# THE EFFECTS OF LIVESTOCK GRAZING ON VEGETATION AND LEPIDOPTERANS IN ENDANGERED ALVAR SITES IN MANITOBA'S INTERLAKE

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# Abstract

Alvar is a globally rare type of ecosystem characterized by open, flat, windy terrain that experience dry summers and frozen winters, and by incomplete vegetation dominated by shrubs, grasses, and herbs intermixed with patches of exposed calcareous pavement. Alvars often contain unique limestone land formations, and are hot spots for biodiversity, containing potentially species rich plant and animal communities. In Manitoba alvar supports a mixture of tall grass prairie and boreal forest species that do not grow together in any other types of ecosystem and thus alvars make a unique contribution to the biodiversity of the province. Alvars have a restricted geographical distribution and are only found in the temperate boreal regions of northern Europe and North America.

Several sites in the southern Interlake area of Manitoba contain areas identified by the Manitoba Alvar Initiative as true alvars. The Interlake region is sparsely populated and the dominant economic land uses are mining and agriculture. Livestock production is prevalent especially in areas with exposed rock patches and thin soils that are not suitable for crop agriculture. Little is known about the extent and quality of the various alvar sites, or the impacts of anthropogenic activities such as livestock grazing on alvar communities in the Interlake.

Disturbances including domestic grazing may be necessary to maintain diverse alvar plant communities and in European alvars livestock have been used to remove encroaching shrubs and young trees, which can pose a threat to the biotic diversity of alvars. Where alvar vegetation communities are subjected to minimal or no grazing pressure and the absence of fire, alvar may experience a progression in successional stages eventually resulting in a forested eco-system. Intense grazing can cause damage to desired alvar plant species, increased frequency of invasive species, drought susceptibility, nutrient loading, and soil compaction. The effects of grazing in Manitoba's alvar sites have not been thoroughly studied thus there is a need to determine the effects of grazing on these fragile ecosystems.

Indicator species of plants and animals are useful as predictors when comparing the effects of disturbance on ecosystems. Bioindicator studies using indicator species to reflect the impacts of disturbance can be used to determine if natural areas are being

damaged, areas that most need protection and rehabilitation, or indicate if a particular land management strategy is effective. In this study, plants and Lepidopterans were used as indicators of alvar health between grazed and ungrazed areas. Lepidoptera and plants have long evolutionary relationships and may be used as indicators of future changes at higher trophic levels in alvar ecosystems. Changes in Lepidopteran diversity may signal future ecological changes and indicate areas sensitive to anthropogenic habitat disturbance.

I hypothesized that there would be differences in environmental conditions, and in plant and Lepidopteran diversity between grazed and ungrazed sites. The intention of this research was to assist policy makers and land managers determine which alvars should be given top priority for protection and improve the understanding of the effects of grazing.

Assessment of soil and structural variables of the alvar sites showed that soils in grazed sites were significantly more compacted than soils in ungrazed sites. Grazed sites alsa had significantly higher levels of soil nitrate than ungrazed sites, which may be linked to lower plant species richness in grazed alvar sites. The sodium concentration was also significantly higher in grazed sites compared to ungrazed sites and excess levels of sodium, which may lead to soil salinization that may have effects on the growth of certain plant species.

Plant species richness was significantly higher in the ungrazed sites, likely as a result of encroaching forest species. Ungrazed sites had significantly higher numbers of individual trees and trees with larger diameter at breast height. Ungrazed sites supported a variety of shade-tolerant plant species that were less prevalent in the grazed sites. Grazed sites were associated with invasive grasses, and shade intolerant/grazing tolerant plant species. There was considerable variation between grazed alvar sites in the plant community composition on a landscape level. Ungrazed sites were more uniform in plant species and several indicator species for each treatment types were identified.

There were fewer trends in associations of specific butterfly or moth species between grazed or ungrazed alvars. Rarefied moth species richness was significantly higher in the ungrazed alvars. The butterflies appeared to be more closely associated than moths to the presence of their larval and nectar hosts. Feeding guild analysis of moth taxa

indicated a higher proportion of tree and shrub feeders, and generalist species in ungrazed sites, while grazed sites had a higher proportion of shrub/ground specialist species.

The grazing pressure on the alvars in this study was considered to be on the low end of the scale of grazing intensity. While effects of grazing were found for some plants and Lepidopterans, the best management strategy for the short-term is to ensure future grazing is maintained at a low intensity, and perhaps time graze later in the season to maximize Lepidopteran access to nectar resources. All grazed alvars should be subject to regular soil tests to monitor the levels of compaction, nitrate and sodium, as these variables can be damaging to the plant community when in excess, and may have indirect effects on Lepidoptera well.

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# Chapter 1

# Introduction

Alvar is a globally rare type of ecosystem with naturally open terrain dominated by shrubs and grasses, and discontinuous soil over limestone pavement, which typically experience seasonal flooding and drought conditions (Catling 2014, NatureServe 2014, Catling 2016). Alvar vegetation tends to be dominated by shrubs, grasses, herbs, lichens and mosses, with patches of exposed calcareous pavement and very few trees (<60%) (Bouchard 1997, Eriksson & Rosen 2008, NatureServe 2014). Alvars are unique in that they are hybrid communities that combine elements of the boreal forest and prairie grasslands, though the environment is inhospitable to some forest species due to the thin soil mantle (Stephenson 1983, Catling 2016). Alvars often support diverse plant and animal communities, including rare species and species that have developed specialized strategies to exploit the harsh environment, and therefore alvars make a unique contribution to global biodiversity (Eriksson & Rosen 2008). There are threatened species of bird, insect, vascular plant, moss, lichen and fungi found in alvars, which are either linked with or confined to alvar habitats around the world (Eriksson & Rosen 2008). In Canada, alvars support several species that are globally, federally and/or provincially listed as “at risk”. Many alvar species have been given provincial conservation status “S” rankings from S1 (very rare) - S3 (uncommon) indicating potential vulnerability to extirpation in Manitoba (Catling et al. 2014).

Alvars occur over limestone bedrock which can vary widely in hardness, with harder rock formations weathering at a slower rate and soft rock eroding quickly, resulting in unique formations such as sinkholes, cliffs and caves (Reschke et al. 1999). Manitoba’s alvars are part of the Narcisse, Fairford, Hilbre, and Hodgson soil series and all of these soil series’ are based on limestone bedrocks or strongly calcareous glacial alluvium deposits (Government of Manitoba 2010). Inland limestone cliffs, such as those found at the margins of the Mable Ridge alvar in Manitoba are rare, hotspots for biodiversity especially rare plant species (MAI 2012). These rock deposits are particularly valuable from a conservation perspective, but they are also economically desirable. The Interlake region of Manitoba where alvars occur is sparsely populated and the dominant land uses are mining and agriculture. Livestock production is prevalent especially in areas with poor soil quality and exposed rock surfaces that are not suitable for crops (MAI 2012). However if grazing activities are too intense they can have harmful effects on fragile alvar habitat, such as removing plants and trampling plants and soil (Titlyanova et al. 1988, Eriksson & Rosen 2008). Rusch (1988) suggested that alvar grasslands are of interest to ecologists who wish to understand the ecological mechanisms that support their high species richness and the impact of economic activities.

Alvars have a restricted geographical distribution in temperate boreal regions of the Northern hemisphere above the glacial boundary, and are distributed across northern Europe and to a lesser extent in North America (Catling 2016). Belcher (1992) noted that there is a high degree of variation in the species composition between alvars within Canada and in Europe, indicating the need to protect examples of alvars in each region. Nordic alvars near Oland, Sweden (56°44′N 16°40′E) experience a semi-continental oceanic climate, average yearly precipitation of 420 mm, and mean monthly temperatures ranging from 0.3°C in January to 19°C in July (SMHI & Sweden Environmental Protection Agency 2018). By comparison alvars in Manitoba (51°4′59″N 97°37′12″W) experience a sub-humid, cool continental climate, average yearly precipitation of 511mm, and average monthly temperatures ranging from -18.8°C in January to 18.5°C in July (Environment Canada 2018). Several alvar sites in the southern Interlake area of Manitoba have been recently surveyed and confirmed to be alvar by experts with the Manitoba Alvar Initiative (MAI 2012).

Alvar makes a unique contribution to the biodiversity of the Interlake area but little is known about the extent and quality of the various alvar sites in Manitoba, or the impacts of activities such as livestock grazing on alvar communities (MAI 2012). Manitoba Sustainable Deveopment is taking steps towards the protection of representative alvars in Manitoba under the recently amended provincial Endangered Species and Ecosystems Act (2014). Alvar is currently listed as an Endangered ecosystem under this legislation, however this designation alone does not guarantee enforceable legal protection. Only after Protected Zones are designated will specific alvars be legally protected from industrial or residential development and then management plans can be written and acted upon to ensure the long-term maintenance of this rare and fragile ecosystem. Although general features of alvars have been described in Manitoba (Hamel and Foster 2004, MAI 2012), the effects of management activities including domestic grazing, on alvar in Manitoba are unknown. Grazing has been demonstrated to be necessary for the maintenance of diverse alvar communities in Europe, as cattle and other livestock remove encroaching shrubs and trees, which may otherwise pose a threat to the characteristically open, tree-less alvars (Eriksson & Rosen 2008). Catling (2016) briefly studied vegetation on opposite sides of a fence-line dividing grazed and ungrazed alvar at two sites in Manitoba, and found grazing had a strong impact on the plant community composition.

The goals of this study were to assess the overall ecosystem quality of alvar sites in Manitoba and to compare grazed and ungrazed alvar sites in order to determine the effects of grazing on the soils, plants and Lepidoptera. The main objective was to examine differences in the plant and Lepidopteran (butterfly and moth) communities, and the physical characteristics between individual sites and between grazed and ungrazed alvars to determine how they differ. By comparing the diversity of the vegetative community and using butterflies and moths as indicators of different trophic levels of the animal community, the objectives of this study were:

- Improve the understanding of alvar ecosystem quality in Manitoba's Interlake
- Inventory the vegetation community and the Lepidopterans (butterflies and moths) in alvar communities both grazed and ungrazed by livestock
- Measure abiotic (ground surface and soil) conditions to assist in determining grazing impacts
- Determine if differences exist in plant and insect associations and diversity, or environmental conditions between grazed and ungrazed treatments and specify what those differences are

# Chapter 2

# Literature Review

## 2.0 Overview

An alvar is defined by the MAI (2012) as a “globally uncommon ecological community characterized by a thin or absent layer of soil over a limestone or dolomite bedrock.” Alvar means ‘unproductive land’ in Swedish and is described as a rock barren ecosystem with specific environmental conditions and ecological processes (Catling 2016). Alvar is characterized by open, flat, windy meadows with incomplete vegetation cover that experience dry summers and frozen winters. The alvar bedrock resists drainage and retention of water, and causes occasional flood and drought conditions which result in a unique biotic community of plants, lichen and bryophytes (MAI 2012). The alvar ecosystem in Manitoba is considered particularly unique due to the characteristic blending of boreal forest, aspen parkland and tall grass prairie species (Reschke et al. 1999). Plant communities of alvar are rich in species, the MAI (2012) found upwards of 150 species of plants in Manitoba’s alvars, and many of these species have adapted to the harsh conditions experienced by alvar (Eriksson & Rosen 2008). Catling (2009) explained that the alvar ecosystem type is similar to limestone tundra, but alvar is distinct because it exists as part of a mosaic within a forested landscape. There are five ecological processes that greatly influence the alvar communities of Ontario (Reschke et al. 1999), these include: hydrology, soil factors (chemistry, depth and moisture), fire regimes, herbivory, and invasive species.

Alvars are characteristically flat and have poor drainage capacity, which results in the formation of permanent and ephemeral pools and larger wetlands in some areas while other areas remain dry and tundra-like (Eriksson & Rosen 2008). Limestone produces fine textured soils that hold moisture near the surface, but lose moisture easily to evaporation in comparison to coarser granite based soils (Wentworth 1981). Alvars can be classified into two types: those that resemble grasslands (including shrublands and wetlands), and those that are sparsely vegetated pavements. Grassland type alvars are wetter and flood seasonally, while alvar pavements are drier and do not flood regularly. The capacity of soil to hold water is reduced when the profile is thin, because there are fewer spaces between soil particles to hold water. Limestone is high in calcium and magnesium (Wentworth 1981). Reschke et al. (1999) found that generally alvar soils become saturated with rainfall and then dry out slowly until desiccated. Most alvars experience wet conditions in the spring and fall which are interrupted in July and August with a period of drought at which all ponding ends and the wilting point for the vegetation may be reached (Reschke et al. 1999). Surface temperatures on some exposed rock alvars can reach very high temperatures (ie. 50ºC), which can lead to total desiccation of the ecosystem (Reschke et al. 1999).

## 2.1 Distribution

Alvar can be found around the globe in the boreal forest eco-zone, in Europe, North America and Asia. Alvar in Europe is limited to the Baltic region: Sweden, Estonia, Finland and Russia in Asia, with 58% of all alvar globally found in only one 15,089 ha site on Oland Island, southeast of Sweden (Stephenson 1983, Reschke et al. 1999, Eriksson & Rosen, 2008). The majority of North American alvars are located on post-glacial plateau areas with prolonged summer drought conditions (Corkery 1996, Catling 2016). Alvar sites occur adjacent to the Great Lakes in Ontario, and in Quebec, New York State, Michigan, Vermont and Ohio (Stephenson 1983, Bouchard 1997, Reschke et al. 1999). In Canada, alvars exist in a fragmented distribution along the edges of the Canadian Shield from Newfoundland to the Northwest Territories (Catling 2009). Alvars can be found in Newfoundland, PEI, Quebec, Ontario, Manitoba and the Northwest Territories (Catling et al. 2014). There are several alvar sites in Manitoba's Interlake region, concentrated midway between the southern basins of Lakes Winnipeg and Manitoba. The most studied alvars in Canada are in Ontario, located on the Bruce Peninsula, Pelee Island, the Burnt Lands, Manitoulin Island and near Kingston (Catling 2009, Catling et al. 2014), while other Canadian alvars have received less academic attention. In Great Britain and Ireland limestone barrens, an alvar-like ecosystem, are protected by Limestone Pavement Orders and designated as Areas of Special Scientific Interest, in order to conserve wildlife and geology (Limestone Pavement Conservation 2013). Alvar on Drummond Island, Michigan contains treeless areas that are reminiscent of alvar grasslands and research suggests that these alvar sites have never been forested and represent stable communities that are resistant to tree and shrub encroachment and colonization by invasive species (Stephenson 1983).

## 2.2 Natural history

The Manitoba Interlake area is located over limestone parent material that was deposited during the Paleozoic era during both the Silurian (west Interlake) and Ordovician (east Interlake) periods (Corkery 1996). Alvars have formed primarily in areas of the world that were covered by glaciers during the last Ice Age; the advance of these glaciers scraped away most of the soils and left some areas with thin calcareous soils and exposed limestone pavement. During the Pleistocene glaciation period the Laurentide and Cordilleran ice sheets covered most of Canada and parts of the United States and the scouring action of the heavy masses of ice produced areas of flat topography (Catling 2016). Alvars around the world are relic post-glacial ecosystems, which have formed in areas where glacial scouring and sedimentation by glacial lakes that occurred following the retreat of the glaciers (Corkery 1996). Over time a tundra landscape developed with characteristic cold winters and very dry summers (Eriksson & Rosen 2008). Eventually many of these areas became forested as the soil mantle re-developed and only few prairie-like areas unsuitable for tree growth remained (Bouchard 1997). These remaining, relatively thin soiled grassland areas developed into modern alvars, which resemble the related prairie habitats, indicating that alvar could be remnants of historical prairie ecosystems (Reschke et al. 1999).

Alvars are maintained long-term by disturbances that remove the encroaching shrubs and trees, which tend to encroach on alvar at the forest edges. Alvars have been naturally maintained since the post-glacial period as a result of the limiting environmental factors as well as periodic fires, drought and flooding (Catling 2014). The thinner alvar soils are more susceptible to natural disturbances such as erosion, drought, wildfire and flooding than thick soils (Leppik et al. 2013). Certain alvars may have been be created by fires, and Reschke et al. (1999) reported that some present day alvars were previously identified as forested in historical land surveys, and have since been burned by wildfires. However many alvar sites show no evidence of fire and have existed for long periods of time indicated by the ancient trees present (Reschke et al. 1999). Flooding in alvars occurs when precipitation and snowmelt do not drain and then form pools over impermeable rock, which results in the die off of woody species allowing other types of plants to increasingly invade (Partel et al. 1999). Catling (2014) concluded that regular flood and drought periods may neutralize the threat of woody species encroachment in alvar grasslands, together with regular wild fires. Drought also promotes fires by creating drier conditions and increasing fuel (like downed woody debris) (Catling 2014).

Thin soils, such as those found in alvars, are more drought-prone than thicker soils because the water is held closer to the surface and thus is more easily evaporated. Drought can cause 10-100% mortality of woody species in alvar meadows and actually helps maintain high biodiversity of herbaceous plants and grasses, which can be attributed to inconsistency in soil depth and topography (Catling 2014, Catling 2016). The distribution and abundance of plants are diagnostic of environmental conditions; for example dry, alvar habitats are dominated by drought tolerant herbaceous plants that have adapted to dry conditions over time (Catling 2016). Catling (2014) estimated that the Burnt Lands alvar in Ontario has experienced periodic droughts killing 50% of woody individuals at intervals of about 30 years, thus preventing shrub encroachment. Catling (2014) found that some of the junipers killed in the Burnt Lands alvars were up to 90 year in age and had survived many droughts previous to 2012 when they died.

## 2.3 Vegetation diversity

Alvars in Manitoba support a unique vegetation community including plants with "phyto-geographical origins including Arctic, Cordilleran, boreal, prairie and Eastern mixed-wood deciduous forest plant assemblages" (Catling et al. 2014). Catling (2016) found that moisture regime, soil depth, topography, percent bare rock cover and disturbance (grazing) are the most important environmental factors affecting vegetation composition in Manitoba alvars. Certain plant species are specialized to specific habitat and microclimate niches that vary in moisture availability, soil depth and shade level (Catling, 2016). In Manitoba alvar communities exist mainly as grassland and shrubland types, vegetation in grassland alvar types is dominated by prairie plant species, while shrubland types are dominated by boreal plant species (NatureServe 2014, Catling 2016).

Plants provide an essential resource base for small herbivores such as invertebrates, amphibians, reptiles, birds, and small mammals (Damhoureyeh and Hartnett 1997).

### 2.3.1 Trees & shrubs

Alvars characteristically have less than 60% tree cover (Reschke et al. 1999) and alvar trees often exhibit stunted growth, as trees do not have enough resources to grow large in most alvar habitats. The deeper cracks in the pavement (up to 30cm) help create a mosaic of environmental conditions within alvars by allowing the growth of some trees and more forest plant species (Catling 2016). Tree growth in rock fissures threatens alvar because the fissure will be widened further and the development of an organic layer at the surface over time results in a deeper soil, increasing the likelihood the alvar will transition into woodland. Most alvar community types studied by Jones and Reschke (2005) had a stable boundary between alvar and woodland attributed to the edaphic factors such as a thin soil mantle or biotic factors such as competition with grasses. Primary tree species that can be found in alvars in Manitoba are Trembling aspen, *Populus tremuloides* Michx (severely restricted by soil depth), White spruce, *Picea glauca* (Moench) Voss and Bur oak, *Quercus macrocarpa* Michx, which are limited to stunted clumps.

