.05$) as indicated by *.

Transect	Burn History (years)	Density 2007*		Density 2008		Height 2007*		Height 2008		Litter Depth 2007*		Litter Depth 2008*		Bare Ground 2007 ^{ab}		Bare Ground 2008 ^b	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
		D21	1	2.75	1.30	3.02	1.00	18.17	5.72	19.86	8.17	13.75	19.65	3.54	1.48	32.5	28.63
YQ	1	6.58	4.31	4.5	1.28	25.17	4.37	20.32	1.11	6.42	0.95	10.10	2.19	15.62	4.20	16.87	3.48
1B1	2	3.75	1.20	6.84	0.86	37.56	10.93	40.42	5.59	9.56	5.62	18.67	16.78	22.73	13.76	2.03	1.62
1B21	2	3.06	1.49	7.67	0.74	28.41	13.54	39.73	3.23	10.81	4.57	17.01	5.43	28.98	16.34	3.28	2.81
D31	2	4	1.31	3.64	0.52	30.69	4.66	33.36	2.18	1.06	1.81	6.80	6.61	36.95	8.77	12.58	4.34
301	7	6.68	2.47	5.86	2.22	36.25	3.80	34.56	8.72	14.69	3.73	12.67	3.57	9.56	4.61	1.64	2.51
311	7	6.25	0.98	6	1.11	29.66	3.57	37.16	8.88	25.31	9.86	24.89	9.37	4.61	7.97	1.33	2.45
SP	10	8.63	4.77	6.54	2.42	30.16	13.04	35.57	9.02	28.12	21.18	46.36	19.51	21.88	39.61	0	0
1A ^a	40	11.81	8.35	7.42	2.48	35.17	3.40	40.18	5.78	16.25	4.42	43.36	23.65	2.84	2.85	0.08	0.16
2A	40	11.87	2.04	4.39	2.69	43.59	9.11	30.49	18.44	30.34	14.02	18.12	14.81	2.66	2.48	0.70	0.82
2B	40	9.06	0.94	6.34	1.17	41.78	12.38	37.27	5.94	18.12	4.12	13.36	9.27	7.58	4.39	4.53	7.31
2C	40	4.18	0.65	5.20	1.58	29.72	4.68	36.86	11.97	15.37	4.18	13.91	5.72	17.06	5.45	2.89	2.81
411	40	5.87	1.27	5.75	2.28	36.66	13.38	39.63	13.19	45.62	9.27	30.70	15.81	6.64	9.82	1.56	1.59
421	40	4.06	2.22	5.37	0.87	36.03	7.05	39.70	14.40	31.25	15.31	27.5	13.86	3.67	4.55	1.87	3.75
D01	40	5.17	2.37	5.25	0.82	41.83	17.97	36.70	2.54	15.33	20.30	22.02	4.38	16.98	13.77	0.42	0.48
E01	40	4.31	1.53	6.06	2.91	32.16	7.59	30.54	6.86	35.75	17.00	18.36	11.37	7.12	10.37	10.39	10.52
ACA1 ^c	40	5.75	2.57	8.77	0.99	42.4	10.02	40.29	2.12	25.94	5.72	26.02	4.49	2.58	3.19	0.94	0.81
ACB1	40	7.06	2.82	5.44	0.66	39.91	6.39	39.68	3.49	39.69	16.88	42.66	10.87	1.02	1.34	6.25	1.96
GB	40	4.56	1.98	5.58	1.49	30.28	4.23	23.58	3.29	14.5	8.68	15.11	5.18	3.98	3.12	0	0
SM	40	9	2.78	5.25	1.09	33.5	14.61	44.46	6.77	38.75	10.68	27.71	14.61	8.44	8.01	0	0
WH	40	3.25	1.32	3.41	0.48	27.21	4.49	17.22	2.44	5.08	4.01	3.02	0.26	20.62	21.69	16.46	2.34

^a For surveys in CFB Shilo (see Table 1 for list of transects), $n = 220$ for vegetation height, density and litter depth in 2007, and $n = 880$ in 2008.

^b For surveys in CFB Shilo (see Table 1 for list of transects), $n = 880$ for bare ground estimate in 2007 and in 2008.

^c For surveys in areas surrounding CFB Shilo (see Table 2 for list of transects), $n = 104$ for all vegetation parameters in 2007, and $n = 416$ in 2008.

4.2 Relationship between fire history and habitat structure

In 2007, the time since last burn significantly influenced all vegetation variables.

With an increase of one year in time since burn, the amount of bare ground significantly decreased by 0.025 percent (Table 10). In contrast, litter depth, vegetation density and vegetation heights were positively influenced by time since last burn (Table 10).

In 2008, the average height and density of the vegetation could not be explained by the time since the last burn in the study area. However, consistent with the 2007

observations (Table 10), the time since the last burn positively influenced the average litter depth (Table 10). Further, the amount of exposed bare ground decreased with time since the last fire event (Table 10), which was also consistent with the 2007 observations (Table 10).

Table 10. Model of temporal influence of fire on habitat structure in south-western Manitoba, in 2007 and 2008, using generalized linear regression models with Poisson distribution. Parameter estimates (β), standard error (SE), and probability values (P) are shown ($\alpha=0.05$).

Vegetation Parameter	Predictor Variable	2007			2008		
		β	SE	P	β	SE	P
Percentage of Bare Ground	Time since last burn (years)	-0.025	0.002	<0.001	-0.025	0.003	0.001
Average Litter Depth (mm)	Time since last burn (years)	0.016	0.002	<0.001	0.009	0.001	<0.001
Average Height (cm)	Time since last burn (years)	0.005	0.001	0.001	0.001	0.001	0.297
Average Density	Time since last burn (years)	0.006	0.003	0.020	0.002	0.003	0.572

4.3 Relationship between fire history and abundance of Sprague's pipit

In 2007, there were an average of 0.80 (0.73 STDEV) Sprague's pipit found per 3.2 hectare point count plot in the region, over two rounds of surveys (Table 8; Figures 2 and 3). The density and distribution of Sprague's pipit could not be significantly explained by the time since the last fire event in the study sites in 2007 ($\beta=0.005$, $SE=0.007$, $p=0.419$).

In 2008, an average of 0.80 (0.68 STDEV) Sprague's pipit were found in each point count plot over two rounds of surveys (Table 8; Figures 3 and 4). Similar to 2007,

the density and distribution of Sprague's pipit was independent of the time since the last fire event in the Shilo prairie habitat ($\beta=0.002$, $SE=0.007$, $p=0.775$).

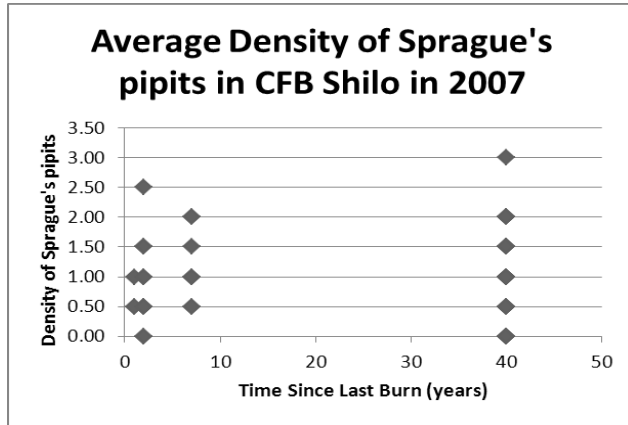


Figure 2. Average density of Sprague's pipit per point count plot in CFB Shilo in 2007.

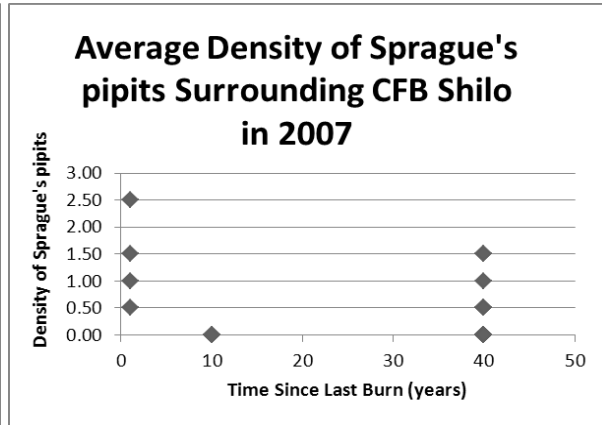


Figure 3. Average density of Sprague's pipit per point count plot in study sites surrounding CFB Shilo in 2007.

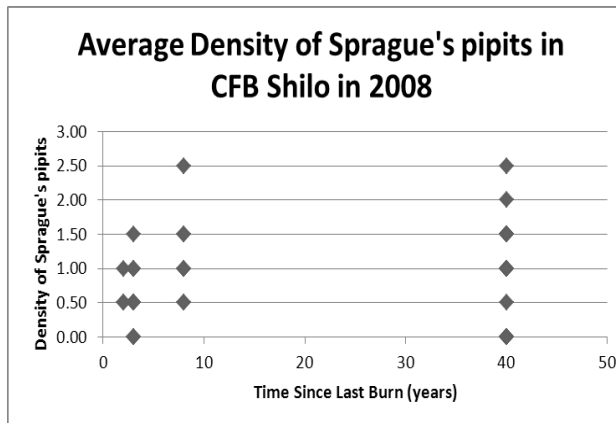


Figure 4. Average density of Sprague's pipit per point count plot in CFB Shilo in 2008.

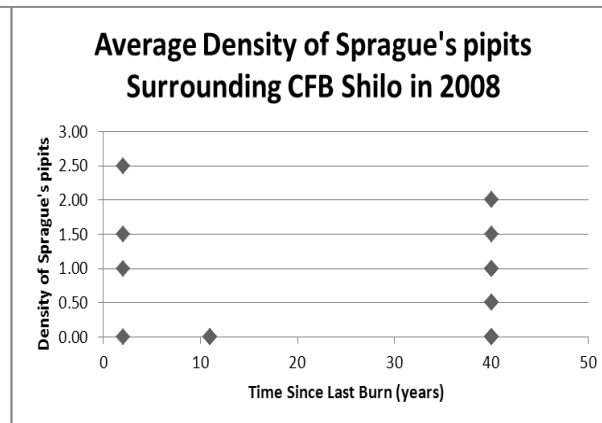


Figure 5. Average density of Sprague's pipit per point count plot in study sites surrounding CFB Shilo in 2008.

4.4 Relationship between fire history and abundance of invertebrates

Beetles (Coleoptera) responded to fire history consistently in June and July of 2007. The June abundance of Coleoptera significantly decreased by 0.012 (SE 0.001) individuals with time since burn ($p<0.05$) (Table 11). Similarly, there was a significant

decrease ($p < 0.05$) of 0.024 (SE 0.001) Coleoptera per year since the last burn in July (Table 11). The Family richness of Coleoptera was independent of time since burned.