In Manitoba the dominant species of shrubs present are Shrubby Cinquefoil *Dasiphora fruticosa* L., Creeping Juniper *Juniperus horizontalis* Moench, and Common Juniper *Juniperus communis* L. Other less dominant shrubs that may be present include: Common Bearberry *Arctostaphylos uva-ursi* L., *Rhus* species (Sumac), Chokecherry *Prunus Virginiana* L., and Western Snowberry *Symphoricarpos occidentalis* Hook (Hamel & Foster 2004). Junipers and Shrubby Cinquefoil often encroach on alvar sites in the absence of management intervention (grazing or mechanical clearing), or possibly due to fire suppression. In Nordic alvars, juniper grew on drier soils while Cinquefoil was more frequent on wetter soil types (Rejmanek & Rosen 1988). Leppik et al. (2013) has used the percentage cover of creeping juniper as a general indicator of the overall quality of alvar. There are several management techniques that can be used to control the encroachment of shrubs and trees, or remove a dense shrub canopy, which are discussed in upcoming sections.

### 2.3.2 Understory vegetation

Nordic alvar habitat is known to support a wide range of plant communities, and a rich plant community is essential to support a diverse array of animal species (Eriksson & Rosen 2008). The Manitoba Interlake alvar communities are able to support a wide range of species and there are several distinct types of alvar, which provide many habitat niches and high levels of biodiversity (MAI 2012). Alvar supports a mixture of boreal forest and prairie plants that are not commonly associated with one another in either forest or grassland ecosystems (MAI 2012). Each distinct type of alvar (grassland, shrubland, savannah and wetland) has a unique plant species composition. Belcher (1992) compared alvar from various sites in the Great Lakes region and found that plant species composition was positively correlated to both soil depth and plant biomass.

High species richness persists even at relatively small scales within Nordic alvars due to the diversity of mosses and lichens (Rusch 1988). The low topographic relief and mesic conditions of certain Manitoba alvar sites is an ideal habitat for a number of non-vascular plant species (Caners 2012). An assortment of surfaces, ledges and crevices with varying degrees of humidity and exposure means than there are various microhabitats suitable for mosses, lichens, and liverworts with differing life requirements within Manitoba's alvar sites (Caners 2012). Caners (2012) reported that the presence of some areas in alvars with a closed tree or shrub canopy are important because they create areas of cooler temperatures necessary for some species of non-vascular plants. Leppik et al. (2013) found that species richness of mosses and lichens in Northern Europe decreases with increasing density of herbaceous plants and due to reduced diversity of microhabitats available to smaller, non-vascular species.

A listing of all plant species found to date in Manitoba alvars has been developed including their current NatureServe rankings and level of rarity, adapted from information in the MAI report (Appendix 1, Table 2). Reschke et al. (1999) suggested the native plant and insect diversity (especially those confined to alvars) maybe used as site quality indicators in the Great Lakes alvars.

## 2.4 Bioindicators

A widely cited definition of biological diversity, or biodiversity, is "the variety and variability among living organisms and the ecological complexes in which they occur" (Noss 1990) and there are many different measures of biodiversity. Biodiversity in plants is a result of species adaptations to the variation in climatic and soil gradients, slope/aspect, elevation/topography, latitude, and geology, and diverse plant communities result in diverse animal communities and ecosystems (Kimmins 1997). Maintenance of biodiversity is frequently a top goal of conservation management practices (Kimmins 1997, Ober & Hayes 2010) and monitoring indicators of biodiversity is useful as a predictive method to reduce future loss of biodiversity, which is a key aspect in the adaptive management cycle (Noss 1990, Kremen 1993, Dengler 2009).

Indicator species are useful as predictors when comparing similar site types and help distinguish differences between treatment types when comparing diversity (Dufrene & Legendre 1997). Noss (1990) recommended monitoring biological indicator species as part of a comprehensive strategy that focuses on key habitat structural elements in addition to species assessments. Biological indicators, or bioindicators, are used in ecological studies when sampling a wide variety of animals is not feasible; instead researchers focus on a few select groups of species. Measurable indicator species or assemblages can be selected to assess the status of biodiversity and monitor ecosystem change (Noss 1990). Bioindicator studies can be used to determine areas at significant risk of impoverishment (Noss 1990), indicating those sites that most need protection and rehabilitation.

While a few indicator species may be valuable in comparing between communities quickly, conservation research may be more beneficial when it involves observing community level assemblages, such as a community of plants or insects (New 2004). Species or taxa that make useful indicators are those: which are taxonomically well defined, easy to collect, specialized for their habitat, with stable populations (in undisturbed areas) and a known general life history (Bouchard 1997). In order to maximize effectiveness, ecosystem monitoring should include some animal species along with the monitoring of the plant community (Taylor and Doran 2001).

### 2.4.1 Invertebrates: Insect Bioindicators

Terrestrial invertebrates are a very diverse group of terrestrial animals where they occupy a wide variety of niches and microhabitats and they provide a rich source of data for the improvement of conservation and management planning (Kremen et al. 1993). Diversity develops from various processes including coevolution where patterns of repeated interaction between two ecologically related groups of organisms (plants and herbivores for example) actually alters the organisms over many generations (Ehrlich 1964). Insects make particularly useful bioindicators because they can be found in abundance in all terrestrial habitats, and there is a great diversity of insect species found in habitats with rich plant communities (Bouchard 1997). Insects are a highly diverse taxon and have been widely used in conservation research (Kremen et al. 1993, Buddle et al. 2006, Jonason et al. 2014). Previous studies of invertebrate diversity in the Great Lakes alvars have included spiders (Araneae) and certain insect groups (such as Coleoptera, Lepidoptera, Hymenoptera, etc.) as environmental indicators (Bouchard 1997).

Ehrlich (1964) concluded that plant-herbivore interactions have been very important in the development of terrestrial diversity. Insects can be used as bioindicators that provide “early warnings” of ecological change because they respond more quickly to changes than vertebrates do whereas the detection of vertebrate responses may be too late to implement proactive management strategies (Kremen et al. 1993, Blake et al. 2003). Many insect species are known to associate with just one or few species of host plants, which they depend on for food and shelter, and if these host plants decline so do the insects that depend on them (Shaffers 2008). Shaffers (2008) determined based on surveys in the Netherlands that there is an important link between insect assemblage composition and the local floristic species composition. Lewinsohn et al. (2005) reported a causal relationship between the diversity of host plants and the diversity of the herbivorous insect associated with them based on their metadata review of previous studies. Certain families of Lepidopterans have been used as effective indicators of overall species richness of Lepidopterans and habitat disturbance affecting plants in Eastern North American forest communities (Summerville et al. 2004).

### 2.4.2 Order: Lepidoptera

Lepidoptera are the most diverse and largest order of insects associated primarily with flowering plants, with ~20,000 species of butterflies and ~140,000 species of moths currently named (New 2004). Moths are critically important to biodiversity conservation since they provide key ecological services (Summerville & Crist 2002, Rice & White 2015). Moths in their larval stages are primary consumers that consume vegetation and are an important food resource to species of birds, small mammals, amphibians, and reptiles (Rice & White 2015). The Lepidopteran species function as defoliators, litter decomposers, prey for carnivores and pollinators in vegetated ecosystems, and are thus linked to nutrient cycling, plant population dynamics and predator-prey dynamics (Hammond & Miller 1998, Jonason el al. 2014). Lepidoptera and several other insect Orders have ancestors that evolved simultaneously with the emergence of angiosperms and many Lepidopterans have continued their co-dependent relationship with flowering plants for food and shelter (Ehrlich 1964). Assessing the Lepidopteran community involves studying host resource requirements, including the larval and adult host plants, and understanding the composition of trees, shrubs, herbs, grasses, and lichens (Hammond & Miller 1998).

Like many insects, Lepidopterans are threatened by anthropogenic activities, including habitat loss and fragmentation and agricultural or forestry practices that convert natural vegetation into monoculture crops, and they respond quickly to environmental change due to their dependence on plant hosts (New 2004). The ecology, taxonomy, and distributions of many macro-lepidopteran species are quite well known in comparison to other insects groups. Declines in Lepidopterans can have cascading effects on higher insectivorous animals (Hammond & Miller 1998, Jonason et al. 2014). Lepidopterans (especially larvae) convert plant biomass into animal biomass, which is later consumed by first order carnivores such as birds, amphibians and reptiles (Hammond & Miller 1998). Second order predators, such as hawks, owls, coyotes, and wolves also depend indirectly on Lepidopterans through predation of first order insectivores (Hammond & Miller 1998).

The Lepidoptera are easily collected, diverse, abundant, mobile, and are sensitive to change (Taylor and Doran 2001, Summerville and Crist 2002, New 2004, Summerville et al. 2004, Jonason et al. 2014). Hammond and Miller (1998) stated that Lepidopterans in North America may be used as an indicator taxon and combined with their larval and adult host plants can be used as a basis to assess, monitor and compare habitats, communities and ecosystems. The macro-lepidoptera (butterflies and large moth species) are generally more easily assessed and useful to conservation research compared to the lesser understood micro-lepidoptera (New 2004). Butterflies make effective indicator taxa in North American prairie grasslands, while moths make more effective indicators in forested ecosystems (Summerville et al. 2004). Alvars represent a blend of forest and prairie species therefore this study takes into account both butterflies and moths in Manitoba alvars.

Assemblages of insect groups may be evaluated based on their functional groups, which are often characterized by guilds; where one commonly used index is specialist to generalist ratio (Lewinsohn 2005). In Central Europe Leps et al. (1998) found that species with increased feeding specificity more efficiently utilize resources at the expense of narrowing their food supply to fewer food types and these species are often associated with stable, undisturbed habitats (Leps et al. 1998). Generalist species have decreased feeding specificity and this allows them to be more flexible in colonizing habitats and increases their potential food supply, allowing them to take advantage of a greater range of ecological niches.

### 2.5 Conservation

Functioning alvar ecosystems are hotspots for biodiversity, and European nature conservation agencies consider the protection of alvar grasslands essential to halting biodiversity loss (Leppik et al. 2013). The Canadian Botanical Association lists alvar as an “Area of Special Conservation Concern for Plants” and NatureServe (2014) lists the Great Lakes Alvars of Ontario as Globally Imperilled (G1-G3, high risk of extirpation) due to few occurrences, recent widespread declines, threats and other factors. Though they have been listed as Endangered under provincial legislation, none of the alvars in Manitoba are currently under legal protection from development, and conservation management strategies have not yet been developed. The endangered designation means “continued [ecosystem] viability is at serious risk across a significant portion of its range in Manitoba" (ESEA 2014). Two-thirds of alvar in Manitoba is found on Crown Land (2673 hectares), the remaining one-third of Manitoba alvar occurs on privately owned land (1261 hectares) (MAI 2012). Publically owned lands are leased from the government for economic development by ranchers, grazing livestock herds, and for mining and quarrying for valuable natural resources.

The process to recover degraded alvars is often lengthy due to the soil profile and species composition, therefore it is important to focus conservation efforts on preserving the remaining areas and enlarging existing habitat fragments (Leppik et al. 2013). Biodiversity conservation policy in alvars should apply a holistic and integrated management approach given the high species richness and the tendency for alvar to occur as a mosaic with other habitat types (Eriksson & Rosen 2008, Leppik et al. 2013). Hammond and Miller (1998) recommend the maintenance of natural open meadows within a forested landscape and the limitation of livestock grazing in herb-grass dominated communities to preserve richness and abundance of Lepidopterans. Management practices resulting in the removal of certain larval host plant species will also result in a decline in Lepidopterans that depend on those host plants and potentially a decline in first order predator species, and in species higher up the food chain (Hammond & Miller 1998). In Manitoba the goal has been to focus initial conservation efforts on preserving representatives of each alvar type and subtype in the Interlake region (MAI 2012).

### 2.5.1 Woody encroachment

Alvar ecosystems frequently exist as part of a mosaic with forested areas and under certain conditions alvars can be encroached upon by the expansion of trees and shrubs, which may outcompete species dependent on alvar habitat. The closed shrub canopy of ungrazed alvar shrublands/savannah is a hindrance to the germination of many herbaceous, grassland species, which do not tolerate shade (Rusch 1988). This results in the reduction in the biodiversity with continued shrub encroachment. In Maxton Plains, Michigan (an alvar-like ecosystem) *P. tremuloides* is the most important and effective species in terms of woody encroachment, followed by *J. hortizontalis* and *P. glauca* as these species produce seeds easily distributed by animals (Stephenson 1983). Shrubland and savannah alvar types tend to be more susceptible to tree and shrub encroachment than grasslands and pavements, because of the thicker soil and greater availability of resources (Reschke et al. 1999). The areas identified by Rosen (1988) as the most susceptible to colonization and expansion of shrubs and trees in Nordic alvars include the edges of alvar ecosystems, alvar types with relatively deep soil, elevated sandy ridges, fissures or depressions in the bedrock and alvar areas surrounding either permanent or temporary water bodies. Stephenson (1983) reported that the invasion process of shrubs observed in Michigan was slow and sporadic, due to the gap in size-age classes suggesting that the success of seedlings was 'episodic' with high mortality likely during drought periods.

Besides domestic cattle, white-tailed deer are the second most frequent herbivorous species that influence the ecology of Manitoba's alvars. Stephenson (1983) observed that deer browsing along the forest edges (transition zones) was important to stopping encroachment by shrubs and trees in Michigan alvars. Adequate grazing pressure is key to maintaining the open nature of the alvar ecosystem, however additional clearing may be necessary to complement the grazing regime or replace it if grazing is not appropriate (Eriksson & Rosen 2008). Indirect effects of grazing include increased frequency of invasive species, nutrient supplementation and increased off road vehicle use in grazed areas (Rosen 1982, Reschke et al. 1999). Inadequate or no grazing pressure creates the need for mechanical clearing of shrubs by humans using machinery, which can range from chainsaws to large forestry equipment (Leppik et al. 2013). Rosen (1988) recommended chainsaws only be used to clear shrubs; heavy machinery such as tractors are not recommended due to the fragile nature of the thin soil mantle. If a site has a very high degree of shrub encroachment it may require mechanical clearing to restore the regenerative capacity of the habitat for alvar plant species. Leppik et al. (2013) suggested that the removal (scraping away) of patches of topsoil could be considered a more effective restoration treatment than clearing alone as this provides small disturbances for plant regeneration.

Not all alvars require fire to maintain their open character; some types benefit from regular moderate burns which may occur hundreds of years apart, while others are maintained by grazing or resource limitation alone (Reschke et al. 1999). Controlled burning was found by Reschke et al. (1999) to be beneficial to some types of alvar communities (such as Savannah and Shrubland types) in the Great Lakes, which experience a reduction in shrub and weed cover, and a resurgence of native species post-fire. Previous research has indicated that the majority of Ontario alvars have been burned at some point in their history and that this burning often results in higher biodiversity, but that fire is not necessary to maintain the openness of alvars with relatively thin soils (Jones & Reschke, 2005). There is contradictory evidence regarding the effect of fire on alvar ecosystems, however if this management option is being considered, Catling (2009) recommended any use of fire in managing alvars be done with caution. Catling (2009) also recommended that only small portions of an alvar should be burned at one time to allow the flames to be carefully controlled, and to create a mosaic of habitat with different seral stages represented. Alvar biodiversity can be maximized by maintaining the availability of a gradient of seral stages of alvar habitat (Catling et al. 2010). The higher diversity of vascular plants in burned sites in Ontario is correlated with higher diversity of pollinating insects, because of an increased abundance of nectar and pollen producing herbs and shrubs, food plants for butterfly and moth larva and nesting sites for bees (Taylor & Catling 2011). The use of fire is not appropriate for all types of alvars but can be used successfully to control shrub encroachment and maximize biodiversity of plants and insects. Natural fires should be allowed to burn when possible and controlled burning should not be employed as a management strategy only as a last resort and with caution (Jones and Reschke 2005).

### 2.5.2 Mining & quarrying

Alvar sites are threatened by mining and quarrying activities due to their extensive reserves of limestone and dolomite near the surface. Twenty-six percent of Manitoba alvar is under mining claim or quarry lease (MAI 2012). Gossan Resources Limited has a claim to 6245 ha of land in the southern Interlake area, and 567 ha of the Clematis alvar is part of their Inwood Magnesium Project, which mines for dolomite for building materials via open pit methods (Hamel & Foster 2004). Open pit mining effectively destroys any ecosystem that is present by scraping all biomass and mineral soil away. The Marble Ridge alvar has also been partially affected by mining and quarrying activities and there is evidence of blasting happening directly adjacent to alvar habitat. Certain types of land use, including these destructive mining activities, may actually cause damage even when occurring on land adjacent to alvar (Eriksson & Rosen

2008). The Gastony's cliffbrake *Pellaea gastonyi* Windham., a rare plant species, is threatened by habitat loss due to its preference for the exposed limestone cliffs of some alvars (Friesen & Murray 2015). Mining and quarrying leases pose a great threat to alvars and the species that depend on this habitat.

### 2.5.3 Outdoor recreation

The communities in the vicinity of alvars have potential to expand local economic growth using alvar-based eco-tourism. Examples from the Great Lakes area include wildflower displays and interpretive trails, which attract tourists, naturalists and photographers (Reschke et al. 1999). Alvars tend to attract large numbers of people due to the rich diversity and rare species, and recreation use may cause damage to the vegetation community, in particular small and fragile species of non-vascular plants and rare species (Eriksson & Rosen 2008). The soils found in alvars, like the vegetation communities are fragile and susceptible to increased erosion and compaction from foot or tire traffic. The Clematis alvar in Manitoba is part of a Wildlife Management Area and is used for other types of outdoor recreation, such as hunting, which may involve the use of ATVs and other off road vehicles that are damaging to the fragile soils. Ruts in the thin soil caused by off-road vehicles interfere with the natural soil conditions and these activities should be limited (Reschke et al. 1999) as off road vehicles affect drainage patterns and help to introduce invasive species. Alvar areas should remain accessible to people, however some restrictions to foot and vehicle traffic are necessary to prevent damage to the ecosystem.

Anthropogenic influences on alvars include foot traffic by naturalists and ruts made by the tires of off road vehicles often used by hunters. Alvar soils are susceptible to erosion and Eriksson and Rosen (2008) recommend taking measures to channel visitors, using designated paths (or raised boardwalks) to reduce soil degradation and trampling of vegetation. These boardwalk trails ideally would be educational, with informative signs that identify notable and unique species and features of the ecosystem. Motorized vehicle access to alvar should be kept to a minimum and should be concentrated to existing roads and tracks, or areas with intact vegetation cover (and avoid areas with lichen and bryophyte cover) (Eriksson & Rosen 2008).