The response of grasshoppers (Orthoptera) to time since burned was inconsistent between June and July abundances in 2007. Overall, in June the abundance of Orthoptera was independent of time since burned (Table 11). However, in July 2007, there was a significant ($p < 0.05$) decrease in Orthoptera abundance with time since burn (Table 11). Orthoptera Family richness declined with time since burned, too, but only in July (Table 11).

Table 11. Model of association between time since burn (in years) and the abundance and richness of invertebrates per plot (3.2 ha) at CFB Shilo study sites in south-western Manitoba, in June and July 2007, using generalized linear regression models with Poisson distribution. Parameter estimates (β), standard error (SE), and probability values (P) are shown ($\alpha = 0.05$).

Invertebrate Species	Predictor Variable	June 2007			July 2007		
		β	SE	P	β	SE	P
Abundance of Coleoptera	Time since last burn (years)	-0.012	0.001	<0.001	-0.024	0.001	<0.001
Family Richness of Coleoptera	Time since last burn (years)	-0.001	0.004	0.745	-0.001	0.004	0.837
Abundance of Orthoptera	Time since last burn (years)	0.001	0.002	0.691	-0.005	0.001	<0.001
Family Richness of Orthoptera	Time since last burn (years)	0.002	0.004	0.642	-0.036	0.0002	<0.001

4.5 Relationship between invertebrate resources and density of Sprague's pipit - 2007

There was no significant effect in June or July between total invertebrate species richness and abundance on Sprague's pipit (Table 12). Similarly, there was no relationship between invertebrate Family richness and abundance of each focal (prey)

species of invertebrates (Orthoptera and Coleoptera) and the density of Sprague's pipit ($p>0.05$) (Table 12).

Table 12. Model of relationship between density of Sprague's pipit per plot (3.2 ha) and the richness and abundance of invertebrates in June and July 2007 at CFB Shilo, in south-western Manitoba, using generalized linear regression models with Poisson distribution. Parameter estimates (β), standard error (SE), and probability values (P) are shown ($\alpha=0.05$). All relationships are non-significant.

Songbird Species	Predictor Variable	June 2007			July 2007		
		β	SE	P	β	SE	P
Sprague's pipit	Total Invertebrate	-0.001	0.000	0.304	-0.000	0.000	0.254
	Abundance						
	Total Invertebrate	0.146	0.196	0.452	0.004	0.004	0.323
	Richness						
	Abundance of	-0.003	0.006	0.856	0.004	0.003	0.362
	Orthoptera						
	Family Richness	0.004	0.018	0.473	0.002	0.005	0.317
	of Orthoptera						
Abundance of	-0.004	0.002	0.268	-0.002	0.001	0.405	
Coleoptera							
Family Richness	0.150	0.139	0.853	0.201	0.109	0.071	
of Coleoptera							

4.6 Effects of habitat structure on abundance of Sprague's pipit

The density and distribution of Sprague's pipit in 2007 could not be significantly explained ($p>0.05$) by any of the quantified components of habitat structure (Table 13). Similarly, in 2008, the density and distribution of Sprague's pipit in the study sites could not be significantly explained ($p>0.05$) by any of the quantified components of habitat structure (Table 13).

Table 13. Model of associations between habitat structure and the density of Sprague's pipit per plot (3.2 ha) in south-western Manitoba, in 2007 and 2008, using generalized linear regression models with Poisson distribution. Parameter estimates (β), standard error (SE), and probability values (P) are shown ($\alpha=0.05$). All relationships are non-significant.

Songbird Species	Predictor Variable	2007			2008		
		β	SE	P	β	SE	P
Sprague's pipit	Percentage of Bare Ground	-0.010	0.011	0.335	-0.009	0.020	0.645
	Average Litter Depth (mm)	-0.015	0.011	0.271	-0.017	0.011	0.133
	Average Height (cm)	-0.003	0.015	0.975	0.000	0.085	0.366
	Average Density	-0.028	0.044	0.405	0.100	0.015	0.994

4.7 Effects of habitat structure on invertebrates

The abundance of both ground beetles (Coleoptera) and grasshoppers (Orthoptera) in June 2007 significantly increased ($p<0.05$) with percentage of bare ground, vegetation density and litter depth (Table 14). The abundance of both Coleoptera and Orthoptera individuals decreased with an increase in vegetation height (Table 14). The Family richness of Coleoptera was independent of the vegetation variables; however, Family richness of Orthoptera declined with an increase in vegetation density.

The relationship between the abundance of Coleoptera and vegetation structure in July tended to conflict with the June observations (Table 14). The percentage of bare ground, litter depth and vegetation density negatively influenced the abundance of Coleoptera in July (Table 14). Unlike the observations in June, the average height of the vegetation positively influenced the abundance of Coleoptera in July (Table 14).

Increases in Orthoptera abundance in July was explained by the percentage of bare ground and average litter depth, which was consistent with the observations made in June (Table 14). Overall, declines in Orthoptera abundance could be explained by an

increase in vegetation density, which is in contrast to the response of Orthoptera abundance to vegetation density in June.

The response of Family richness of Orthoptera to habitat structure was inconsistent between June and July. For example, the Family richness of Orthoptera could only be explained by the average density of the vegetation in June (Table 14), whereas in July the Family richness of Orthoptera could be explained by the percentage of bare ground, vegetation density and litter depth (Table 14).

Table 14. Model of associations between vegetation composition and abundance of Coleoptera and Orthoptera at CFB Shilo in south-western Manitoba, in June and July 2007.

Invertebrate Species	Predictor Variable	June 2007			July 2007		
		Parameter Estimate (β)	Standard Error	P Value	Parameter Estimate (β)	Standard Error	P Value
Abundance of Coleoptera	Percentage of Bare Ground	0.016	0.002	<0.001	-0.006	0.002	<0.001
	Average Litter Depth (mm)	0.003	0.002	<0.001	-0.020	0.002	<0.001
	Average Height (cm)	-0.041	0.002	<0.001	0.027	0.002	<0.001
	Average Density	0.122	0.008	<0.001	-0.060	0.008	<0.001
Family Richness of Coleoptera	Percentage of Bare Ground	0.014	0.010	0.158	-0.006	0.010	0.552
	Average Litter Depth (mm)	0.008	0.008	0.979	-0.005	0.008	0.829
	Average Height (cm)	-0.003	0.008	0.951	0.001	0.008	0.971
	Average Density	0.055	0.035	0.341	0.021	0.036	0.249
Abundance of Orthoptera	Percentage of Bare Ground	0.029	0.004	<0.001	0.006	0.002	0.035
	Average Litter Depth (mm)	0.025	0.004	0.002	0.007	0.002	0.027
	Average Height (cm)	-0.036	0.004	<0.001	-0.007	0.003	0.045
	Average Density	0.085	0.016	<0.001	-0.019	0.011	0.001
Family Richness of Orthoptera	Percentage of Bare Ground	0.006	0.009	0.477	0.045	0.005	<0.001
	Average Litter Depth (mm)	-0.004	0.008	0.153	-0.014	0.005	<0.001
	Average Height (cm)	-0.017	0.009	0.056	0.002	0.005	0.488
	Average Density	-0.111	0.038	<0.001	-0.035	0.020	<0.001

5.0 Discussion

While the influence of fire on the vegetation of prairie grasslands has been well documented, there has been relatively little research examining effects of fire on grassland songbirds in mixed-grass prairie (Johnson 1997, Madden et al. 1999, Brawn et al. 2001). Although prairie fires could negatively affect grassland songbirds in the short term, particularly during the summer months during the breeding season if fire consumes nests of eggs or nestlings, in the absence of fire populations of prairie passerines may start to decline, or ultimately disappear (Askins 2002).

Johnson (1997) conducted a long-term study of fire effects on birds in mixed-grass prairie, where grassland birds were surveyed over a 23 year period in areas that were subjected to a variety of prescribed-burn regimes. However, this study did not survey Sprague's pipit. Madden et al. (1999) examined the association between fire history and the densities of Sprague's pipit in areas with a burn history of up to fifteen years and in other areas where fire was considered absent (fire history was >80 years). Pylypec (1991) examined the influence of fire on the densities of Sprague's pipit over a three year period post-fire in a controlled burn setting. Evidently, research on the response of Sprague's pipit to fire is limited, and an understanding of the effects of fire at the northern limits of the range of Sprague's pipit would contribute to our understanding of its conservation needs. Further, it is important to understand the role of resource availability in mediating the effects of fire on Sprague's pipit. I am not aware of another study that has explored the effect of fire on invertebrate resources concurrent with abundance surveys of Sprague's pipit, to determine the role of invertebrates in Sprague's pipit's response to fire.

5.1 Influence of burn history on mixed-grass prairie and the density of Sprague's pipit

Habitat management differed significantly throughout the study sites in the study area, and as a result the disparity in burn histories between the sites was great. Land use at CFB Shilo involved accidental fires and prescribed burns as a result of and in preparation for military training, and fire histories ranged from one year to forty years. However, in many of the areas surveyed in this study, the habitat is designated as dry-fire training areas (Sherry-Punak Murphy, personal communication). As a result, there is a significantly decreased likelihood of these areas ever getting burned as a result of ammunition from live fire training, or as a result of controlled burns prior to training events. These areas are more on the perimeter of the training area, and are therefore not as actively used.

The Yellow Quill pasture has had prescribed burns in the past, and does seem to be under a managed burn regime with the Nature Conservancy. Spruce Woods Provincial park experienced one accidental burn in the area surveyed. The other prairie within the study sites had either no management or management that did not incorporate burning. The private pastures were grazed, and like fire, grazing is a form of natural disturbance to mixed-grass prairie.

Generally, with an increase in time since burn, the amount of bare ground decreased, the litter build-up increased, and the vegetation height and density also increased. The results of this study are consistent with those of Wilson and Shay (1990) and Madden et al. (1999). Madden et al. (1999) found that in areas with repeated fire in mixed-grass prairie, vegetation height, density and litter depth decreased. Wilson and

Shay (1990) found an increase in the frequency of bare ground and a decrease in litter in burned areas.

Madden et al. (1999) also found that succession of the habitat structure in mixed-grass prairie progressed from minimal forbs with reduced litter and short, sparse grassy areas following fire events, to areas with more prominent amount of forbs and litter in two to eight years following fire events, to a dense, shrubby habitat with minimal forbs and grasses in an absence of fire. This suggests that if there was a long-term absence of fire in the future, the habitat structure in the mixed-grass prairie of this region would likely progressively change to a community of largely shrubby prairie with minimal forbs and grasses.

However, my conclusion that fire history did not influence densities of Sprague's pipit was not consistent with findings from other research. Pylypec (1991) studied the short-term (three year post-burn) effects of fire on Sprague's pipit and found adverse effects on pipit densities in the first two years following a burn event, but by the third year the densities were similar to those of unburned areas. I may have had too few sites that had experienced recent fires to detect such short-term effects. Madden et al. (1999) found that Sprague's pipit responded favorably to the amount of fire, and were absent from mesic prairie that has not experienced fire for long periods.