### 2.5.4 Climate change

Climate change is already affecting regions all over the globe, with shifting weather patterns and increased frequency of extreme weather events (Pachauri et al. 2014). In northern Europe it has been forecasted that future climate shifts will result in milder winters with shorter frozen periods and more humid summers, which is likely to impact northern plant and animal communities (Eriksson & Rosen, 2008). This predicted shift in conditions would also facilitate the growth of larger plant species and a denser canopy, and the eventual transition of alvars into dense tall grass prairie or boreal forest ecosystems. Livestock are traditionally housed during the four to six months of winter to allow the recovery of the soil and plant community, and Eriksson & Rosen (2008) advise that grazing in the winter months should be avoided. However, milder winters would allow for grazing to occur throughout more of the year, which could control the expansion of trees and shrubs, though it could also result in decreased regeneration by herbaceous species and increased soil damage (Eriksson & Rosen 2008). If winters become milder due to climate change in Manitoba then grazing leaseholders may want to graze their animals during the winter, which may potentially impact alvar grasslands.

## 2.6 Grazing

### 2.6.1 Effects on the plant community

Plant responses to grazing are herbivore and plant species specific and depend on many factors including: native or domestic animals, timing and intensity of defoliation, competition, resource availability, and dietary preferences of the grazers (Damhoureyeh and Hartnett 1997). Plant responses to grazing may lead to impacts on the butterfly and moth communities, if larval food or adult nectar resource plants are affected. Intensive or long-term grazing is incompatible with the health of butterfly populations due to the extensive removal of plant biomass. However productivity studies on grasslands in North America have shown that grazing may increase the overall grassland productivity under certain conditions, though this increase may be short-term (Titlyanova et al. 1988, Damhoureyeh and Hartnett 1997).

Catling (2016) found significant differences between grazed and ungrazed Manitoba alvar areas in terms of plant species composition and functional group composition. In her comparative study Catling (2016) determined that grazed alvar grasslands tend to contain prairie plant species while ungrazed alvars are boreal species dominated. Different alvar community types respond differently to grazing, however some general responses to grazing are expected based on previous work.

*Populous tremuloides*, which frequently encroaches on alvars in Manitoba, was found by Catling (2016) to be more abundant in ungrazed areas, as they are vulnerable to damage from cattle activities. In grazed habitats Catling (2016) observed a significant decline in woody perennials such as *J. horizontalis*, *D. fruticosa* and *A. uva-ursi* while Prairie Cinquefoil *Potentilla pensylvanica* L. ssp. *bipinnatifida* Douglas was more abundant in the grazed plots. *Arctostaphylos uva-ursi* and *J. horizontalis* are often damaged by trampling but are not actually eaten by cattle. Cattle do eat new growth of *Potentilla* spp. and the result is reduced cover but unchanged frequency (Catling 2016). Catling (2016) found that shrubs are increasingly grazed when there is lower cover of graminoids available. In a ten-year study Towne et al. (2005) found that big bluestem *A. gerardii,* prairie Junegrass *K. macrantha,* and annual and perennial forbs, particularly Missouri goldenrod *S. missouriensis* and heath aster *S. ericoides* increased in cover over time in tall grass prairie sites that were grazed by cattle.

Intense grazing reduced native grasses while unpalatable species such as Flat-stemmed Spikerush *Eleocharis elliptica* Kunth var. *compressa* Sullivant and introduced grasses maintain or increase their abundance (Catling 2016). Graminoids observed by Catling (2016) that increased under grazing pressure included Alpine Bluegrass *Poa alpine* L.*,* Creeping Bentgrass *Agrostis stolonifera* L., invasive Kentucky Bluegrass *Poa pratensis* L. and Bendy Ditrichum *Ditrichum flexicaule* Schwägrichen. *Ditrichum flexicaule* is a moss species that prefers open, recently disturbed areas, and this species may expand in distribution following a disturbance such as grazing (Catling 2016). Additionally, herbs such as Canada Thistle *Cirsium arvense* L.*,* Red Clover *Trifolium pratense* L. and Rough Fleabane *Erigeron asper* (Nutt.) were much more abundant in the grazed plots (Rosen 1982, Catling 2016). Catling (2016) found that Prairie Dropseed *Sporobolus heterolepis* A. Gray*,* Upland White Aster *Solidago ptarmicoides* (previously *Oligoneuron album*) Torr. & A. Gray*,* Crawe's Sedge *Carex crawei* Dewey and Smooth Blue Aster *Symphiotrichum laeve* L. were absent in grazed plots, and Northern Bedstraw

*Galium boreale* L.*,* Balsam Ragwort *Packera paupercula* Michx.*,* Rough fescue *Festuca hallii* Vasey*,* Howell's Pussytoes *Antennaria howellii* ssp. *neodioica* Greene*,* Bastard Toadflax *Comandra umbellata* L.*,* Stiff Goldenrod *Oligoneuron rigidum* L.*,* Field Goldenrod *Solidago nemoralis* Aiton, and Wild Bergamot *Monarda fistulosa* L. were greatly reduced in grazed plots. Yellow Lady's Slipper *Cypripedium parviflorum* Salisb. only occurred on the ungrazed side of the shrubland community as the roots of the orchid maybe damaged by trampling (Catling 2016).

Lichens and mosses can provide stability from erosion, drought and nitrogen deficiency, but are particularly sensitive to grazing (Catling 2016). Catling (2016) found grazing decreased the cover of bryophytes and lichens in alvars and while some types of mosses and lichens are more tolerant to grazing, fruticose lichens like *Cladonia* spp. and mosses like *Tortella* spp. and Abietinella Moss *Abietinella abietina* Hedwig were particularly susceptible to damage from grazing and take a long time to recover (Rosen 1982).

Leppik et al. (2013) found that grazing is necessary to create small disturbances in the ground surface, which increases the heterogeneity of the available microhabitats for plants. Grazing produces a vegetation structure that is more open due to the removal of plants and the creation of gaps from trampling, that helps to maintain the richness of species (Rusch 1988). Certain species are able to germinate more frequently in these small, disturbed patches created by the feeding activities and hooves of livestock (Rusch 1988). Grazing is also beneficial to the ecosystem by adding nutrient rich fertilizer and controlling the expansion of trees and shrubs without the use of machinery. The grazed alvars in Manitoba studied by Catling (2016) did not exhibit positive effects from grazing such as increased biodiversity, which could have been due to inappropriate livestock grazing pressure (Catling 2016). Rosen (1982) concluded that anthropogenic livestock grazing in Nordic alvars causes damage to mosses and lichens, vascular plants, shrubs, and ruderal (pasture) species, as well as increasing erosion and nutrient loading. While some of these grazing effects are beneficial, many of them may detrimental to fragile alvar ecosystems.

### 2.6.2 Overgrazing & undergrazing

If alvar vegetation communities are subjected to minimal grazing pressure (and no other form of management), the alvar ecosystem will experience increased plant height and density, organic material will accumulate, more shade tolerant species will migrate into the area, reducing prairie grasses and herbaceous species, and eventually resulting in a forested ecosystem (Eriksson & Rosen 2008). Alvars with dense, tall vegetation such as shrublands and savannahs have a relatively thick soil mantle that makes them more susceptible to shrub encroachment. Alvar ecosystems with relatively thin soil mantles are less vulnerable to encroachment by shrubs and trees than areas of thicker soil, and they may not require grazing as part of the management regime and could be susceptible to the threat of overgrazing.

Overgrazing occurs due to frequent, long-term heavy grazing from early spring to fall each year without giving effective rest periods for the plant community to regenerate (Bailey et al. 2010). Overgrazing decreases the photosynthetic capacity of North American grasslands by removing maturing plants and weakening the regenerative capacity of the ecosystem by degrading the soil (Titlyanova et al. 1988). Overgrazing has several detrimental effects including: prevention of growth (above and below ground) and reproduction of plants, increased susceptibility to drought, and the elimination of species of tall grasses and forbs preferred by cattle (favouring low growing weedy species instead)(Bailey et al. 2010). When plant growth is inhibited by grazing this results in a reduction of the amount of dead plant material contributed to the soil, which increases soil temperature/evapotranspiration, reduces water infiltration, increases soil compaction and reduces the amount of shade available for seedlings (Bailey et al. 2010). Increased soil compaction that occurred as a result of long-term cattle grazing may affect vertical water distribution and this increases the vulnerability of butterfly larvae to desiccation in late summer (Royer et al. 2008).

The repeated trampling by livestock compromises the integrity of alvar soils, especially in areas with a relatively thin soil mantle, and therefore these areas are the most vulnerable (Leppik et al. 2013). Overgrazing also results in the compaction and erosion of alvar soils of all thicknesses (Eriksson & Rosen 2008). Without a satisfactory layer of soil to germinate in and extend roots into, plants are increasingly unable to grow to maturity and reproduce in overgrazed areas. Titlyanova et al. (1988) reported that biomass of vascular plants, mosses and lichens in alvar grasslands are reduced in sites with heavy grazing pressure. Intense grazing can lead to the reduction in abundance of grasses and increases in the abundance of plants which are not favoured by cattle for grazing (Reschke et al. 1999). Large amounts of manure being deposited causes grassland soils to become increasingly nitrogenous, which can be beneficial at first, but if nitrogen levels continue to increase and become too high over time the ecosystem will become dominated by undesirable, nitrophilous ruderal species, which outcompete characteristic alvar species (Titlyanova et al. 1988). Grazing is sometimes necessary to maintain the openness of alvars, however the intensity of grazing needs to remain within a certain range to be effective. The effects of grazing depend on factors such as stocking rate (grazing intensity or pressure), grazing regime, and the duration of the grazing season (Pavlu et al. 2003).

### 2.6.3 Grazing Pressure & Regime

Grazing is the most important land use type to consider in maintaining the quality of Nordic alvars from a conservation perspective, because grazing pressure which is too high or too low represents a major threat to alvar (Eriksson & Rosen 2008). The site-specific response to grazing differs based on the initial site conditions, such as vegetation composition, community type, environment, grazing history and current grazing activity (Catling 2016). Appropriate grazing pressure is especially important in areas that have thicker soils and are prone to the overgrowth of shrubs, while in sites with thin soils this is not as problematic as plant growth is naturally controlled by resource limitation (Eriksson & Rosen 2008). Based on their studies of Oland alvar in Sweden, Eriksson and Rosen (2008) recommend an average grazing intensity (or pressure) of one "animal unit" per 5-6 hectares, with one animal unit representing one adult cow. Grazing pressure in animal unit months (AUM) per hectare is calculated by taking the number of animal units multiplied by the number of months the animals are grazing for, divided by available grazed area (Pavlu et al. 2003). For the Oland alvars, for example, if one animal unit is grazed for five months on five hectares this equals one AUM/hectare. Alvars in Manitoba are primarily grazed by domestic cattle but occasionally horses and bison have been observed grazing on alvar, and these species would represent different relative animal units (MAI 2012). Eriksson and Rosen (2008) recommended against grazing different types of livestock on alvar sites during the same year because fewer species of plants will be left to produce seeds for the following spring, as different types of herbivores have different preferred food species. Optimal grazing pressures for Nordic alvar sites vary within a range of one animal unit per three to ten hectares depending on soil conditions (Eriksson & Rosen 2008).

Long-term, continuous grazing in European alvars decreased the richness and diversity of plant species, while rotational grazing regimes resulted in increased biodiversity (Rosen 1982). Conversely, Pavlu (2003) found that species diversity and abundance were not significantly different between continuous and rotational grazing regimes in European alvars. In rotational grazing regimes, pastures were divided into smaller areas and these are grazed in sequence, followed by a rest period for each pasture (Pavlu et al. 2003). In continuous grazing animals are kept on a pasture area for the duration of the grazing period (Pavlu et al. 2003). In their comparison of continuous and rotational grazing effects on vegetation Pavlu et al. (2003) found that continuous grazing resulted in growth of species that are resistant to frequent defoliation, such as short species of grasses and some herb species, such as those from the genus *Trifolium* (clovers). Rotational grazing promoted the growth of tall grasses that are sensitive to defoliation, and Yarrow *Achillea millefolium* L., *Plantago* species (plantains), and *Ranunculus* species (buttercups) (Pavlu et al. 2003). Continuous grazing was the method generally preferred by ranchers because of its lower capital costs (Pavlu et al. 2003). Alvars that are continuously grazed have less chance to restore the native vegetation therefore rotational grazing is preferable as this gives the ecosystem periods to restore native species (Catling 2016). Catling (2016) recommended lower stocking rates, shorter grazing periods and long recovery periods, using an adaptive management strategy and taking the level of drought into consideration as combined effects of grazing and drought may result in a dramatic decrease in species richness (Pavlu et al. 2003).

### 2.6.4 Invasive Species

The overall level of invasion by non-native species in Manitoba's alvars is low (MAI 2012). However, non-native species might be introduced to the alvar habitat in hay bales brought in to supplement the cattle feed or may be transported in cattle dung from material consumed in other pastures. “Many low-yield meadows and pastures in Czech Republic were ploughed and reseeded with more productive species” (Pavlu et al. 2003), and a similar treatment may have occurred in some alvar meadows in Canada. Less stable and more disturbed alvar sites in the Great Lakes (such as grazed sites) were found by Stephenson (1983) to be more vulnerable to invasion by non-native species. Brownell and Riley (2000) found that in Ontario alvars, long-term grazing led to increased abundance of introduced species and reduced abundance of native species, and Catling (2016) found that same effect in Manitoba’s alvars. Catling (2016) found that long-term cattle grazing significantly increased the frequency and cover of introduced species in Manitoba alvars, while native plant cover was greater in the ungrazed areas. Catling (2016) also found significantly greater species diversity and richness in the grazed plots, which is attributed to the addition of introduced species absent in ungrazed plots. In overgrazed conditions native prairie species are replaced by exotic species, Kentucky bluegrass *P. pratensis*, Canada bluegrass *P. compressa*, and smooth brome *Bromus inermis* (Dana 1997). *Achillea millefolium, T. officinale, P. pratensis, A. stolonifera* and *P. vulgaris* are introduced species with traits that lead to their success in disturbed habitats (Catling 2016). Catling (2016) suggested that introduced species are outcompeting native species for nutrients or the native species are being removed by grazing cattle and replaced by introduced species in some Manitoba alvars. Invasive species found in Manitoba alvars are listed in Appendix 1, Table 3. Protecting, monitoring and restoring, if necessary, the native vegetation community of alvars is important for preserving the unique ecology of alvars in the future (Catling 2016). The effects of grazing on alvars in North America have not been thoroughly studied, and further research is needed to determine the full effects of grazing on alvar communities (Cating 2016).

### 2.7 Problem Statement & Research Questions

Lacking legal protection, and conservation management actions, alvars in Manitoba are vulnerable to both naturally occurring and anthropogenic threats (MAI, 2012). Little is known about which management strategies will be the most effective to maintain the types of alvar found in Manitoba. The goal of the present study is to determine how the agricultural practice of grazing livestock is affecting alvar ecosystems in Manitoba with regard to plant and Lepidopteran diversity, which can be used to examine overall differences in community composition between alvars. The results of the study will contribute to the development of conservation policies for the protection and maintenance of alvar ecosystems and assist decision-makers in designating alvar sites that are of the highest conservation priority.

My research questions were:

1. Does cattle grazing result in differences in the overall composition of the plant and Lepidopteran communities in alvar sites in the Interlake region of Manitoba?
2. Is the occurrence of individual species of plants and Lepidopterans different between grazed and ungrazed alvars?
3. Does grazing by cattle change environmental conditions in alvars that may influence the occurrence and distribution of species in the plant and Lepidopteran community?

### 2.7.1 Approach

The overall approach was to assess the plant and Lepidopteran diversity in ungrazed and grazed alvar sites in central Manitoba, Canada. To assess Lepidopterans as an indicator taxon ultra violet light traps were used to collect samples of the nocturnal moth community (New 2004, Jonason et al. 2014) and insect hand nets were used during daytime surveys for diurnal butterflies (Wittman et al. 2017) in six alvar sites in the Manitoba Interlake region. Physical site characteristics were assessed (assessment of the bare soil and exposed pavement, the depth of litter and soil, as well as soil nutrient analysis). I assessed the plant community at multiple scales by establishing transects through alvar meadows and sampling a ‘nested’ series of quadrats regularly along the length of the transect.

# Chapter 3
# Methods

## 3.1 Study sites & selection

Alvars in Manitoba are found in the southern Interlake region, in the Municipalities of Fisher, Armstrong and Bifrost, which consists of largely agricultural land and aspen parkland. There are several large areas of alvar formations in Manitoba's Interlake region totaling an area of 3930 ha MAI (2012). These alvars are bordered by aspen parkland at all sites and boreal coniferous forest (*P. glauca* and *Pinus banksiana* Lamb.) adjacent to some sites (Catling 2016). The alvars available to be studied in Manitoba's Interlake are located on public Crown lands, and these include alvars referred to as Marble Ridge (A, B and C sections), Clematis, Poplarfield, Peguis and Sylvan by the MAI (2012). Several more alvar areas occur on private land however these were not available for the present study.

I acquired aerial photographs (1:20,000, 5km tiles) from the Manitoba Land Initiative (2015) and GIS layers of Manitoba's Interlake region with various relevant layers (Crown land alvar boundaries, vegetation, hydrology, roads) from Manitoba Sustainable Development (2015). I used a combination of digitized aerial photos and GIS mapping to visually assess the condition and structure of potential alvar sites (Blake et al. 2003), including their accessibility by road prior to field visits. This exploration was followed by physical site visits in 2016 to select the locations of specific study sites within each alvar area for each treatment type (grazed and ungrazed). Study sites were chosen such that all sites were geographically proximal, flat in topography, and are classified into similar alvar vegetation classification types using the classification scheme from the MAI (2012) (Table 2). Aerial photos were used to determine the location of uncultivated openings in the primarily agricultural or forested landscape. Final site locations were chosen in the field in consultation with Manitoba Sustainable Development staff (pers. comm. W. Watkins 2016).

Crown land leases on the alvars in Manitoba have been held for up to 37 years and it is generally assumed that these areas have been grazed for the duration of the lease (Catling, 2016). Alvar site Marble Ridge A shows signs of overgrazing while the B and C parts of Marble Ridge are more moderately grazed (pers. comm. W. Watkins 2016).

Overgrazed sites (like Marble Ridge A) are identified by reduction in plant height, lack of leaf litter, warmer soils, increased soil compaction, high evapotranspiration, and reduced plant root biomass (Bailey et al. 2010). The measurement of grazing intensity used to describe the impact of the livestock in alvars was animal unit months per hectare and the range of grazing pressure was estimated to range from 1.23 to 1.29 per hectare (Table 1). Animal Unit Months (AUM) per hectare was calculated for each site based on personal communications with the leaseholders and followed the standard calculation procedure recommended by the Province of Manitoba Department of Agriculture (2017). The grazing regime used by all leaseholders in the alvars studied was continuous grazing for the duration of the summer months.

The Sylvan alvar has been used for nearly 60 years as a community pasture, which has been heavily grazed by cattle over that time period. I excluded Marble Ridge A and Sylvan as candidates for this study due to these site representing areas that are potentially overgrazed and therefore may differ in structure and composition from the other alvars. Given the large size of the Marble Ridge alvar two lesser grazed sites were chosen in Marble Ridge B and one site in Marble Ridge C. The two Marble Ridge B sites are separated by 2.6 km and the Marble Ridge C site is separated from the B sites by approximately 4.8 km (refer to Figure 1).

The Clematis alvar by comparison is largely free of human disturbance, appearing to not have been used for grazing or cultivation, and is largely free of invasive species (Hamel & Foster, 2004). The Clematis alvar region is more densely vegetated, with many more stunted trees and less exposed bedrock, and it is designated as a Wildlife Management Area (WMA). The Peguis alvar also is mostly free of human influence and it is similar to Clematis in vegetation density with many small trees and shrubs encroaching into alvars from forest edges. Therefore two ungrazed sites were established in Clematis alvar approximately 2.7 km apart, one in the North section of the alvar and one in the south section. The third ungrazed alvar site was established in the Peguis alvar approximately 70 km from the Clematis sites (Figure 1).

After photo and field inspections of the candidate sites I decided to compare three replicates of grazed sites and three replicates of ungrazed sites with the objective of comparing between the sites and between two treatment types. Thus the treatment groups were: Marble Ridge B (two replicates, East and West, denoted MRB-E and MRB-W) and Marble Ridge C (one replicate, denoted MRC) representing the grazed treatment, and Clematis (two replicates, North and South, denoted CLM-N and CLM-S) and Peguis (one replicate, denoted PEG) representing the ungrazed treatment. Further options for candidate sites were not available to increase the number of replicates to four of each treatment (only one alvar was left for consideration, Poplarfield) therefore I decided to proceed using three replicates of each treatment to maintain equal group sizes. Information on the size, vegetation classification, location and treatment for each replicate is shown in Table 1.

Table 1. Summary of selected study sites

| Alvar Site Name | Sub-site | Latitude | Longitude | Total Size (Hectares) | Approx. Area of Site Surveyed ($m^2$) | Treatment | AUM/ Hectare |
|---|---|---|---|---|---|---|---|
| Clematis | | | | 476 | | | |
| | North | N50 37.025 | W97 31.786 | | 348,943 | Ungrazed | |
| | South | N50 35.790 | W97 31.814 | | 351,763 | Ungrazed | |
| Peguis | | N51 13.999 | W97 23.517 | 213 | 281,522 | Ungrazed | |
| Marble Ridge B | | | | 977 | | | |
| | East | N51 06.639 | W97 28.938 | | 328,667 | Grazed | 1.23 |
| | West | N51 05.633 | W97 30.461 | | 237,154 | Grazed | 1.29 |
| Marble Ridge C | | N51 04.083 | W97 27.383 | 647 | 399,768 | Grazed | 1.24 |

Table 2. Vegetation classification of selected sites adapted from MAI (2012). Checkmark indicates the vegetation type was present.

| Site Name | Sub-site | Grassland | Savannah | Shrubland | Wetland |
|---|---|---|---|---|---|
| Clematis | | ☑ | ☑ | ☒ | ☒ |
| | North | | | | |
| | South | | | | |
| Peguis | | ☑ | ☒ | ☑ | ☒ |
| Marble Ridge B | | ☑ | ☒ | ☑ | ☑ |
| | East | | | | |
| | West | | | | |
| Marble Ridge C | | ☑ | ☑ | ☑ | ☒ |

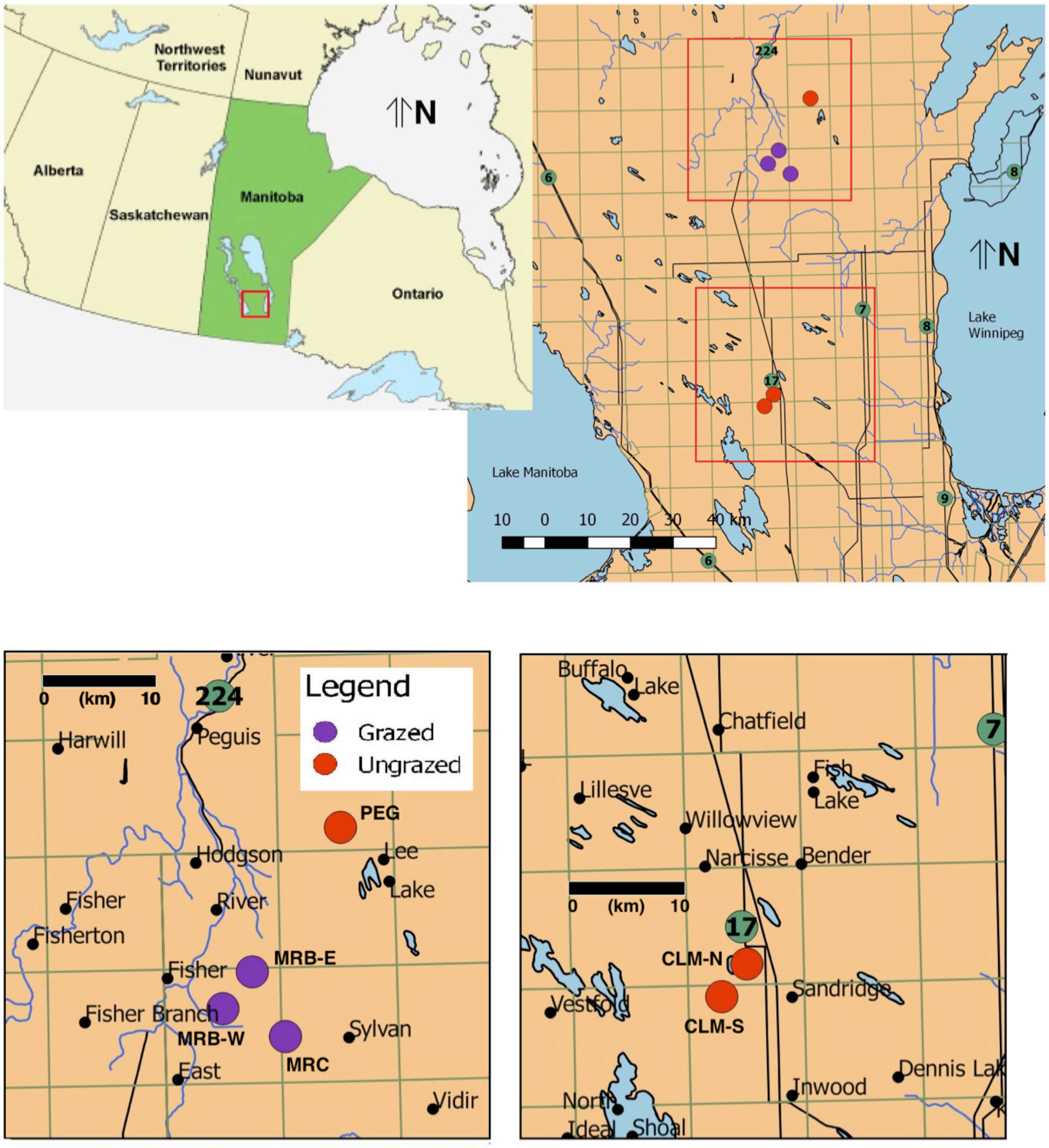

Figure 1. Maps of the Manitoba Interlake area indicating the approximate locations of all Manitoba Crown land alvars

## 3.2 Experimental design & data collection

### 3.2.1 Vegetation and environment

Quadrat sampling is a standard approach for estimating density, number of individuals, biomass and other characteristics of a plant population (Belcher et al 1992, Sanderson 1995, Summerville & Crist 2002, Catling 2009, and Leppik 2013). The standard sampling approach to assess plant diversity measures at multiple scales is to estimate species composition in a series of nested squares or quadrats of varying sizes

(Dengler 2009). For the vegetation assessment two 100 m transects were used as a basis for sampling of trees, shrubs, herbs, graminoids, moss, and lichen, as well as collecting samples of soil and measurements of physical variables. Alvar habitats exist within a forest matrix, transects were established centrally in the most accessible, open (few trees) and largest meadow areas within the sites. Transects were placed in the approximate center of each alvar site to ensure they occupied typical alvar habitat. In two of the sites, transects would have been interrupted by either vehicle tracks (CLMS) or forest edge habitat (PEG) and were instead placed as two 50 m transect lines to avoid these areas, which may have skewed the results if included.

During mid-June 2016 I established a series of ten 10 x 10 m quadrats on alternating sides of each transect line (Figure 2), resulting in 120 quadrat plots in total. Trees and shrubs greater than 3 m tall were counted within each 10 x 10 m plot and measurements were taken for height (using a Model PM-5 clinometer by Suunto) and diameter at breast height (DBH) for each tree. In the absence of trees in the plot, I estimated the distance from the sample plot to the nearest trees/forest edge. Within each 10 x 10 m quadrat, I established a series of smaller quadrats nested in one of the outer corners of the large quadrat (Figure 3), which was randomly selected by coin flip. The first was a 5 x 5 m quadrat in which I counted individual stems of shrub species less than 3 m tall and estimated their percent cover within the quadrat. The next quadrat in the series was 1 x 1 m in size and I estimated the percent cover of each species of herb, forb, and grass present in the quadrat (Figure 4). To survey lichens and mosses, I established a 25 x 25 cm quadrat and estimated the percent cover of moss species and lichens in the quadrat.

Figure 2. Transect and plot layout

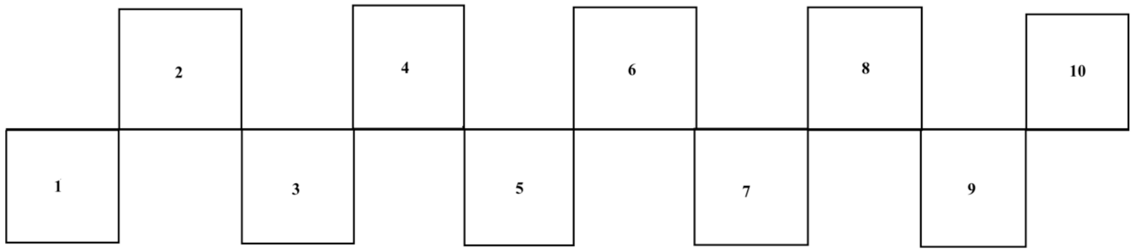

Figure 3. Nested quadrat layout (black square represents the 25 cm square)

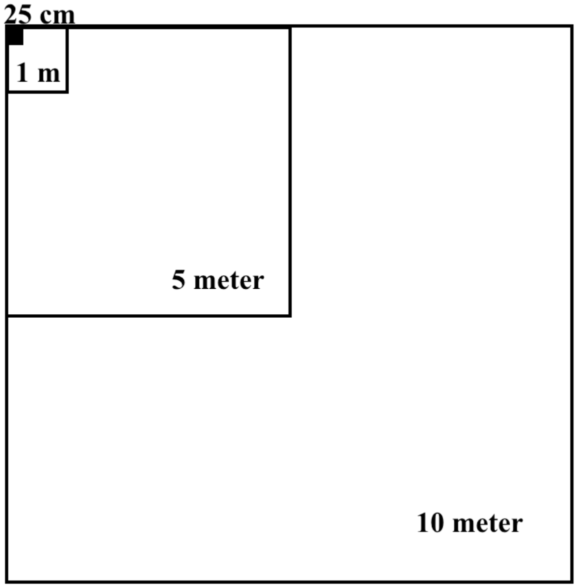

Figure 4. Example of a 5 x 5 m and 1 x 1 m quadrat in the field

Half of the vegetation plots were sampled a second time during the 2016 summer season in mid-August to capture the variation between early summer and late summer plant community composition. Preliminary plant sampling in August showed that few new species were found in the second surveys (less than 25% of quadrats had new species) thus it was decided to survey approximately half of the number of quadrats that were sampled in June to make available further time for butterfly surveys and sampling physical variables such as soil.

Prior to sampling I compiled a list of known alvar vegetation species (Appendix 1) based on previous work by the MAI (2012) and Catling (2016), and created a checklist data sheet with the expected species to record vegetation community survey data in the field. Basic keys and species descriptions in Plants of the Western Boreal Forest and Aspen Parkland by Johnson et al. (1995) were used to make preliminary field identifications. Some specimens observed were not on the checklist or were difficult to identify in the field and were brought in to the laboratory to be identified using Budd's Flora of the Canadian Prairie Province (1979) and further web resources to confirm. Taxonomy was updated after all identifications were made based on the taxonomic authority website Canadensys Vascan (Brouillet et al. 2010).

Various soil variables that may be important to consider in the comparison of grazed and ungrazed alvars included grain size (texture), moisture, soil depth, litter depth, and soil micronutrient/ion composition (Stephenson 1983, Eriksson & Rosen 2008). Various soil variables were measured in each 1 x 1 m sample quadrat plot at the same time as the completion of the vegetation surveys, including litter depth, soil depth, and soil compaction. I recorded the estimated percent ground cover of each plot that was not vegetated, estimating percentages of bare soil and bare pavement separately. The depth of the litter and depth of the mineral soil were measured in two locations at the plot edge and in the center of the plot, using a meter stick to measure the litter and a trowel with depth measurements on the blade to measure the soil (down to the rocky pavement). A soil compaction probe (Pocket Penetrometer from Soil Test Inc.) was used to measure the amount of soil compaction.

Ten samples of soil (~250 mL) were collected from each site using a trowel and returned immediately to the laboratory at University of Winnipeg and frozen. The soil in alvars is very thin, and the samples were taken at a depth of approximately 10 cm. For unbiased moisture analysis, soil samples were collected in all plots within two rain-free days to avoid distortion due to more recent rainfall. The soil samples were stored in the freezer at -30°C until they were transported to and analyzed for moisture content and nutrient composition by Farmer's Edge Laboratories Winnipeg for the "Basic Plus Agricultural Soil Analysis Test" package including analysis of: moisture content, pH, nitrate, phosphate, potassium, sulphate, electrical conductivity, organic matter, calcium, magnesium, sodium, base saturation and cation exchange capacity. Table 3 provides units of measurements used the soil nutrient analysis testing, including the units of measure and the methodology used by Farmer's Edge. Appendix 6 contains the raw environmental variable data for all physical variables measured.

Table 3. Farmer's Edge Basic Plus Soil Analysis Test Summary 2016

| Variable | Nutrient | Units | Method |
|---|---|---|---|
| NO3 | Nitrate | mg/kg | Agitation in Calcium Chloride & Automated Colorimetry |
| PO4 | Phosphate | mg/kg | Olsen's Method & Automated Colorimetry |
| K | Potassium | mg/kg | Agitation in Ammonium Acetate & ICP OES |
| SO4 | Sulfate | mg/kg | Agitation in Calcium Chloride & ICP OES |
| pH | Hydrogen Ion Concentration | none | Saturated Soil-Paste |
| EC | Electrical Conductivity | dS/m | Saturated Soil-Paste |
| OM | Organic Matter | % | Loss-on-Ignition |
| Ca_Calc | Calcium | mg/kg | Agitation in Ammonium Acetate |
| Mg_Calc | Magnesium | mg/kg | Agitation in Ammonium Acetate |
| Na_Calc | Sodium | mg/kg | Agitation in Ammonium Acetate |
| BS Total | Total Base Saturation | % | |
| BS Ca | Base Saturation Calcium | % | |
| BS K | Base Saturation Potassium | % | |
| BS Mg | Base Saturation Magnesium | % | |
| BS Na | Base Saturation Sodium | % | |
| CEC | Cation Exchange Capacity | meq/100g | Sum of Exchangeable Acids and Bases per 100g |

ICP OES = Inductively Coupled Plasma Optical Emission Spectroscopy
Adapted from Carter (1993) and Denning et al. (1998).

### 3.2.2 Lepidopterans: Butterflies and moths

The abundance and diversity of butterfly communities is commonly monitored using surveys during the day, when the temperature of the ectothermic butterflies rises with the temperature of the environment and increasing solar radiation (Wittman et al. 2017). The Pollard's (or Pollard-Yates') transect survey technique is a widely used method used to estimate the relative size of adult butterfly populations, particularly in open habitats, including modified versions developed by Thomas (1983) in Britain and by Brown and Boyce (1998) in Wisconsin. I used a modified version of Pollard's method to obtain regular counts of butterflies throughout the summer in the selected sites as described by Thomas (1983). Thomas (1983) used a version of the Pollard's method in which rather than following a straight transect line through a habitat or site, Thomas surveyed in a zigzag pattern covering a greater surface area of the habitat or site. This type of sampling method was also described by Scott (1986), termed the wander method, in which a surveyor or group of surveyors spend a predetermined amount of time within a predetermined area to sample all the butterflies within the sample area to assess the composition of the butterfly community. The butterfly survey transects surrounded the vegetation community sampling transects. Estimates from Pollard's technique can be applicable for conservation purposes (Thomas 1983), specifically in selecting sites for legal protection.

Typically Pollard's transects are from 1-3 km in length however due to the nature of alvar habitat occurring as a mosaic with treed habitats, I modified this method and used a length of transect that could be accommodated by the existing alvar meadows. During summer 2016 and 2017, from June through August, I conducted timed surveys of alvar areas by wandering within the alvars ~15-25 m to each side of each transect, netting as many individuals as possible, and identifying individuals by sight within 5 m (Thomas 1983, Wittman et al. 2017). Survey efforts were determined by calculating the number of people surveying multiplied by the number of minutes surveying, with surveys consisting of approximately sixty to ninety minutes depending on weather conditions and availability of assistant surveyors. Captured individuals were counted and a few were kept as samples to create a reference collection, or identified upon capture and released (if several samples of the species have previously been collected). Samples were returned to the laboratory and frozen until the identification was confirmed.

These butterfly surveys took place under specific criteria to prevent potential bias as a result of variable environmental conditions. The optimum conditions for maximum butterfly activity by butterflies in the region are temperatures from approximately 17°C - 30°C, less than 90% cloud cover, and winds preferably no higher than 20 km an hour (Scott 1986, Wittman et al. 2017). As wind speeds increase, small, weaker flying species of day flying moths and butterflies decrease in activity first, and larger, stronger flying species are the last to decrease their flight activity when winds are strong (New 2004). The optimal times of day for butterfly surveys are between eleven am and three pm (Wittman et al. 2017). Sampling of Lepidopterans must also be extensive enough to incorporate seasonal variation in the Lepidopterans that have differing flight periods throughout the summer (New 2004) therefore butterfly sampling was repeated on an approximately monthly basis in 2016, increased to an approximately weekly basis throughout the summer field seasons.

Nocturnal, ultraviolet light traps, Luminoc ® brand ultraviolet light moth trap (BIOCOM 1998, DL Model, Figure 5), were used to capture adult moths in alvars. These traps were operated from dusk to dawn each night of the sampling period (late May to early September) with trap activation controlled by photocell sensor that detects light levels. Traps were automatically activated at sunset and ceased operation at sunrise (approximately 10 pm to 6 am local time). There were two traps within each of the study sites in 2016, for a total of 12 traps. In the second year of sampling I increased the number of traps per site to three to increase the catch of moths, for a total of 18 traps for 2017. The traps were located centrally within the site where they were placed in trees approximately 4 m above the ground (with a range of ~10 m), within close proximity (<30 m) to the transect lines. Few trees tall enough to securely hang a trap at a height of 4 m were present in the sites due to the nature of alvar ecosystems, so choices of where to hang the traps were limited. Trap containing trees consisted of oak (14), aspen (3) and one jack pine with traps placed as close to plant sampling transects as possible. The traps were emptied approximately every 9 – 11 days, and samples containing moths and other insects were returned to the laboratory and stored frozen until they were removed for sorting, pinning and subsequent identification.