It is possible that the time of year of burn may have contributed to my non-significant results. Herkert and Knopf (1998) suggested that there may be greater nest success if prescribed burns in grasslands occur in the fall rather than in the spring. Although I did not evaluate effects of time of year of burns and intensity of burns, variation in these factors could explain why fire did not affect pipit densities.

The density of Sprague's pipit could not be explained by habitat structure; pipits did not respond to percentage of bare ground, litter depth, vegetation height and vegetation density in either year of the study. These findings are similar to those of Koper and Schmiegelow (2006). The non-significant effect of the vegetation structure on the density of Sprague's pipit indicates that habitat suitability is not based solely on vegetation structure, but that there are multiple characteristics that are driving pipit's territory selection.

My observations suggest that in this region, Sprague's pipit within existing grasslands is generally not affected by burns. However, burns would still contribute to the conservation of Sprague's pipit because, based on the response of vegetation to fire in this study and on findings from other research, incorporating fire into management practices will prevent succession of the prairie to woody habitats that would be perceived as unattractive to Sprague's pipit (Duran 2009).

This research revealed that the existing fire-return interval in this mixed-grass prairie region is not contributing to the population decline of Sprague's pipit. However, if burns were not permitted in future years, we would expect the grasslands on CFB Shilo to gradually succeed to forest, and that would have an adverse impact on the habitat structure and subsequently on the density of Sprague's pipit. The critical habitat for Sprague's pipit have been defined within the amendments to the Sprague's pipit recovery strategy, and include the following attributes: "open areas of upland native prairie (≥ 65 ha), native prairie management units in fair to excellent range condition, limited woody vegetation, limited invasion by exotic grasses, flat to gently rolling topography" (Environment Canada 2011). These critical habitat criteria further supports

the assertion that periodic burns in Shilo would aid in the progression of the quality of the habitat to a condition that meets the critical habitat needs of Sprague's pipit and that pipits might therefore benefit from periodic burns.

5.2 Influence of fire on invertebrate resources

This study suggests that more frequent burns may benefit grasshoppers (Orthoptera) and ground beetles (Coleoptera) in mixed-grass prairie. Orthoptera may demonstrate a strong response to fire, showing decreases in abundance immediately after fires (Swengel 2001). In the intermediate-term following a fire (from 1-12 months following a burn; Swengel 2001), the abundance of Orthoptera seems to recover to original levels (Rice 1932, Dunwiddie 1991). However, these findings have been inconsistent among researchers (Evans 1984, Anderson 1989).

Observations in this study suggest that Family richness of Orthoptera declined with time since burned is consistent with some previous studies. Evans (1984) suggested that an intermediate burn regime appeared to be most suitable for optimal maintenance of forb-feeding grasshopper populations in his findings, and that prairie sites left undisturbed for too long may adversely affect grasshopper populations. The results of this study suggest that burns may benefit Orthoptera over longer time scales.

This study also observed that ground beetle abundance tended to decrease with time since burned. Anderson et al. (1989) also found that on burned sites, Coleoptera were more abundant on burned sites compared with unburned sites. Swengel (2001) cited numerous studies that indicate an increase in abundance of ground beetles in the intermediate-term following a burn. However, Dunwiddie (1991) found no consistent

trends in Coleoptera abundance post-burn. Taken together, this suggests that burns often have a positive effect on beetle abundance.

Ground beetles tend to be environmentally sensitive, and although they are typically capable of inhabiting a wide variety of habitats (Roughley 2001), their response to fire in mixed-grass prairie suggests that they are more likely to thrive if the habitat is exposed to a fire disturbance. The abundance of ground beetles has been linked to the abundance of their prey (Roughley 2001), and it is possible that a lack of fire may change habitat suitability for their prey which subsequently influences their habitat selection.

5.3 Influence of vegetation structure on invertebrates

Grasshopper and ground beetle (Order Coleoptera: Family Carabidae) abundance were positively influenced by the percentage of bare ground in June. More available bare ground exposes the soil and can increase soil temperatures, especially in spring (Hulbert 1988). Increased soil temperatures results in warmer microclimates and this may enable more rapid development for some species of arthropods (Warren et al. 1987), which may explain why grasshopper and ground beetle abundance increased with the amount of bare ground.

Vegetation density in June positively influenced grasshopper abundance; however grasshopper Family richness declined with an increase in vegetation density. Joern (1982) observed that grasshopper species utilize habitats where vegetation density is varied. As vegetation density increases in CFB Shilo, overall the habitat would tend to be more uniform in density, and based on Joern's (1982) findings, the density of the habitat may not be varied enough to support a rich population of grasshoppers. In July,

the grasshopper abundance was also negatively influenced by vegetation density, which is further supported by Joern's (1982) results.

It appears there was no consistent trend in ground beetle abundance in response to vegetation structure in this study. Although ground beetle abundance does decrease with time since burn in prairie in Shilo, fire may not be indirectly affecting ground beetle populations through adverse changes in vegetation structure. As Roughley (2001) indicated, ground beetles tend to occupy a wide variety of habitats. CFB Shilo habitat structure may be sufficient, even in varied post-burn stages, to support beetle populations such as ground beetles.

Although this study simply identified grasshopper species to the Family level and did not identify the developmental stage or characterize the feeding type of the Orthoptera species, the response of Orthoptera may have been better explained had species level analysis and developmental stage been determined.