Figure 5. Nocturnal ultraviolet light trap for moth sampling hung in an alvar tree

Macro moths generally have well-known food plant hosts, are easily caught in light traps and have enough common species to provide data that can be compared between treatments or habitats (Leps et al.1998). Leps et al. (1998) found that population size was positively correlated with food plant abundance for specialized moth species, but found no evidence of such resource limitation for generalist moth species. Summerville and Crist (2002) classified moth species into functional groups based on their preferred type of larval host plant life form; woody plant feeders (sub-categorized into specialists and generalists), forb/grass feeders, decaying vegetation feeders, fungi/lichen/moss feeders and generalist feeders. These classifications can be used to relate Lepidopteran presence to plant inventories in a given area.

Moths are nocturnal and sensitive to the light of the moon, as a consequence they are also attracted to artificial forms of light, which allows for them to be easily caught using light traps (Jonason et al. 2014). Light traps are the most widely used method for surveying communities of nocturnal Lepidopterans and are effective for comparing moth communities between different land use treatments, such as grazed and ungrazed alvars (New 2004). Temperature affects the flight periods and level of activity of moths so sampling for moths using light traps should occur during the warm months from late spring to late summer at regular intervals, preferably coinciding with the warmest temperatures of each month (Jonason et al. 2014). The peak periods of phenological variation and richness of moth species occur in June and early August for temperate deciduous forests (Summerville et al. 2004). Sex, species and taxon related differences in behavior and biology affect the extent to which individual moths will be amenable to sampling in light traps (New 2004). One drawback of the light trapping sampling method is that it fails to catch diurnal moth species that lack a strong response to UV light (Summerville et al. 2004).

Once the field-sampling season was complete I sorted all moth trap samples and removed any by-catch (non-Lepidopterans) from the samples. After sorting the samples, moths and butterflies were placed in a sealed softening jar, containing water and a small amount of phenol crystals to prevent fungal growth on specimens, for 24 to 48 hours to make them soft and pliable for the pinning process (Howe 1975, Scott 1986). Softened insects were pinned to pinning boards with the wings spread to aid in identification and allowed 24 to 48 hours to dry and harden. These samples were then transferred to storage boxes for storage and identification. Identification of certain species of moths can be time consuming and the difficulty is more pronounced with excessive wear to the wing patterns (Summerville et al. 2004). A portion of the moths caught were micromoths that are challenging to pin and identify, so most of these individuals were simply counted as part of the total moth abundance.

The Butterflies of Manitoba (Klassen et al. 1989) and Le Guide des Papillions du Québec (Handfield 1999) were used to identify the various species of butterflies. Moths were identified using Covell (1984), the Moths of America North of Mexico series (Hodges et al. 1983 to 2009), Handfield (1999) and The North American Moth

Photographers Group website (Mississippi Entomological Museum 2012). Butterfly and moth classification was based on Lafontaine (1998), Lafontaine and Fibiger (2006), Lafontaine and Schmidt (2010) and Pohl et al. (2016). Once an expert (R. Westwood, University of Winnipeg) confirmed the identifications, I finalized the abundances (counts) of each macromoth species and calculated the total moth catch per site including micromoth species and damaged individuals. Some individual moths were very worn and not in a condition suitable for identification and these individuals were identified to family (rather than species) level and counted to add to the total catch per site count.

### 3.3 Data Analysis

Lepidopteran and plant abundance data and measurements of various physical variables were analyzed using several approaches to determine if there are significant differences between Manitoba alvar sites overall and between grazed and ungrazed treatment groups. The percent cover of each observed plant species per plot was summed and then averaged for each site to obtain a mean percentage cover of each plant species per alvar site and treatment. The numbers of individual butterflies caught during the surveys were summed for each site and used to calculate total number of butterfly species and the abundance of individual species per alvar site and treatment. The numbers of individuals for each moth species caught in each of the 2 (2016) or 3 (2017) traps in each site were summed for each site and used to calculate the number of moth species and abundance of individual moth species per alvar site and treatment for the years 2016 and 2017 (Bourassa et al. 2010).

Biotic data, collected using techniques such as surveys or traps, usually contain many zero values and uses common units (abundances). The presence of many zeros in biotic data is caused by dataset-rare species that occur in a few of the sample-units. Interpretation of biotic data may either take into account all observed individuals or may be based only on abundant species with rare species removed, as these rare species may be part of the environment or visiting from nearby habitats especially when it comes to mobile insects (Blake et al. 2003). Therefore a second dataset was created with dataset rare species deleted from the data matrix prior to analysis, rare species are considered to be species represented by only one individual observation (Magurran 2004, Peck 2010).

Removal of rare species is noted in the analysis described below, and any analysis performed with rare species removed was also analyzed with rare species included to compare the outcomes.

Many statistical tests require “normal data”, which means that the density of data follows the approximate “normal”, bell-shaped distribution curve and if the raw data does not meet this requirement the data must be transformed (Magurran 1988, Kenkel 2006). The distribution of my Lepidopteran, plant and physical variables was determined using summary statistics to describe the shape of the data and test for the probability that the variables fit the normal distribution. The majority of biological and physical variables follow a log normal distribution (positively skewed, many zero values and few large values) and data transformation was applied to reduce heterogeneity, influence of outliers and skewness (Kenkel 2006). Base 10 logarithmic transformation rescales the values of a response variable so that very high and low values are brought closer to the mean, reducing the range of values and improving linearity and skewness (Peck, 2010).

I checked the distribution of the plant, butterfly and moth data sets using SPSS to explore the shape of the raw data visually by producing histograms, scatterplots and boxplots of their distributions and used the Smirnov test. Assumptions of the normal distribution and equal variance for analyses were met for the plant species survey data and Lepidopteran catches in 2016 and 2017 field seasons after using log 10 transformation (Bourassa 2010).

### 3.3.1 Diversity analysis: Plants, butterflies and moths

Diversity of plant and animal communities is an important factor to consider when identifying high quality habitat for conservation purposes (Hooshmandi 2016). Variation in species diversity may be the result of landforms, disturbance history, and soil characteristics creating gradients of soil moisture, fertility and depth (Kimmins 1997). Magurran (1988) recommended the use of multiple diversity measures to accurately describe complex habitats and populations of organisms when evaluating sites. For the moth, butterfly and plant data sets, species richness, Shannon diversity and evenness, Simpson’s dominance, and Berger-Parker dominance for each alvar site were calculated and compared between sites and treatment groups. Appendix 8 contains a list of the equations used to calculate the aforementioned biodiversity indices (Magurran 1988).

Richness is the total number of species observed in a site and is a fundamental part of measuring community biodiversity and determining conservation strategies, which generally aim to maximize species richness (Gotelli & Colwell 2001, Buddle et al. 2006). Obtaining accurate estimates of species richness is highly dependent on the sampling effort, as assemblages must be sampled exhaustively taking into account that organism activity patterns may vary daily or seasonally (Magurran 2004). Indexes of diversity that combine both richness and abundance are useful for assessing diversity of large groups of species (Kimmins 1997, Magurran 1988). Diversity indices are useful because they are less sensitive to factors such as rare species and sample size (Kimmins 1997).

Alpha diversity is known as local or stand-level diversity and this measure accounts for species richness, abundance and evenness in its calculation (Magurran 2004). The Shannon diversity index (*H'*) has been widely used and accepted as a method to compare alpha diversity of plant and animal species (Wood and Gillman 1998, Magurran 1988, Buddle et al. 2005). The Shannon diversity index increases with the number of species and equality of distribution of species across sites (Beaudry et al. 1997). Shannon diversity assumes an infinite population, random sampling and that all species are represented in the sample although it is sensitive to rare species and sample size (Magurran 2004). The Shannon diversity index normally falls between 1.5 and 3.5.

Beta diversity defined as regional or landscape-level diversity and this measures the difference in species composition and abundance between local assemblages. Beta diversity is defined as the extent of species replacement along an environmental gradient or the turnover of species (gain or loss of species) between sites (Whittaker 1972) therefore gives insight into spatial patterns of biodiversity useful to conservation management decisions. Two commonly used measures of beta diversity are the Sørenson's qualitative and quantitative indices. Sørenson's qualitative index only accounts for the presence or absence of species, has a maximum value of 1 indicating complete similarity (sites have all species in common), and a minimum value of 0 indicating complete dissimilarity (sites have no species in common). Sørenson's quantitative index combines qualitative information with species abundance values. Formulae for the calculation of both these indices may be found in Appendix 8. Both qualitative and quantitative beta diversity of plants, butterflies and moths were calculated because both the presence/absence of species and the density of their distribution may be affected by grazing. I organized the beta diversity values into tables and color-coded the values into low, medium and high categories. The range of these categories were decided based on the overall range of values observed, keeping the categories close to equal. The low category has a greater range than the high and medium categories due to the presence fewer low values than high and medium.

Species evenness (*E'*) is defined as the equitability of species within a site and provides information about the commonness and rarity of the species and the community structure (Magurran 2004). Shannon evenness ranges from 0 (only 1 species is present) to 1 (all species are equally abundant) as it indicates the ratio of actual diversity to maximum possible diversity (Magurran 1988). Shannon evenness is a heterogeneity measure that accounts for the similarity in species abundances and can be easily compared across study sites (Magurran 1988).

Certain indices combine both diversity and dominance measures in the calculation where the degree of importance of the more abundant species in a population can be expressed as part of the diversity value. A commonly used measure of dominance is the Berger-Parker dominance index. The Berger-Parker index (*d'*) is a simple measure of dominance and describes the proportional abundance of most common or dominant species in the community (Magurran 2004) and is less influenced by rare species. The Berger-Parker index is usually expressed as *1/d* where the larger the value translates to an increase in diversity and reduction in dominance.

Simpson's index is also a dominance index measure that is more influenced by common species abundances in comparison to the Berger-Parker index. It expresses the probability two randomly chosen individuals from a large community will belong to different species (Magurran 1988). Simpson's dominance index is inversely proportional to diversity and it is less sensitive to species richness than other measures of diversity (Magurran 2004). Simpson's index is normally expressed as *1/D* such that as the index increases diversity decreases and there is no set range for the values derived from the index (Magurran 2004).

All biodiversity calculations were performed on data sets that had unidentified individuals removed (those not identifiable past the family level). After indices were generated (based on the works of Magurran 2004), the mean diversity measures for plants, butterflies and moths for each site were compared using one way Analysis of Variance (ANOVA) to test for differences between sites and treatments. A Tukey's post-hoc test was used to separate site means if the ANOVA was significant. To test for differences between sites and treatments on log-transformed moth and butterfly data, I used ANOVA followed by a Tukey's post-hoc test. Data transformation (base 10, log[x+1]) was done in PC-ORD version 6.0 to log-transform the species abundance data. A row and column summary of the log transformed species data was produced in PC-ORD and this process automatically calculates richness, Shannon diversity, Shannon evenness, and Simpson's dominance, which were then compared between sites and treatments using ANOVA. An alpha value of $p \leq 0.05$ was considered significant for all analysis. SPSS version 21 (IBM Software 2016) was used for all ANOVA analysis.

The physical variables were summed and averaged for each site and analysis was performed using one-way ANOVA (Bourassa et al. 2010, Taillefer et al. 2010, Peck 2010). One-way ANOVA was used to determine if there was a significant difference in the soil and litter depth, soil compaction, and amount of exposed pavement and bare soil between individual alvar sites and between grazing treatments. Soil nutrients are compared between sites and treatments using one-way ANOVA.

### 3.3.2 Multivariate analysis

Soil and environmental variables were measured using a variety of differing units and before comparing them within multivariate analysis they must be standardized to common units. For example the soil characteristic of pH is the concentration of hydrogen ions present in the soil and is measured on a logarithmic scale, unlike the other soil nutrient variables therefore some transformation is needed. The most common method is correlation standardization that converts raw values to unit-free z-scores based on standard deviation (Kenkel 2006). Standardization by z-scores was used on environmental variable data prior to multivariate analysis, variables included nitrate, pH, calcium, sodium, and cation exchange capacity.

Species responses to environmental factors are complex and multivariate analysis provides useful techniques for summarizing complex associations among species and to examine species responses to environmental factors and management treatments. Cluster analysis is commonly used to assign sample units to increasingly large groups on the basis of variable similarity and classifying these units (sites) into discrete, hierarchical groups (Beaudry et al. 1997, Grigoras 2015, Catling 2016). This analysis is sensitive to large variances therefore relative plant species abundance was log-transformed [$\log_{10}(x+1)$] prior to cluster analysis. Cluster analysis results in a dendrogram that joins the most similar sampling units first continuing such that most similar remaining responses are grouped together iteratively until there is one large group (Peck 2010). Dendrograms using different distance metrics and linkage methods were produced using cluster analysis in PC-ORD version 6.0. The dendrograms were slightly different and were compared to determine which variation provided the most useful information. The clustering patterns created using cluster analysis based on Sørenson's distance metric and group average as a linkage method explained more of the variation between groups as compared to Euclidean distance and Ward's method. Plant, butterfly and moth species abundances were log-transformed [log10(x+1)] prior to multivariate analysis. For the butterfly and moth datasets a second matrix with the data set rare species was created and analyzed for comparison with the unaltered dataset.

Multiple Response Permutation Procedures (MRPP) are used to determine differences in species responses between or among groups of sample units (treatments) based on within group similarities (Peck 2010). MRPP assumes the data are independent and approximately normal, but it does not require equal sample sizes among groups, nor does it indicate how groups differ, only that they are different (Peck 2010). This analysis results in three important values, the T, A, and p-values, the T value is the test statistic that describes separation between groups (McCune and Grace 2002). The p-value indicates the "probability of obtaining as low an average within-group sample unit distance (similarity) as actually observed" and the A-value represents the chance-corrected effect size (McCune and Grace 2002, Peck 2010). MRPP was used to test for similarity in species composition between treatments using Sørenson's distance metric (Bourassa et al. 2010). MRPP was performed using PC-ORD version 6.0 (McCune and Mefford 2005) on log-transformed data for plants, butterflies and moths and a Bonferroni correction for multiple comparisons was also calculated. For the butterfly and moth datasets a second matrix with the data set rare species removed was created and analyzed for comparison with the unaltered dataset.

Indicator species analysis (ISA) determines which species are most frequent and abundant in the varying treatment groups and assess the degree to which a species indicates a particular site or treatment (Peck 2010, Grigoras 2015, Catling 2016). For ISA abundance data must be independent and normally distributed, and usually log transformation was used to increase the normality of the data distribution (Beaudry et al. 1997, Kenkel 2006, Peck 2010). To investigate the presence of characteristic or indicator species within treatments following MRPP, ISA was used to determine which species are constant and abundant within differing treatment groups. Indicator Value (IndVav) indicates the relative abundance and constancy of a species within a group, and the maximum IndVal of 1 occurs when individuals of a species are found exclusively in one group of sites and occur in all sites within that group (Dufrene and Legendre 1997). Indicator values were tested for significance at the $p < 0.05$ level, using Monte Carlo randomization with 1000 permutations (McCune et al. 2002, Taillefer et al. 2010). Monte Carlo permutation testing results in a p-value indicating the probability of observing the species based on the treatment (Peck 2010). ISA was carried out on plants, butterflies and moths on log transformed data excluding unidentified individuals.

The effect of unequal catch size on insect survey collected data occurs as a result of differences in trap attractiveness, species response to stimuli, species activity patterns, or other bias in collection methods. This may be corrected for using rarefaction analysis, which calculates the richness of species estimated at a standardized number of individuals captured or observed during a survey (Beaudry et al. 1997). Rarefied species richness reflects the difference in attractiveness of multiple traps for example or slightly differing survey and detection ability of butterfly surveyors. Rarefaction curves approximate the number of species in iterative subsamples to standardize across study sites estimating the species richness at the smallest number of caught individuals per site (Buddle et al. 2006). The assumptions that must be met by the data for rarefaction to be appropriate are: sufficient sampling effort, comparable sampling methods, taxonomic similarity and closed communities of discrete individuals, reasonable random placement of traps (moths) and independent random sampling (butterflies) where each observer is independent (Colwell et al. 2004).

To investigate species diversity between sites and treatments, rarefaction analysis was applied to the data before standardization and after the removal of unidentified individuals using EcoSim version 7.0 (Gotelli and Entsminger 2004). Rarefaction was individually based on 1000 permutations for butterfly data collected in 2016 and 2017 (Bourassa 2010). During rarefaction analysis I based my estimates of species richness and comparisons of the rarefaction curves at the 95% confidence interval, for the butterflies in the analysis included standardizing diversity comparison all at a total of 180 samples for each site. Rarefaction was individually based on 1000 permutations and compared the estimated number of observed species represented by 200 individuals for moths in 2016 and 2017. During rarefaction analysis I compared estimates of species richness on the rarefaction curves at the 95% confidence interval.

Redundancy analysis (RDA) is a guided ordination technique that combines PCA with linear regression analysis to summarize the linear relationship between each species response and the explanatory variables selected for the RDA (Peck 2010). RDA orders sample units and responses simultaneously, "based on linear relationships between patterns of redundant co-occurrences" in response variables (species and sites) and explanatory (environmental) variables (Peck 2010). Redundancy analysis produces a triplot for each biotic data set (plants, butterflies and moths), which places each species in ordination space constrained by the treatments and the significant environmental (soil) variables. Sites/species that are grouped closely to each other are more similar while sites/species that are far away from each other are more different in terms of species composition.

RDA is commonly used to test to see if an a priori hypothesized pattern is present or explore response patterns while controlling for variation related to explanatory variables and then followed by Monte Carlo permutation testing (Peck 2010). Catling (2016) used RDA to determine specific relationships between plants and soil depth, soil moisture and percent cover of bare rock. Leps et al. (1998) used RDA to test for the influence of abiotic explanatory variables on vegetation and moth community composition, followed by Monte Carlo tests to determine the statistical significance of the RDA results. I used RDA analysis in Canoco version 5 to analyze the inter-relationships between plants, moths and butterfly communities, sites, treatments, and significant environmental variables by seeing how they are plotted in ordination space. Prior to analysis environmental variables were examined for the presence of correlated variables. For the plant RDA, I first included all species and tested environmental variables individually to discern which variables were important to the distribution of the species and sites. Once I reduced the variables to only the statistically significant, I determined the amount of variation being explained by each species, and reduced the species included in the graph to only those explaining >1% of the total variation, as these are the species most affected by the treatment. I followed the same protocol in the moth and butterfly redundancy analyses to focus the analysis on only the most explanatory species and create uncluttered result figures.

While the availability of host plants is an important factor in the impact of habitat disturbance on moth communities, life history traits such as feeding specialization/ preferences are also important to consider (Rice & White 2015). For example a species that is specialized to depend on only one or two host plants is more vulnerable to the impacts of habitat disturbance, such as grazing, if its host plants are being affected. Rice and White (2015) compared moth assemblages in urban areas of Michigan using nocturnal light traps and analyzed differences in body size and feeding guild dominance between two habitat disturbance treatments. Aikens and Buddle (2011) determined various hunting/feeding guilds of spiders and beetles to assess the differences in relative dominance of guilds between vertical strata of the forest canopy then used a Chi-squared test to determine differences in guild dominance between the vertical strata.

Species were classified into their feeding guild based on Moths of America North of Mexico series Fascicles 1 to 25 (Hodges et al. 1983 to 2009), Moths of Eartern North America (Covell 1984), The Butterflies of Manitoba (Klassen et al. 1989), and Les Papillons du Québec (Handfield 2011). The feeding guilds were established for all moth species recorded in the study and then each moth species was assigned to a larval host plant feeding guild including: tree, tree-shrub, shrub, tree-ground, shrub-ground, and ground-layer (grass/herb/lichen/moss) specialist categories, and generalists, making a total of seven guilds. Feeding guilds were derived from several similar studies where moths were assigned to host plant groups for the purpose of comparing diversity between treatment groups (Lewinsohn 2005, Schaffers 2008). I determined how many individual moths were recorded for each guild within each treatment type then used a Chi-squared test in SPSS to determine if there were significant differences in the number of moths in each feeding guild between grazed and ungrazed alvar sites.

# Chapter 4
# Results

## 4.1 Summary

The two hypotheses tested addressed the following questions: 1) were there significant differences in plant, butterfly, and moth assemblages, and environmental/soil characteristics between all alvar sites, and 2) were there significant differences in plant, butterfly and moth assemblages, and environmental/soil characteristics between grazed and ungrazed treatment sites as a result of grazing-related environmental changes.

In total, 113 plant species were recorded in 2016 (35 families) between the two surveys that took place in early and late summer. The total percent cover of plants observed by species (or family when identification to species was not feasible) summarized by site are presented in Appendix 2.

In 2016, 443 individual butterflies comprising 36 species in five families were observed and 1,114 individual butterflies comprising 36 species in five families were observed in 2017 (Table 4). Total number of butterflies caught by species in 2016 and 2017 are summarized by site in Appendix 5.

Table 4. Summary of number of butterfly captures in 2016 and 2017 in Manitoba's Interlake alvars by site. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| | | **2016** | | **2017** | |
|---|---|---|---|---|---|
| **Site** | **Treatment** | **Total # butterflies identified** | **Total # species** | **Total # butterflies identified** | **Total # species** |
| MRBE | Grazed | 90 | 16 | 155 | 24 |
| MRBW | Grazed | 84 | 16 | 193 | 23 |
| MRC | Grazed | 61 | 16 | 214 | 21 |
| CLMN | Ungrazed | 54 | 16 | 169 | 21 |
| CLMS | Ungrazed | 63 | 16 | 127 | 21 |
| PEG | Ungrazed | 91 | 19 | 256 | 25 |

In total, 1,867 individual moths comprising 97 species in 7 families were caught in 2016 and 1,831 individual moths comprising 104 species in 11 families were caught in 2017 (Table 5). A total of 137 moth species were collected over the entire study period. A few families and species dominated the moth fauna but many species were scarce, occurring in only a few sites or unique to one site or one treatment. There were 42 scarce moth species (with only one individual) collected over both sampling seasons. There were 4 moth species with over 100 individuals in both sampling years. While there was overlap of moth species identified in both 2016 and 2017 years, some moth species were found in only one year. The most abundant families of moths were Noctuidae, Tortricidae, Pyralidae and Geometridae, with 848, 350, 334, and 283 individuals, respectively, collected in 2016 and 2017 (Table 6). The total number of moths trapped by species in 2016 and 2017 including unidentified individuals are summarized by trap number in Appendix 3 and by sampling date in Appendix 4 (unidentified individuals are termed unknowns in the Tables and Appendices).

Table 5: Summary of number of moth captures in 2016 and 2017 in Manitoba's Interlake alvars by trap number. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| **Site name** | **Treatment** | **2016 Moth trap #** | **Total # moths identified** | **Total # species** | **Total # moths** | **2017 Moth trap #** | **Total # moths identified** | **Total # species** | **Total # moths** |
|---|---|---|---|---|---|---|---|---|---|
| MRBE | Grazed | 12 | 72 | 31 | 168 | 1 | 25 | 17 | 63 |
| | | 14 | 68 | 27 | 112 | 7 | 29 | 13 | 64 |
| | | | | | | 11 | 23 | 11 | 28 |
| MRBW | Grazed | 9 | 81 | 15 | 154 | 3 | 25 | 11 | 44 |
| | | 11 | 72 | 14 | 108 | 8 | 46 | 18 | 92 |
| | | | | | | 9 | 78 | 27 | 264 |
| MRC | Grazed | 4 | 46 | 20 | 167 | 6 | 44 | 20 | 109 |
| | | 18 | 114 | 30 | 309 | 17 | 11 | 7 | 29 |
| | | | | | | 20 | 77 | 31 | 162 |
| CLMN | Ungrazed | 8 | 72 | 22 | 99 | 2 | 27 | 9 | 47 |
| | | 13 | 81 | 13 | 141 | 10 | 109 | 20 | 148 |
| | | | | | | 12 | 40 | 18 | 67 |
| CLMS | Ungrazed | 1 | 21 | 9 | 25 | 5 | 7 | 4 | 5 |
| | | 3 | 74 | 20 | 138 | 15 | 24 | 14 | 81 |
| | | | | | | 19 | 84 | 14 | 156 |
| PEG | Ungrazed | 2 | 106 | 20 | 157 | 4 | 47 | 22 | 69 |
| | | 20 | 136 | 26 | 289 | 13 | 141 | 32 | 183 |
| | | | | | | 18 | 72 | 23 | 220 |

Table 6: Summary of moth captures by Family by trap in 2016 and 2017 in Manitoba's Interlake alvars.

| Family | 2016 Number of species | Number in Grazed Sites | Number in Ungrazed Sites | 2016 Total # moths | 2017 Number of species | Number in Grazed Sites | Number in Ungrazed Sites | 2017 Total # moths |
|---|---|---|---|---|---|---|---|---|
| Crambidae | 5 | 13 | 11 | 24 | 3 | 11 | 20 | 31 |
| Drepanidae | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| Erebidae | 21 | 35 | 37 | 72 | 19 | 95 | 46 | 141 |
| Geometridae | 12 | 35 | 75 | 110 | 23 | 41 | 132 | 173 |
| Lasiocampidae | 1 | 91 | 79 | 170 | 1 | 0 | 2 | 2 |
| Noctuidae | 47 | 117 | 81 | 198 | 49 | 198 | 452 | 650 |
| Nolidae | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 2 |
| Notodontidae | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Pyralidae | 4 | 70 | 98 | 168 | 2 | 54 | 112 | 166 |
| Sphingidae | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 2 |
| Tortricidae | 8 | 104 | 113 | 217 | 8 | 53 | 80 | 133 |

## 4.2 Plant and environmental assessment

### 4.2.1 Differences between sites and treatments

The number of plant species and diversity measures by site are shown in Table 7. There was a significant difference in plant species richness between sites (ANOVA p = 0.007) (Table 7). The site with the lowest species richness was MRBE and the site with the highest species richness was PEG. There was no significant difference in total percent plant cover, percent herb, and grass cover, percent moss and lichen cover, and percent introduced species between sites (Table 8). There was also no significant difference in Shannon diversity, Shannon evenness, Simpson's dominance and Berger-Parker dominance of the plant community between sites (Table 7).

In terms of treatments, the transects in grazed sites were significantly greater distances from the nearest tree when compared to the ungrazed sites (ANOVA p = 0.046) (Table 8) indicating lower levels of encroachment by trees into grazed alvar meadows. Ungrazed sites had significantly greater tree stems than the grazed sites (ANOVA p=0.017) and the trees in ungrazed sites had significantly higher diameter at breast height (DBH, ANOVA p=0.017). Ungrazed sites had significantly higher plant species richness than the grazed sites (ANOVA p = 0.004) (Table 7). There was no significant difference in total percent plant cover, percent herb and grass cover, percent shrub cover, tree height, percent moss and lichen cover, and percent introduced species between grazed and ungrazed sites (Table 8). There was also no significant difference in Shannon diversity, Shannon evenness, Simpson's dominance and Berger-Parker dominance between grazed and ungrazed sites (Table 7). When comparing diversity plant species richness was significantly different between grazed and ungrazed treatments, but there were no significant differences between diversity, evenness or dominance between sites or between treatments.

Table 7. Mean plant community diversity index comparisons between sites and between treatments. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| Site | Species Richness | Shannon Diversity H' | Shannon Evenness J' | Simpson's Dominance 1/D | Berger-Parker Dominance 1/d |
|---|---|---|---|---|---|
| **Site** | | | | | |
| MRB-E | 45.0a | 3.1 | 0.6 | 14.1 | 6.0 |
| MRB-W | 56.5ab | 3.5 | 0.7 | 23.4 | 9.0 |
| MRC | 49.5a | 3.3 | 0.6 | 17.9 | 7.0 |
| CLM-N | 60.0ab | 3.2 | 0.6 | 13.1 | 5.6 |
| CLM-S | 60.0ab | 3.4 | 0.7 | 13.1 | 6.2 |
| PEG | 71.0b | 3.7 | 0.7 | 24.3 | 7.5 |
| $F_{5,7}$ | 10.26 | 3.96 | 3.97 | 1.96 | 0.52 |
| p-value | **0.007** | 0.062 | 0.062 | 0.218 | 0.752 |
| **Treatment** | | | | | |
| Grazed(3) | 50.3 | 3.3 | 0.6 | 18.5 | 7.4 |
| Ungrazed(3) | 63.7 | 3.4 | 0.7 | 16.8 | 6.5 |
| $F_{1,4}$ | 13.58 | 1.12 | 1.12 | 0.19 | 0.50 |
| p-value | **0.004** | 0.314 | 0.314 | 0.671 | 0.496 |

[1.] Significant differences highlighted in bold.

[2.] Means in rows followed by the same letter are not significantly different, ANOVA, Tukey's post-hoc test (p>0.05).

Table 8. Mean plant community variable comparisons between sites and between treatments. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| Site | Total % Plant Cover | Herb Grasses % Cover | Shrubs % Cover | Distance to Trees (m) | Tree Stems | Tree Height (m) | Tree DBH | Moss Lichen % Cover | % Introduced Species |
|---|---|---|---|---|---|---|---|---|---|
| **Site Comparison** | | | | | | | | | |
| MRB-E | 89.9 | 48.7 | 14.6a | 19.2abc | 0.0 | 0.0 | 0.0 | 36.6 | 1.5 |
| MRB-W | 80.3 | 66.3 | 23.0ab | 32.8c | 0.0 | 0.0 | 0.0 | 8.7 | 10.1 |
| MRC | 89.1 | 67.2 | 16.9ab | 23.5bc | 0.0 | 0.0 | 0.0 | 21.1 | 1.7 |
| CLM-N | 83.1 | 47.9 | 66.6c | 10.8ab | 5.0 | 4.4 | 12.0 | 14.5 | 0.1 |
| CLM-S | 85.7 | 57.0 | 43.5bc | 14.6abc | 1.0 | 2.5 | 4.0 | 30.3 | 0.3 |
| PEG | 83.7 | 79.8 | 19.5ab | 0.7a | 60.0 | 3.3 | 4.5 | 13.9 | 1.8 |
| $F_{5,7}$ | 0.78 | 1.00 | 16.88 | 9.29 | N/A | N/A | N/A | 2.36 | 2.10 |
| p-value | 0.600 | 0.490 | **0.002** | **0.009** | N/A | N/A | N/A | 0.196 | 0.163 |
| **Treatment Comparison** | | | | | | | | | |
| Grazed (3) | 86.4 | 57.0 | 18.4 | 25.2 | 0.0 | 0.0 | 0.0 | 14.7 | 1.2 |
| Ungrazed (3) | 87.5 | 57.3 | 43.2 | 8.8 | 22.0 | 3.4 | 6.8 | 13.0 | 0.5 |
| $F_{1,4}$ | 0.05 | 0.00 | 3.19 | 8.15 | 15.48 | 5.60 | 15.65 | 0.07 | 1.45 |
| p-value | 0.843 | 0.975 | 0.148 | **0.046** | **0.017** | 0.077 | **0.017** | 0.807 | 0.295 |

[1] Significant differences highlighted in bold.

[2] Means in rows followed by the same letter are not significantly different, ANOVA, Tukey’s post-hoc test (p>0.05).

### 4.2.2 Landscape diversity

Beta diversity was assessed using the Sørensen's qualitative index, which compares sites pairwise based on presence/absence of each variable (species), and Sørensen's quantitative index, which uses both species presence and abundance to determine the level of similarity between two sites. Similarity ranges from 0-1, 0 being completely dissimilar and 1 being completely similar. Plant species presence/absence (qualitative) indicated a medium degree of similarity among the sites overall, however when the species percent cover is also taken into account (quantitative), the overall degree of similarity of the plant community is much lower between sites (Table 9).

Table 9. Sørensen's qualitative and quantitative % similarity matrixes for 2016 plant survey. Category legend: high (red, 1.0-0.7), medium (orange, 0.7-0.4) and low (green, 0.4-0.0). Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

Beta Similarity Qualitative

| | **Grazed** | | | **Ungrazed** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.5906 | 1 | | | | |
| **MRC** | 0.6571 | 0.6541 | 1 | | | |
| **CLM-N** | 0.5478 | 0.646 | 0.6053 | 1 | | |
| **CLM-S** | 0.5811 | 0.7105 | 0.6853 | 0.775 | 1 | |
| **PEG** | 0.559 | 0.6424 | 0.6538 | 0.7168 | 0.7439 | 1 |

Beta Similarity Quantitative

| | **Grazed** | | | **Ungrazed** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.4296 | 1 | | | | |
| **MRC** | 0.9447 | 0.5517 | 1 | | | |
| **CLM-N** | 0.2207 | 0.2856 | 0.2534 | 1 | | |
| **CLM-S** | 0.3403 | 0.3584 | 0.326 | 0.5818 | 1 | |
| **PEG** | 0.2816 | 0.2829 | 0.2897 | 0.3487 | 0.4483 | 1 |

### 4.2.3 Cluster analysis

In the cluster diagram the alvar sites grouped together first (furthest left) are the most similar, which indicates that the majority of the variation between these sites is accounted for by the species percent cover/abundance. Vegetation cluster analysis results (Figure 6) indicates two groupings based on plant community composition. These groupings are consistent with the grazed and ungrazed treatments.

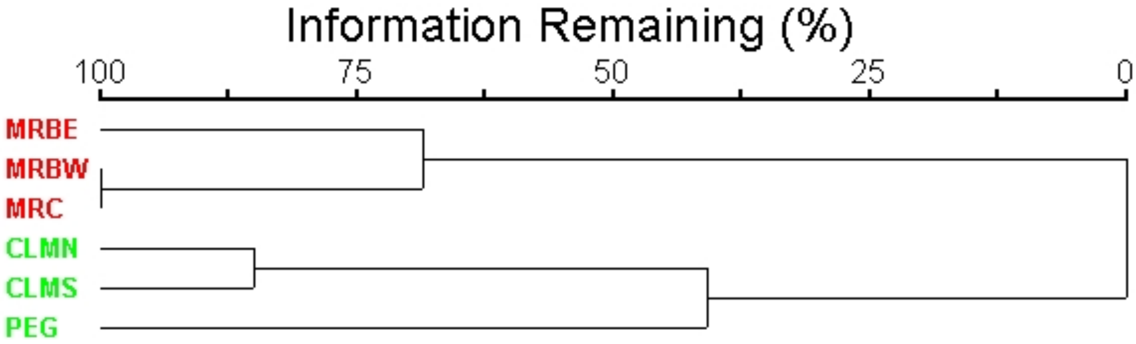

Figure 6. One-way cluster analysis for vegetation: percent cover for plant species per site in 2016. Red is grazed treatment and green in ungrazed treatment. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.2.4 Soil assessment

The mean soil variable values by site and soil variable raw values by transect are summarized in Appendix 6. Environmental characteristics that were significantly different between sites included nitrate concentration (ANOVA, $p = 0.008$), pH (ANOVA, $p = 0.009$), calcium (ANOVA, $p = 0.033$), sodium (ANOVA, $p = 0.009$), and cation exchange capacity (CEC, ANOVA, $p = 0.028$) (Table 10). Several additional variables were tested as part of the analysis package purchased and I have included the full comparison table of environmental and soil variables (Appendix 7).

Nitrate concentration was the highest in site MRC and the lowest in CLMN and PEG. The pH level was highest in MRBW and lowest in CLMS. Calcium was highest in CLMS and lowest in PEG. Sodium was highest in MRBE and lowest in PEG, and cation exchange capacity (CEC) was highest in CLMS and lowest in PEG (Table 10). There was no significant difference in soil depth, litter depth, soil compaction, percent exposed pavement, or percent exposed bare ground between sites (Appendix 7).

Grazed sites had significantly higher nitrate concentration than ungrazed sites

(Table 11, ANOVA, $p = <0.001$). Grazed sites had significantly higher pH (more basic) compared to ungrazed sites (more acidic) (ANOVA, $p = 0.003$) and had significantly higher sodium compared to ungrazed sites (ANOVA, $p = 0.010$). Grazed sites had significantly higher soil compaction than ungrazed sites (ANOVA, $p = 0.017$).

There was no significant difference in phosphorus, potassium, sulphate, electrical conductivity, organic matter, calcium, and magnesium between grazed and ungrazed sites (Table 11). There was also no significant difference in cation exchange capacity, soil depth, litter depth, percent exposed pavement, and percent exposed bare ground between grazed and ungrazed sites (Table 11).

Table 10. Significant environmental variables comparisons between sites. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| | | | **Grazed (3)** | | | **Ungrazed (3)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Units** | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** | **$F_{5,24}$** | **p-value[1]** |
| Nitrate | mg/kg | 13.48ab[2] | 10.33ab | 15.77b | 2.83a | 3.29ab | 2.30a | 4.06 | **0.008** |
| pH | na | 7.37ab | 7.52b | 7.37ab | 7.30ab | 6.75a | 6.98ab | 3.99 | **0.009** |
| Calcium | mg/kg | 6046.00ab | 6822.00ab | 5862.00ab | 7980.00ab | 8518.00b | 5176.00a | 2.95 | **0.033** |
| Sodium | mg/kg | 18.10b | 15.54ab | 11.24ab | 10.446a | 12.40ab | 9.70a | 3.97 | **0.009** |
| CEC | meq/100g | 40.46ab | 44.40ab | 42.52ab | 52.50ab | 65.60b | 37.42a | 3.06 | **0.028** |

[1] Significant differences highlighted in bold.

[2] Means in rows followed by the same letter are not significantly different, Tukey's test ($p>0.05$).