5.4 Response of Sprague's pipit to Invertebrate Resources

Sprague's pipit did not show a response to the abundance of invertebrate resources in either the June or July 2007 models, which suggests that there are sufficient food resources throughout my study area to support the densities of Sprague's pipit that are found here. However, availability of food resources might become important as Sprague's pipit populations increase, as recommended by the Canadian Sprague's Pipit Recovery Strategy (Environment Canada 2008). This thesis did not explore between-species competition for resources, yet the presence of other generalist feeders such as the western meadowlarks (*Sturnella neglecta*) and grasshopper sparrows (*Ammodramus bairdii*) that feed on a broad range of grasshopper species (Joern 1986)

could further influence the available resources for pipits. Belovsky and Slade (1993) studied avian predation on grasshoppers and found that large and small grasshoppers decreased in relative abundance in response to avian predation. These findings show that avian predation does affect grasshopper density, and the presence of other feeders could reduce the availability of this prey item for Sprague's pipit.

Although beetles and grasshoppers are the main constituents of the diet of Sprague's pipit, Robbins and Dale (1999) stated that the percentage of grasshoppers in the pipits' diets increased from 4% to 47% later in the breeding season and the percentage of ground beetles decreased from 41% to 12%, thus the importance of grasshoppers increase later in the breeding season. Over time if prairies remain unburned, I would predict that fewer grasshoppers will be available for pipits at a potentially resource-limiting period of their life-cycle. Beetle abundance also tended to decrease with time since burn, suggesting that this invertebrate food resource might also decline if the habitat in Shilo remains unburned for an extended period of time.

The diet of Sprague's pipit varies regionally (Robbins and Dale 1999), and therefore it is difficult to determine how reliant pipits are dependent on grasshoppers and beetles in CFB Shilo. A more comprehensive understanding of the diet of Sprague's pipit in CFB Shilo would provide insight into whether burns positively affect the resource availability for pipits.

It appears that Sprague's pipit may not be choosing their habitats based on the abundance of grasshoppers or beetles and therefore this study did not support the hypothesis that pipits may be selecting habitats based on resource availability and would be therefore found in higher densities in areas that supported a greater abundance of

their invertebrate prey. However, results from only one field season of invertebrate surveys are insufficient to conclude that pipit densities are not influenced by available invertebrate resources. The results do suggest that these variables could be a limiting factor to the success of pipits in poorly managed prairie regimes, especially in the absence of fire. Further research on the correlation between invertebrate resource availability and pipit abundance is warranted.

6.0 Management Implications

6.1 Recommendations for Fire Management at CFB Shilo and Surrounding Habitat

Based on the findings of this research, if the current management practices at CFB Shilo remain unchanged and periodic fires continued to occur in all areas, then CFB Shilo will continue to support the population of Sprague's pipit. Although CFB Shilo does have a large number of controlled and accidental burns within the training area, many of the areas surveyed in this study were not used for live-fire training and therefore were not actively managed for controlled burns, and were less likely to experience accidental burns because only dry-fire training is permitted in these areas. One area had experienced a burn 7 years prior to this study, and that was a result of an accidental burn from training, but that had been the only burn in approximately the last 40 years.

Given the reduced likelihood that these areas will be subjected to a fire disturbance through controlled or accidental means, I would advise management to consider a burn plan for these areas. There were only four categories of burns in this study; 1, 2, 7 and 40 years post-fire. If management ensured that these areas were at least subjected to this type of burn frequency in the future, then we could be sure that the habitat in these particular sites would still support pipit populations.

Similarly, if the existing management practices for the study sites surrounding CFB Shilo remain unchanged, then there would unlikely be adverse effects on the population of Sprague's pipit. However, of the fire histories in the surrounding study

sites, only one site (Yellow Quill pasture) had a prescribed burn regime, as fires in other sites were a result of accidental burns.

Ensuring that a prescribed burn regime was incorporated into management approaches and applied to all areas of CFB Shilo and in the surrounding habitat, would help to ensure that the prairie in these areas does not degrade and become unsuitable for pipits. Results of the research on invertebrates in Shilo also suggest that an established burn regime may also ensure that the invertebrate resource availability of the primary prey for Sprague's pipit is not adversely affected. Although invertebrate surveys were not conducted outside of Shilo, this assertion may also be true for the similar mixed-grass prairie habitats.

Johnson (1997) suggested that prescribed burning be incorporated into management for conservation of the northern Great Plains. Wright and Bailey (1982) infer that fire management should include habitats with a variety of burn regimes of different fire-intervals, amongst areas that have not been burned for many years. This recommendation for fire management does reflect the current state of burn history in the areas surveyed at CFB Shilo and in the surrounding region; that is, there exist habitats with varied burn histories (1, 2 and 7 years post-fire) and includes areas that have not been burned for many years (40). However, the burn histories in CFB Shilo have been a result of infrequent accidental fires, and outside of Shilo only one area had a managed fire. A fire regime that involve controlled burns (and do not rely on accidental fires) that maintain this diversity in burn history is therefore advised. Because Sprague's pipit avoids area that have been recently burned (Pylypec 1991, White 2010), it would appear

that it would be more beneficial to have habitats in a variety of successional stages to ensure suitable habitat is available for the pipit.

6.2 CFB Shilo compared with surrounding grasslands

In CFB Shilo, the mean densities of Sprague's pipit were higher than the densities in the surrounding study sites for both years of the study. CFB Shilo has a higher incidence of accidental fires, as well as controlled fires, due to the nature of their environmental management requirements to support military training. While the results of this study suggest this is not detrimental to pipits, they also suggest that more frequent burns do not benefit pipits. This raises the question, then, regarding why density of Sprague's pipit is higher on Shilo than in the surrounding region.