*CEC = Cation Exchange Capacity

Table 11. Environmental variables comparisons between treatments.

| Variable | Units | Grazed (3) | Ungrazed (3) | $F_{1,4}$ | p-value[1] |
|---|---|---|---|---|---|
| Nitrate | mg/kg | 13.19 | 2.81 | 20.13 | **<0.001** |
| Phosphorus | mg/kg | 11.75 | 15.77 | 0.80 | 0.380 |
| Potassium | mg/kg | 180.47 | 218.33 | 2.02 | 0.167 |
| Sulphate | mg/kg | 8.70 | 7.00 | 2.81 | 0.105 |
| pH | na | 7.42 | 7.01 | 10.50 | **0.003** |
| EC | na | 1.08 | 0.96 | 0.71 | 0.407 |
| Organic Matter | % | 19.44 | 22.22 | 0.83 | 0.370 |
| Calcium | mg/kg | 6243.33 | 7224.67 | 1.96 | 0.173 |
| Magnesium | mg/kg | 1291.33 | 1586.07 | 2.16 | 0.153 |
| Sodium | mg/kg | 14.96 | 10.85 | 7.69 | **0.010** |
| CEC | meq/100g | 42.46 | 51.84 | 2.96 | 0.097 |
| Soil Depth | cm | 7.51 | 8.31 | 0.20 | 0.666 |
| Litter Depth | cm | 0.77 | 0.51 | 1.37 | 0.268 |
| Soil Compaction | kg/cm2 | 2.65 | 2.01 | 8.13 | **0.017** |
| % Pavement | % | 5.07 | 2.45 | 1.27 | 0.286 |
| % Bare Ground | % | 8.52 | 10.05 | 0.16 | 0.694 |

[1] Significant differences highlighted in bold.

[2] ANOVA with Tukey's post-hoc test ($p<0.05$).

### 4.2.5 Multiple Response Permutation Procedure & Indicator Species Analysis

The results of multiple response permutation procedure (MRPP) analysis indicated that the plant diversity was different between grazed and ungrazed sites (MRPP, $T = -2.935$, $A = 0.222$, $p = 0.022$) and diversity was higher in the ungrazed sites. The indicator species analysis (ISA) analysis for plants did not identify any significant indicator species by treatment ($p < 0.05$). Though no plant species were significant indicators of either treatment, there were several species that had high Indicator Values (IndVal>90) (Table 12) showing a strong association between these species and either the grazed or ungrazed treatment.

Table 12. Indicator species analysis for plants including all species with an IndVal>90.

| Species | Group | IndVal | p-value |
|---|---|---|---|
| *Betula occidentalis* | Ungrazed | 100 | 0.10 |
| *Shepherdia canadensis* | Ungrazed | 100 | 0.10 |
| *Populous tremuloides* | Ungrazed | 100 | 0.10 |
| *Quercus macrocarpa* | Ungrazed | 100 | 0.10 |
| *Polygala senega* | Ungrazed | 100 | 0.1062 |
| *Bromus porteri* | Ungrazed | 100 | 0.1062 |
| *Elymus trachycaulus* | Ungrazed | 100 | 0.1062 |
| *Arctostaphylos uva-ursi* | Ungrazed | 98.8 | 0.1062 |
| *Potentilla pensylvanica* | Grazed | 98.6 | 0.1062 |
| *Medicago lupulina* | Grazed | 98.5 | 0.1062 |
| *Andropogon gerardii* | Ungrazed | 98 | 0.3067 |
| *Zizia aptera* | Ungrazed | 97 | 0.2997 |
| *Solidago ptarmicoides* | Ungrazed | 94.7 | 0.1062 |
| *Geum triflorum* | Grazed | 94.4 | 0.1062 |
| *Poa pratensis* | Grazed | 94.4 | 0.1062 |
| *Abietinella abietina* | Grazed | 94.2 | 0.1062 |
| *Lithospermum canescens* | Ungrazed | 94 | 0.1062 |
| *Cladina moss* | Ungrazed | 94 | 0.1062 |
| *Scutellaria galericulata* | Ungrazed | 93.9 | 0.1062 |
| *Comandra umbellata* | Ungrazed | 91.8 | 0.1062 |
| *Melilotus officinalis* | Ungrazed | 90.7 | 0.4993 |
| *Koeleria macrantha* | Grazed | 90.6 | 0.1062 |
| *Taraxacum officinale* | Ungrazed | 90.4 | 0.1062 |
| *Fragaria virginiana* | Ungrazed | 90.1 | 0.1062 |

### 4.2.6 Redundancy Analysis

In the redundancy analysis (RDA) for plants the first axis explained 49.29% of the variation and the second axis explained 7.96% of the variation between plants and the environmental variables (Figure 7). The grazed sites significantly grouped together with nitrate concentration in the soil ($p < 0.0001$). The ungrazed sites were located on the negative quadrant of the RDA well away from the grazed sites on the positive side. The first axis explained the majority of the variation separating plants more associated with the two treatment types on the horizontal axis. The second axis separated the ungrazed sites from MRBW, MRBE and MRC, which were also separated from each however axis two only accounts for 7.96% variation so this was not indicative of a significant effect.

Plants appear to be concentrated in two areas of the RDA with a tight concentration of plant species associated with the grazed treatments, a second concentration of plant species associated more closely with the ungrazed sites. The diagram contains fifty species, so for simplicity the species that explained most of the variation between grazed and ungrazed treatments were determined and included in the RDA. Plant names were abbreviated to the first three letters of the genus and first three letters of the species for the RDA, for example *Geum triflorum* is labelled *Geu tri* in the diagram.

The grazed treatment was closely associated with three-flowered avens *Geum triflorum* Pursh, pussytoes *Antenaria* spp., common yarrow *Achillea millefolium* L., sedges *Carex* spp., hop clover *Medicago lupulina* L., and wiry fern moss *Abietinella abietina* M. Fleisch. There were several species of plants found to be closely associated with the ungrazed treatment sites, such as trembling aspen *P. tremuloides*, bearberry *A. uva-ursi*, spring birch *Betula occidentalis* Hook., upland white aster *Solidago ptarmicoides* B. Boivin, Virginia strawberry *Fragaria virginiensis* Miller, reindeer lichen *Cladina* spp. and moss *Aulacomnium palustre* Schwagr. These and additional plant species and the significance of the associations will be discussed further in Chapter 5.

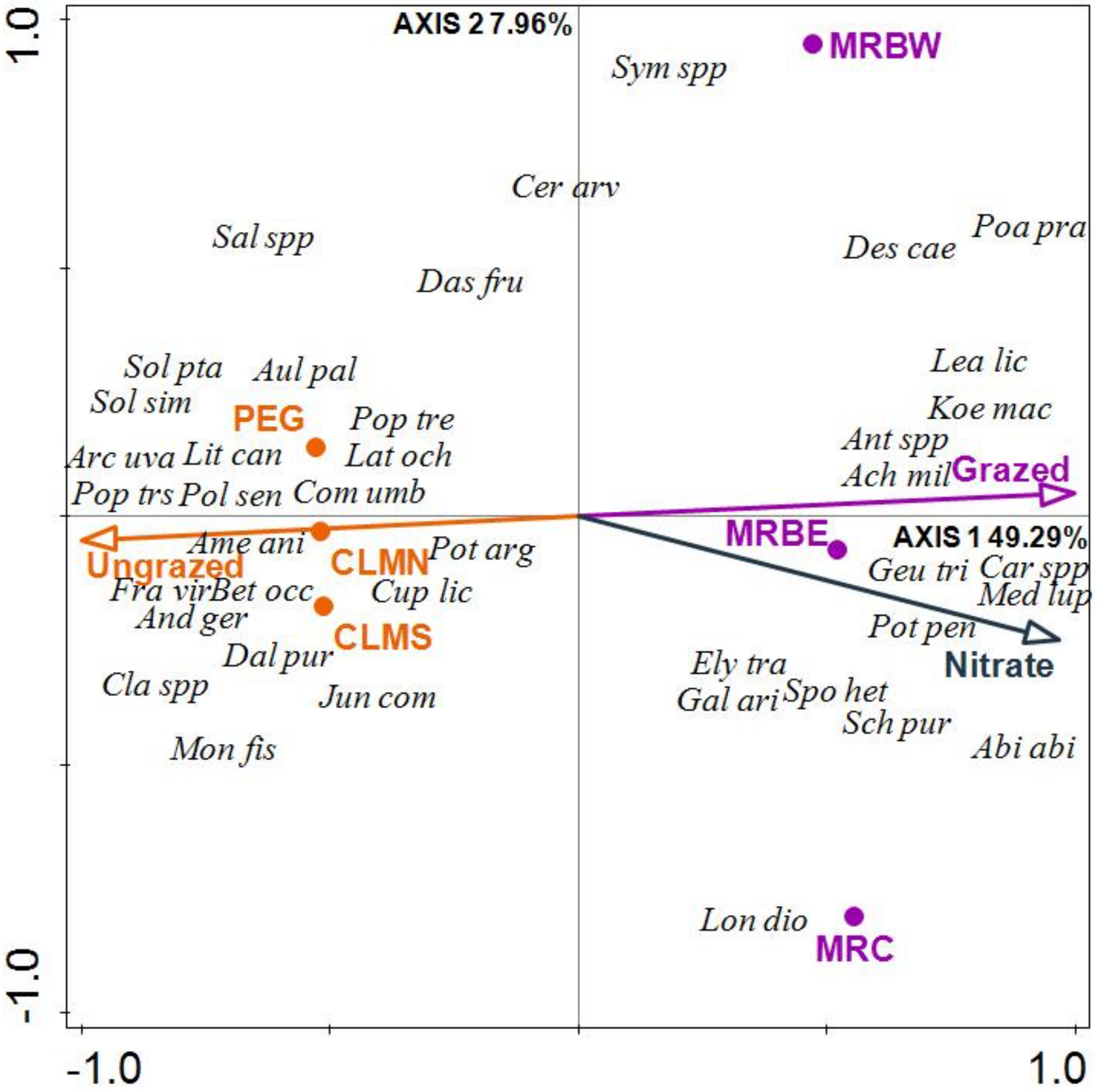

Figure 7. Redundancy analysis triplot of the 50 plant species that explained the most variation. Species acronyms listed in Appendix 2. Significance of axis 1 = 49.29% and axis 2 = 7.96%. Purple represents the grazed treatment, and orange represents the ungrazed treatment. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.3 Butterfly assessment

#### 4.3.1 Differences between sites and treatments

There was no significant difference in butterfly species richness, Shannon diversity, Shannon evenness, Simpson's dominance, or Berger-Parker dominance between grazed and ungrazed sites (Table 13). There was also no significant difference in Shannon diversity, evenness, or Simpson's dominance between grazed and ungrazed sites (Table 14).

Table 13. Butterfly species diversity indices comparison between treatments

| Treatment | # Individuals | Species Richness | Shannon Diversity H' | Shannon Evenness J' | Simpson's Dominance 1/D | Berger-Parker Dominance 1/d |
|---|---|---|---|---|---|---|
| Grazed (3) | 265.67 | 27.33 | 2.66 | 0.69 | 10.86 | 5.60 |
| Ungrazed (3) | 253.33 | 27.67 | 2.47 | 0.64 | 7.77 | 3.55 |
| $F_{1,4}$ | 0.401 | 0.02 | 3.69 | 3.69 | 4.13 | 5.41 |
| p-value | 0.437 | 0.897 | 0.127 | 0.127 | 0.112 | 0.081 |

[1.] ANOVA with Tukey's post-hoc test.

Table 14. Butterfly species diversity indices comparison between treatments.

| Site | Shannon Diversity H' | Shannon Evenness E | Simpson's Dominance 1/D |
|---|---|---|---|
| Grazed (3) | 3.14 | 0.95 | 1.05 |
| Ungrazed (3) | 3.13 | 0.94 | 1.05 |
| $F_{1,4}$ | 0.05 | 4.37 | 0.51 |
| p-value | 0.828 | 0.105 | 0.514 |

[1.] ANOVA with Tukey's post-hoc test.

### 4.3.2 Landscape diversity

Butterfly species presence/absence (qualitative beta diversity) indicated a high degree of similarity while the quantitative analysis showed reduced species sharing between sites (Table 15).

Table 15. Sørensen’s qualitative and quantitative % similarity matrixes for 2016 and 2017 butterfly survey (abundance). Category legend: high (red, 1.0-0.7), medium (orange, 0.7-0.4) and low (green, 0.4-0.0). Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

Beta Similarity Qualitative

| | **Grazed** | | | **Ungrazed** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.7037 | 1 | | | | |
| **MRC** | 0.6786 | 0.6667 | 1 | | | |
| **CLM-N** | 0.7273 | 0.7547 | 0.6545 | 1 | | |
| **CLM-S** | 0.6923 | 0.8 | 0.5769 | 0.7843 | 1 | |
| **PEG** | 0.6667 | 0.7931 | 0.7 | 0.7797 | 0.75 | 1 |

Beta Similarity Quantitative

| | **Grazed** | | | **Ungrazed** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.6756 | 1 | | | | |
| **MRC** | 0.6245 | 0.6703 | 1 | | | |
| **CLM-N** | 0.4553 | 0.44 | 0.5301 | 1 | | |
| **CLM-S** | 0.5172 | 0.4754 | 0.5462 | 0.7458 | 1 | |
| **PEG** | 0.5017 | 0.3846 | 0.4084 | 0.4 | 0.4395 | 1 |

### 4.3.3 Cluster analysis

Butterfly cluster (Figure 8) results indicated two groupings based on the butterfly community composition. These groupings are consistent with the grazed and ungrazed treatments, and similar to the cluster results of the plant community, indicating a close association between these two groups.

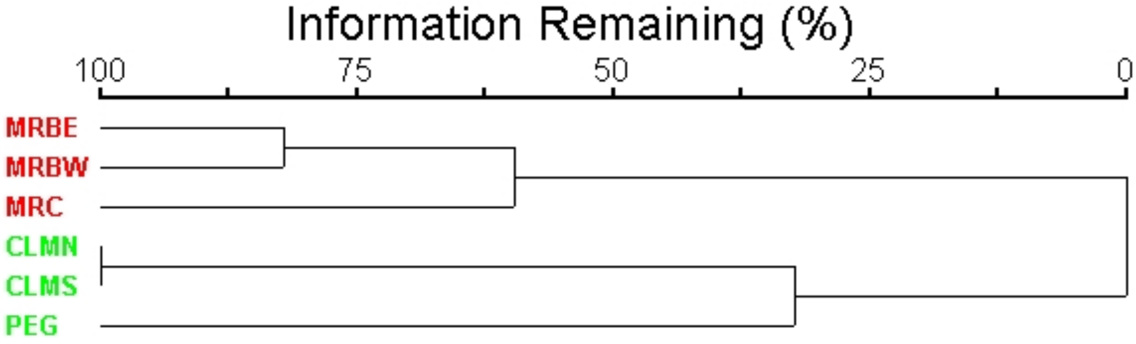

Figure 8. One-way cluster analysis for butterflies: mean log transformed abundance for butterfly species per site in 2016 and 2017. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.3.4 Multiple Response Permutation Procedure and Indicator Species Analysis

The results of MRPP analysis indicated that grazed and ungrazed treatments had a significantly different effects on butterfly composition (MRPP, T = -0.841, A = 0.1318, p = 0.028). The ISA analysis of butterflies did not indicate any significant indicator species (p <0.05). Though no butterfly species were significant indicators of either treatment, there were several species that had high Indicator Values (IndVal>60) (Table 16) indicating an association between these species and either the grazed or ungrazed treatment.

Table 16. Indicator species analysis for butterflies with IndVal>60.

| Species | Group | IndVal | p-value |
|---|---|---|---|
| *Plebejus ida* | Ungrazed | 89.2 | 0.10 |
| *Erebia epipsodea* | Grazed | 81.8 | 0.10 |
| *Callophrys polios* | Ungrazed | 78.2 | 0.29 |
| *Plebejus saepiolus* | Grazed | 75.7 | 0.10 |
| *Pieris rapae* | Grazed | 72.1 | 0.10 |
| *Limenitis archippus* | Ungrazed | 70.4 | 0.10 |
| *Satyrium titus* | Ungrazed | 66.7 | 0.39 |
| *Cupido amyntula* | Ungrazed | 66.7 | 0.39 |
| *Aglais milberti* | Grazed | 66.7 | 0.40 |
| *Polygonia faunus* | Grazed | 66.7 | 0.40 |
| *Pontia Protodice* | Grazed | 66.7 | 0.41 |
| *Erynnis juvenalis* | Ungrazed | 66.7 | 0.41 |
| *Speyeria atlantis* | Ungrazed | 66.3 | 0.41 |
| *Speyeria cybele* | Ungrazed | 65.4 | 0.31 |
| *Hesperia comma assiniboia* | Grazed | 63.1 | 0.41 |

### 4.3.5 Rarefaction

Rarefaction analysis produced a series of standardized species accumulation curves for butterflies to determine if there was a difference in rarefied species richness between site or treatments. In these accumulation curves (Figure 9) butterfly richness values were standardized to the level of 180 observations, estimating the rarefied species richness. Rarefaction analysis of butterflies indicated there are three significantly different groups based on the 95% confidence interval. The group with the lowest rarefied richness included sites MRBW and CLMS, while sites MRC and CLMN had moderate richness. The highest rarefied richness was observed in sites MRBE and PEG, however the rarefaction curves did not indicate a significant treatment effect.

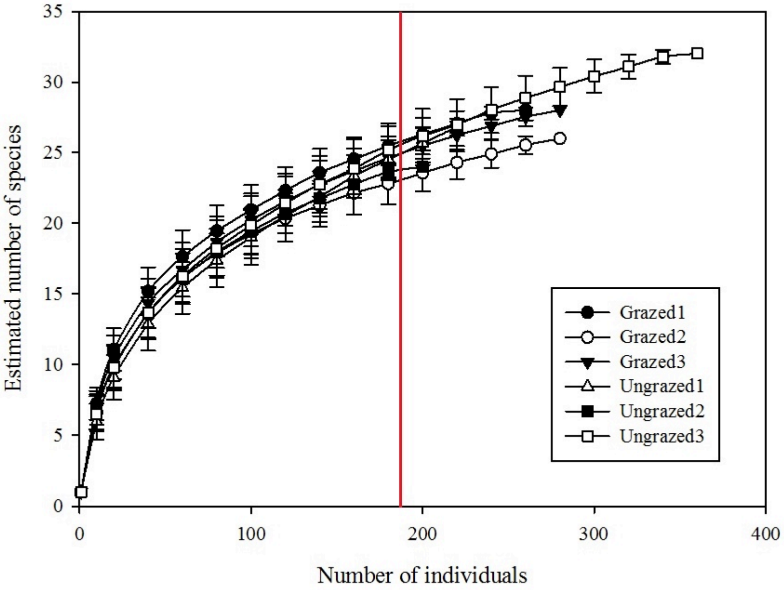

Figure 9. Rarefaction estimate of expected species richness (mean ± SD) of butterflies for each Alvar site. Grazed sites are MRBE (1), MRBW (2) and MRC (3), ungrazed sites are CLMN (1), CLMS (2) and PEG (3).

### 4.3.6 Redundancy Analysis

In the RDA for butterflies the first axis explained 40.39% of the variation and the second axis explained 11.42% of the variation between butterflies and the environmental variables (Figure 10). The grazed sites grouped together with nitrate concentration in the soil associated with these sites ($p = 0.072$). The ungrazed sites were located on the negative quadrant of the RDA well away from the grazed sites on the positive side. The first axis explained the majority of the variation separating butterflies more associated with the two treatment types horizontally. The second axis separated the grazed sites with MRBW, MRBE and MRC, which were separated from each other indicating that it appears these sites had more variation between them than the ungrazed sites. Butterflies appear to be concentrated in two areas of the RDA with a loose concentration of butterfly species associated with the grazed treatments, a second concentration of butterfly species slightly more closely associated with the ungrazed sites. This triplot is very similar to the RDA triplot for plants, indicating that the composition of plants and butterflies showed a similar pattern.