Relative to the surrounding study sites, CFB Shilo is a large contiguous tract of mixed-grass prairie. Davis (2004) determined that Sprague's pipit were area sensitive, requiring a patch size no less than 145 hectares. Koper et al. (2009) also found that Sprague's pipit were sensitive to distance to grassland edge. CFB Shilo is surrounded by cropland, roads and hayfields, as well as the boundaries of the aspen parkland from Spruce Woods Provincial Park. While pipits are sensitive to grassland edge, this suggests that CFB Shilo is sufficiently large to support a greater population of Sprague's pipit without significant edge effects. Because of the nature of land use in this region, the remaining mixed-grass prairie is only available in small patchy areas outside of CFB Shilo, and perhaps the size of Shilo is simply more attractive to pipits because of the limited availability of suitable habitat type and patch size in the region around Shilo.

6.3 Recommendations for Conservation Management of Sprague's pipit in South-Western Manitoba

The importance of proper conservation management of mixed-grass prairie cannot be understated given the rapid decline of prairie songbird populations. This is especially true for Sprague's pipit because it is a threatened endemic species that continues to experience population declines (Environment Canada 2008, Sauer et al. 2008). Preventing further loss in size and quality of remaining native prairie is a primary goal of habitat management for the conservation of grassland birds (Askins 2007), and this is not an exception in the conservation strategy for Sprague's pipit. One of the recovery goals in the recovery strategy for the Sprague's pipit is to prevent further loss and degradation of native prairie (Environment Canada 2008).

Habitat management is only one factor that may influence habitat selection of grassland songbirds and their distribution, but it is an important factor in mitigating threats to Sprague's pipit habitat. With conservation in mind, an adaptive management approach for this area should begin with establishing a long-term monitoring program for baseline data on grassland songbirds and habitat structure. Baseline data is essential for making management decisions in the future (Herkert and Knopf 1998), and this data appears to be lacking for this region. At the time of this study, it was not clear whether monitoring programs had been firmly established in CFB Shilo and elsewhere.

In CFB Shilo, I would strongly recommend monitoring pipit distributions across a broad range of areas within the training area, ensuring that many of the areas actively used for training are also sampled, since these sites tend to experience more frequent burns in preparation for and as a result of live-fire training. This would enable Shilo to

develop a better sense of how pipits are using the habitat over time, and could possibly enable the development of habitat-use models if enough data were consistently gathered.

A prescribed burning regime should also be established, although as previously stated, recommendations for burn frequencies are beyond the scope of this study. With the prescribed burn regime, I would recommend monitoring the intensity and completeness of burns as well as maintaining detailed records of the size of burn and the time of year of burns. Maintaining digital records of burns is also advised.

Conservation management must also consider the community response to management decisions. To maximize community diversity, Collins and Barber (1986) suggest an environment must be exposed to a natural disturbance regime. Umbanhowar (1996) also recommends managers incorporate a varied fire frequency in prairie sites. This recommendation would contribute towards conservation of Sprague's pipit by ensuring that grasslands were maintained in an early successional stage by fire, but that sufficient habitat would also be available to pipits displaced by recent fires.

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APPENDICES

Appendix I – Average total invertebrate species abundance found per transect in June and July 2007 per 100-m plot (3.2ha) in CFB Shilo, south-western Manitoba.

Area	Transect	Mean	Standard Deviation	Min	Max	Time Since Burn (years)
Area A	1A	444.75	106.84	326	585	40
Area B	1B1	2053.75	2033.467	281	4830	2
Area B	1B2	1208	700.75	746	2252	40
Area 2	2A	785.25	292.86	533	1206	40
Area 2	2B	561	138.09	461	759	40
Area 2	2C	580.75	128.87	421	734	40
Area 3	301	655.50	156.55	439	799	7
Area 3	311	997.25	230.76	769	1308	7
Area 4	411	1136.50	402.13	682	1652	40
Area 4	421	693.50	171.67	563	931	40
Area D	D01	733	46.53	668	777	40
Area E	D22	1253.50	304.76	1038	1469	2
Area D	D31	1414.25	800.52	623	2496	1
Area E	E01	1060.50	375.38	566	1479	19

Appendix II – Average total invertebrate species order richness found per transect in June and July 2007 per 100-m plot (3.2ha) in CFB Shilo, south-western Manitoba.

Area	Transect	Mean	Standard Deviation	Min	Max	Time Since Burn (years)
Area A	1A	70.5	80.97	4	170	40
Area B	1B1	109.25	139.13	6	301	2
Area B	1B2	81.25	99.95	6	217	40
Area 2	2A	64.00	66.84	6	131	40
Area 2	2B	59.25	70.60	6	155	40
Area 2	2C	49.25	48.78	7	92	40
Area 3	301	46.25	46.01	6	90	7
Area 3	311	58.00	63.01	6	135	7
Area 4	411	47.50	48.54	5	92	40
Area 4	421	45.00	45.76	5	89	40
Area D	D01	45.50	45.73	6	89	40
Area E	D22	42.50	51.62	6	79	2
Area D	D31	56.00	59.36	7	127	1
Area E	E01	45.50	44.64	7	89	19

Appendix III. Invertebrate Abundance by Family in June 2007

Area	Transect	Acrididae	Alydidae	Apidae	Carabidae	Chrysomelidae	Cicadellidae	Curculionidae
Area A	1A	4	0	2	32	0	0	1
Area B	1B1	7	5	0	40	0	0	1
Area B	1B2	15	3	0	37	3	3	0
Area 2	2A	18	1	0	70	1	1	0
Area 2	2B	31	0	0	96	0	2	0
Area 2	2C	37	3	1	28	1	0	0
Area 3	301	21	6	0	50	1	0	1
Area 3	311	44	4	1	31	0	1	0
Area 4	411	57	0	1	52	0	0	1
Area 4	421	50	2	0	26	0	0	0
Area D	D01	33	0	0	115	1	0	0
Area E	D22	0	0	0	34	0	0	6
Area D	D31	124	129	0	123	0	0	3
Area E	E01	8	0	0	55	0	1	1

Area	Transect	Elateidae	Formicidae	Gryllidae	Histeridae	Lygidae	Muscidae	Pentatomidae
Area A	1A	10	298	193	1	0	0	0
Area B	1B1	0	759	71	1	0	2	0
Area B	1B2	0	1371	28	0	4	0	0
Area 2	2A	13	297	335	3	0	6	0
Area 2	2B	17	253	193	3	1	0	3
Area 2	2C	6	306	309	1	0	2	0
Area 3	301	5	176	173	6	10	0	2
Area 3	311	2	607	389	0	9	0	6
Area 4	411	17	1253	396	4	0	0	0
Area 4	421	3	639	353	1	1	0	0
Area D	D01	4	294	481	3	3	0	3
Area E	D22	3	60	140	0	0	0	1
Area D	D31	19	397	56	3	43	0	0
Area E	E01	29	686	301	1	0	0	7

Area	Transect	Scarabaeidae	Scutelleridae	Silphidae	Staphylinidae	Tenebrionidae	Tetrigidae
Area A	1A	8	0	4	4	8	0
Area B	1B1	31	1	2	2	11	0
Area B	1B2	60	0	6	1	11	0
Area 2	2A	194	0	7	6	8	2
Area 2	2B	186	0	16	4	6	1
Area 2	2C	275	3	2	2	20	1
Area 3	301	630	0	7	1	14	2
Area 3	311	358	2	23	4	15	0
Area 4	411	249	0	11	2	11	0
Area 4	421	230	50	5	0	5	0
Area D	D01	178	0	6	3	16	0
Area E	D22	376	1	3	0	19	0
Area D	D31	319	1	22	2	19	0
Area E	E01	7	0	4	0	14	0

Appendix IV. Invertebrate Abundance by Family in July 2007

Area	Transect	Acrididae	Alydidae	Carabidae	Cerambycidae	Ceropidae	Chrysomelidae
Area A	1A	88	14	31	1	0	0
Area B	1B1	91	12	98	0	0	0
Area B	1B2	423	2	57	1	0	0
Area 2	2A	88	4	58	1	0	1
Area 2	2B	104	6	51	0	1	2
Area 2	2C	149	2	9	0	0	0
Area 3	301	100	19	17	1	0	1
Area 3	311	209	6	19	0	1	0
Area 4	411	281	3	54	0	0	0
Area 4	421	270	22	11	0	0	0
Area D	D01	302	2	24	0	0	0
Area E	D22	74	0	10	0	0	0
Area D	D31	918	0	63	0	0	1
Area E	E01	148	0	27	0	0	0

Area	Transect	Cicadellidae	Curculionidae	Elateidae	Formicidae	Gryllidae	Histeridae	Lygidae
Area 1	1A	0	4	12	230	386	0	1
Area B	1B1	2	1	6	2637	3528	1	136
Area B	1B2	0	1	7	520	1502	0	2
Area 2	2A	0	8	8	533	991	1	6
Area 2	2B	1	4	16	509	424	0	2
Area 2	2C	0	0	6	322	393	0	1
Area 3	301	0	1	9	518	213	0	7
Area 3	311	1	4	45	1262	283	4	7
Area 4	411	0	0	10	1029	566	0	1
Area 4	421	0	1	5	542	224	0	0
Area D	D01	0	0	5	624	337	0	0
Area E	D22	0	0	0	244	99	1	0
Area D	D31	0	1	7	2127	319	0	50
Area E	E01	2	2	17	1097	203	0	0

Area	Transect	Mutillidae	Otitidae	Pentatomidae	Scarabaeidae	Scutelleridae	Silphidae
Area 1	1A	3	7	3	53	12	90
Area B	1B1	2	0	1	391	0	52
Area B	1B2	0	0	1	387	1	73
Area 2	2A	1	0	0	92	1	53
Area 2	2B	0	0	1	9	1	24
Area 2	2C	2	0	2	123	7	45
Area 3	301	3	0	4	39	4	26
Area 3	311	1	0	5	124	5	72
Area 4	411	1	0	1	25	1	129
Area 4	421	1	0	9	15	58	75
Area D	D01	0	0	0	0	1	8
Area E	D22	0	0	0	23	6	32
Area D	D31	0	0	5	96	1	199
Area E	E01	1	4	7	0	0	55

Area	Transect	Staphylinidae	Tenebrionidae	Tetrigidae	Tettigoniidae
Area 1	1A	2	47	0	1
Area B	1B1	0	99	1	1
Area B	1B2	0	163	0	24
Area 2	2A	1	28	2	0
Area 2	2B	0	19	0	1
Area 2	2C	3	69	0	0
Area 3	301	0	54	1	1
Area 3	311	6	48	1	0
Area 4	411	0	46	0	3
Area 4	421	0	8	0	4
Area D	D01	0	109	0	2
Area E	D22	0	28	0	0
Area D	D31	0	57	0	12
Area E	E01	0	10	0	0