There were several species of butterflies associated with the ungrazed treatment sites, such as the Northern blue *Plebejus idas* L., hoary elfin *Callophrys polios* Cook & Watson*,* silvery blue *Glaucopsyche lygdamus* Doub., Atlantis fritillary *Speyeria atlantis* Fabr., and great spangled fritillary *Speyeria cybele* Fabr. Northern pearl crescent *Phycoides cocyta* Cramer, and Canadian tiger swallowtail *Papilio canadensis* L. were found nearer to the ungrazed sites than the grazed sites, positioned more toward the center of the diagram.

On the positive side of the first axis species closely associated with the grazed treatment. The species located near site MRBW in the upper right were European skipper *Thymelicus lineola* Ochs., and common sulphur *Colias philodice* Godart. Site MRBE was the most associated to nitrate levels and had a group of species around it, including he common alpine *Erebia epipsodea* Butler, greenish blue *Plebejus saepiolus* Bois., cosmopolitan painted lady *Vanessa cardui* L., common ringlet *Coenonympha tullia* Muller, meadow fritillary *Boloria bellona* Fabr., and common branded skipper *Hesperia comma assiniboia* Lyman. Queen Alexandra's skipper *Colias alexandra* Edwards is located in the lower right near site MRC.

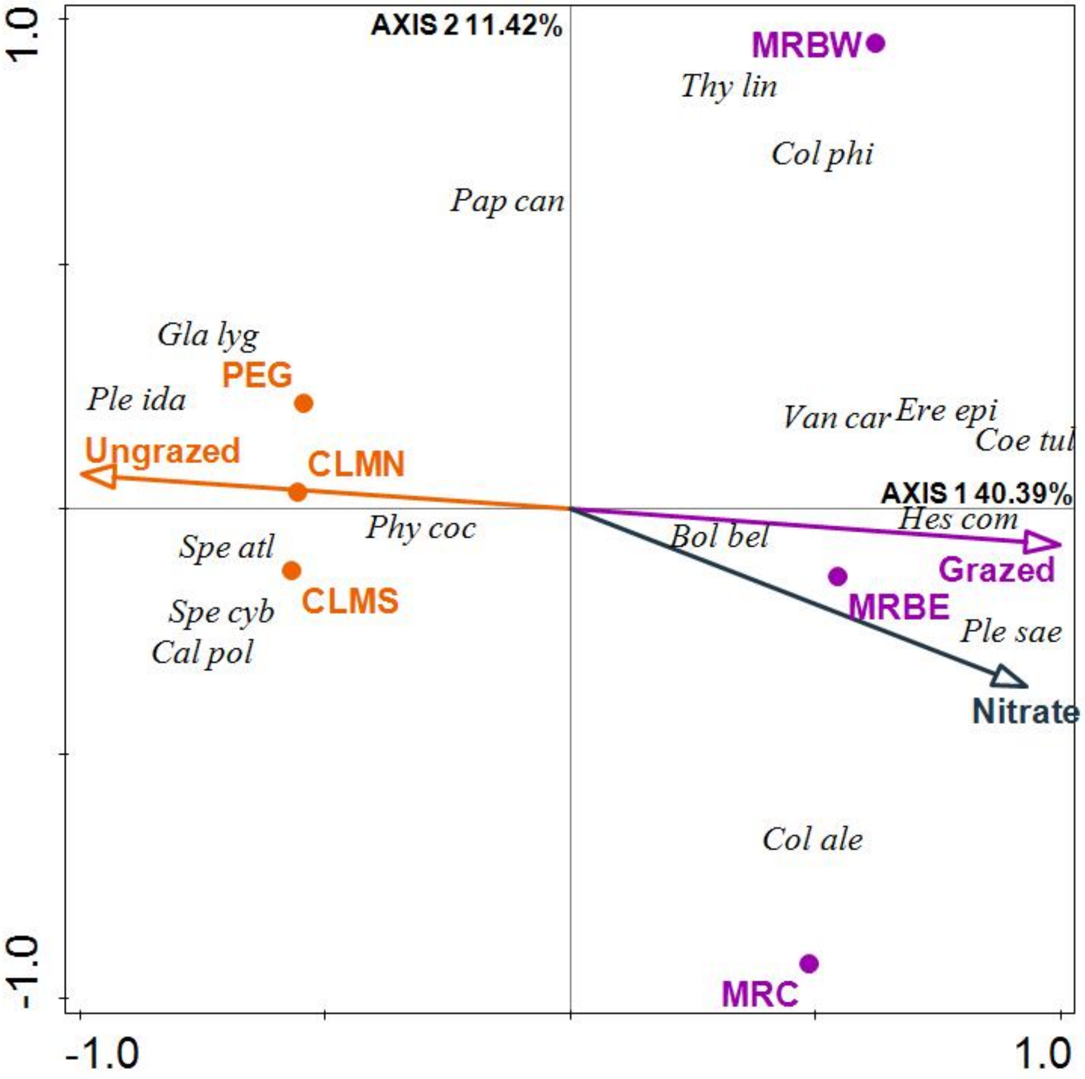

Figure 10. Redundancy analysis triplot of butterfly species that explained ≥1% of the variation. Species acronyms listed in Appendix 5. Significance of axis 1 = 40.39% and axis 2 = 11.42%. Purple represents the grazed treatment, and orange represents the ungrazed treatment. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.4 Moth assessment

#### 4.4.1 Differences between sites and treatments

There was no significant difference in moth species richness, Shannon diversity, Shannon evenness, Simpson's dominance, or Berger-Parker dominance between sites (Table 17). There was also no significant difference in Shannon diversity, evenness, or Simpson's dominance between sites when the data was log transformed prior to analysis (Table 18).

Table 17. Moth species diversity indices comparisons between sites and treatments. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| Site | # Identified | Species Richness | Shannon Diversity H' | Shannon Evenness J' | Simpson's Dominance 1/D | Berger-Parker Dominance 1/d |
|---|---|---|---|---|---|---|
| **Site Comparison** | | | | | | |
| MRB-E | 217 | 22.00 | 2.41 | 0.74 | 10.56 | 4.07 |
| MRB-W | 302 | 18.80 | 1.79 | 0.56 | 3.56 | 2.11 |
| MRC | 292 | 24.00 | 2.16 | 0.64 | 4.70 | 2.76 |
| CLM-N | 329 | 18.80 | 2.09 | 0.65 | 5.55 | 2.86 |
| CLM-S | 210 | 14.40 | 1.84 | 0.63 | 6.49 | 2.66 |
| PEG | 502 | 26.80 | 2.31 | 0.65 | 6.81 | 3.42 |
| $F_{5,24}$ | 1.092 | 1.87 | 1.37 | 1.41 | 1.77 | 1.15 |
| p-value | 0.413 | 0.138 | 0.270 | 0.256 | 0.158 | 0.363 |
| **Treatment Comparison** | | | | | | |
| Grazed(3) | 270.33 | 21.60 | 2.12 | 0.65 | 6.27 | 2.98 |
| Ungrazed(3) | 347 | 20.00 | 2.08 | 0.65 | 6.28 | 2.98 |
| $F_{1,4}$ | 0.743 | 0.32 | 0.06 | 0.00 | 0.00 | 0.00 |
| p-value | 0.437 | 0.579 | 0.815 | 0.991 | 0.995 | 0.996 |

[1.] ANOVA with Tukey's post-hoc test.

Table 18. Moth species diversity indices comparison between sites and treatments. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| **Site** | **Shannon Diversity H'** | **Shannon Evenness E** | **Simpson's Dominance 1/D** |
|---|---|---|---|
| **Site Comparison** | | | |
| MRB-E | 3.02 | 0.95 | 1.07 |
| MRB-W | 2.66 | 0.93 | 1.10 |
| MRC | 2.93 | 0.94 | 1.09 |
| CLM-N | 2.75 | 0.93 | 1.09 |
| CLM-S | 2.42 | 0.94 | 1.13 |
| PEG | 3.11 | 0.94 | 1.06 |
| $F_{5,24}$ | 2.14 | 0.73 | 1.54 |
| p-value | 0.095 | 0.610 | 0.216 |
| **Treatment Comparison** | | | |
| Grazed(3) | 3.98 | 0.95 | 0.98 |
| Ungrazed(3) | 3.82 | 0.94 | 0.97 |
| $F_{1,4}$ | 1.12 | 2.64 | 1.05 |
| p-value | 0.349 | 0.179 | 0.363 |

[1.] ANOVA with Tukey's post-hoc test.

### 4.4.2 Landscape diversity

Moth species presence/absence (qualitative) indicated a medium degree of similarity among the sites overall, however when the species abundance is also taken into account (quantitative), the overall degree of similarity of the moth community was much lower between sites (Table 19).

Table 19. Sørensen’s qualitative and quantitative % similarity matrixes for 2016 and 2017 moth survey (abundance). Category legend: high (red, 1.0-0.7), medium (orange, 0.7-0.4) and low (green, 0.4-0.0). Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

Beta Similarity Qualitative

| | | **Grazed** | | | **Ungrazed** | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.45 | 1 | | | | |
| **MRC** | 0.5139 | 0.5271 | 1 | | | |
| **CLM-N** | 0.4426 | 0.486 | 0.4886 | 1 | | |
| **CLM-S** | 0.4444 | 0.5294 | 0.4603 | 0.4423 | 1 | |
| **PEG** | 0.5037 | 0.4833 | 0.5139 | 0.5246 | 0.4102 | 1 |

Beta Similarity Quantitative

| | | **Grazed** | | | **Ungrazed** | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** |
| | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** |
| **MRB-E** | 1 | | | | | |
| **MRB-W** | 0.3941 | 1 | | | | |
| **MRC** | 0.463 | 0.6218 | 1 | | | |
| **CLM-N** | 0.3156 | 0.4564 | 0.5262 | 1 | | |
| **CLM-S** | 0.3875 | 0.4801 | 0.5701 | 0.5411 | 1 | |
| **PEG** | 0.3234 | 0.5716 | 0.5181 | 0.461 | 0.4621 | 1 |

### 4.4.3 Cluster analysis

The moth cluster results (Figure 11) are different from the plants and butterflies, where the first grouping is between MRC (grazed) and PEG (ungrazed), this group grows larger as it ‘picks up’ CLMN (ungrazed), MRBW (grazed), and CLMS (ungrazed), respectively. This grouping placed MRBE (grazed) in a group of one, indicating that in terms of moth species association and abundance this site is different from the other sites.

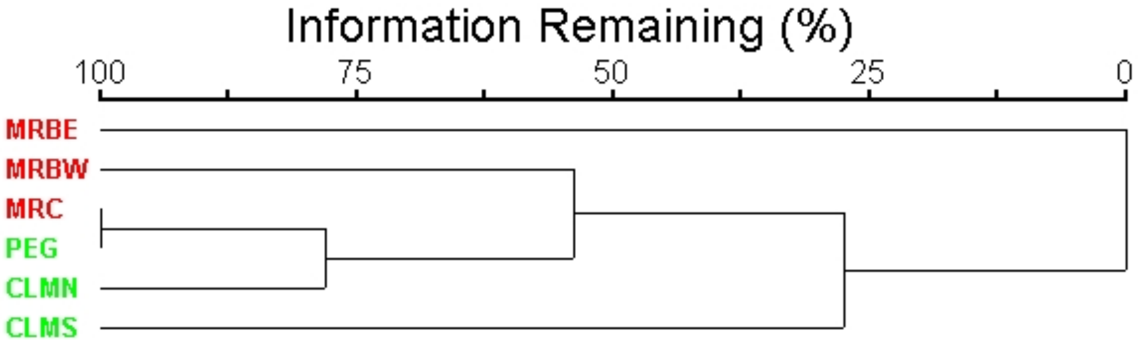

Figure 11. One-way cluster analysis for moths: mean log transformed abundance for moth species per site in 2016 and 2017. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.4.4 Multiple Response Permutation Procedure and Indicator Species Analysis

The results of MRPP analysis indicated that grazed and ungrazed treatments were not significantly different in terms of the moth community composition (MRPP, T = -2.337, A = 0.017, p = 0.205). The ISA analysis of moths did not indicate any significant indicator species (at alpha value <0.05). Though no moth species were significant indicators of either treatment, there were several species that had high Indicator Values (IndVal>60) (Table 20) indicating an association between these species and either the grazed or ungrazed treatment.

Table 20. Indicator species analysis for moths including all species with an IndVal>60.

| Species | Group | IndVal | p-value |
|---|---|---|---|
| *Pronexus miranda* | Grazed | 100 | 0.09 |
| *Apamea devastator* | Grazed | 85.7 | 0.20 |
| *Pseudeustrotia carneola* | Grazed | 80.6 | 0.20 |
| *Argyrostrotis anilis* | Grazed | 75 | 0.40 |
| *Melanapamea mixta* | Ungrazed | 74.8 | 0.09 |
| *Euxoa servitus* | Grazed | 72.4 | 0.09 |
| *Spirameter lutra* | Ungrazed | 67.5 | 0.50 |
| *Meganola minuscula* | Grazed | 66.7 | 0.39 |
| *Hypsopygia costalis* | Ungrazed | 66.7 | 0.39 |
| *Lithomia germana* | Grazed | 66.7 | 0.39 |
| *Polia purpurissata* | Grazed | 66.7 | 0.39 |
| *Amphipoea interoceanica* | Grazed | 66.7 | 0.39 |
| *Apamea sordens* | Grazed | 66.7 | 0.39 |
| *Herpetogramma pertextalis* | Grazed | 66.7 | 0.39 |
| *Hypoprepia miniata* | Ungrazed | 66.7 | 0.40 |
| *Orthosia revicta* | Ungrazed | 66.7 | 0.40 |
| *Renia flavipunctalis* | Ungrazed | 66.7 | 0.40 |
| *Acronicta fragilis* | Ungrazed | 66.7 | 0.40 |
| *Calyptra canadensis* | Grazed | 66.7 | 0.41 |
| *Orthodes majuscula* | Grazed | 64 | 0.30 |
| *Xanthorhoe iduata* | Grazed | 63.9 | 0.49 |
| *Clepsis persicana* | Ungrazed | 63.2 | 0.49 |
| *Crambidia pura* | Grazed | 62.5 | 0.29 |
| *Lucinipolia lustralis* | Ungrazed | 61.8 | 0.39 |
| *Anania extricalis* | Ungrazed | 60.4 | 0.29 |

### 4.4.5 Rarefaction

Rarefaction was used to standardize the species richness at a given number of individual observations for each site when sample sizes or survey effort differ. Based on the species accumulation curves (Figure 12) moths were standardized to the level of 200 individuals observed when estimating rarefied species richness. Rarefaction analysis of moths indicated two distinct groups, the group with the lowest rarefied richness included sites MRBW, CLMN, CLMS, and PEG, while sites MRBE and MRC had significantly higher richness.

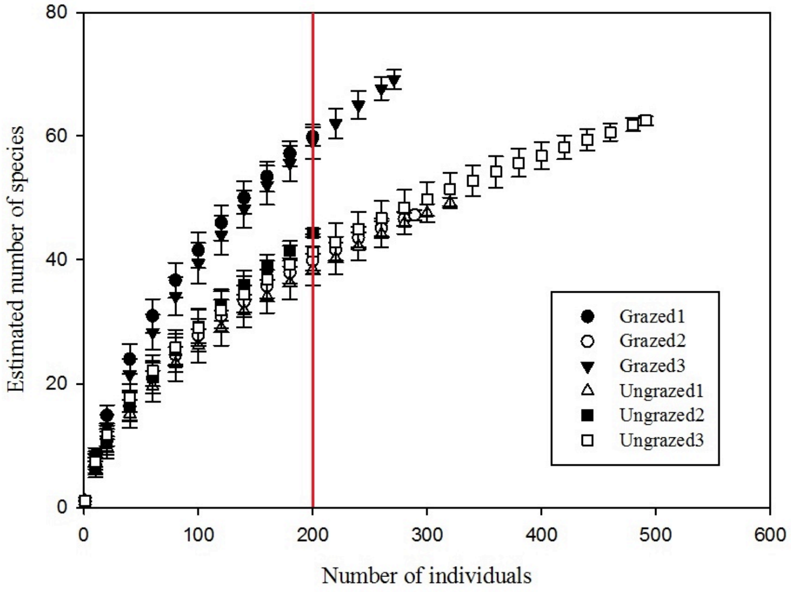

Figure 12. Rarefaction estimate of expected species richness (mean ± SD) of moths for each Alvar site. Grazed sites are MRBE (1), MRBW (2) and MRC (3), ungrazed sites are CLMN (1), CLMS (2) and PEG (3).

### 4.4.6 Redundancy Analysis

In the RDA for moths the first axis explained 24.58% of the variation and the second axis explained 28.83% of the variation between moths and the environmental variables (Figure 13). The nitrate concentration in the soil was not significantly associated with any of the sites or treatments. The grazed sites were located on the negative quadrant of the RDA well away from the ungrazed sites on the positive side. The first and second axis explained the majority of the variation separating moths more associated with the two treatment types. The second axis separated the ungrazed sites with PEG well separated from the other ungrazed sites indicating that it appears to be this site was different from the other ungrazed sites, CLMN and CLMS. Moths appear to be concentrated in two areas of the RDA with a loose concentration of moth species associated with the grazed treatments, a second concentration of moth species associated more closely with PEG. This triplot differs from the plant and butterfly RDA triplots because the grazed treatment sites are grouped together more tightly on the second axis while the ungrazed sites are separated on the second axis, particularly PEG.

There were several species of moths grouped near the grazed sites on the negative side of the first axis, such as slave dart moth *Euxoa servitus* Smith, glassy cutworm *Apamea devastator* Brace., pink-barred lithacodia moth *Pseudeustrotia carneola* Gn., copper underwing moth *Amphipyra pyramidoides* Guenee, scarlet underwing moth *Catocala coccinata* Grote, and to a lesser extent, American dun-bar moth *Cosmia calami* Harvey, and yellow-winged oak leaf-roller moth *Argyrataenia quercifoliana* Fitch. A group of species is located between the grazed sites and ungrazed site PEG, including: clover looper moth *Caenurgina crassiuscula* Haworth, Parthenice tiger moth *Apantesis parthenice* W. Kirby, vestal moth *Cabera variolaria* Guenee, sharp-lined yellow moth *Sicya macularia* Harris, immaculate grass-veneer moth *Crambus persicana* Scopoli, rustic Quaker moth *Orthodes majuscula* Herr. and frigid owlet moth *Nycteola frigidana* Walker.

There were also a number of moth species associated exclusively with the ungrazed sites. Site PEG in the upper right had the highest abundance and species diversity of moths is associated to species confused euscara moth *Euscara confusaria* Hubner, *Xenotemna pallorana* Robin, scalloped swallow moth *Eucirroedia pampina* Guenee, and otter spirameter moth *Spirameter lutra* Guenee. Two species are located in the lower right associated with sites CLMN and CLMS, Rosewing moth *Sideridis rosea* Harvey, and Toothed apharetra moth *Sympstis dentata* Grote. Two additional species strongly associated to the ungrazed treatment were *Melanapamea mixta* Grote and *Macaria occiduaria* Peck.

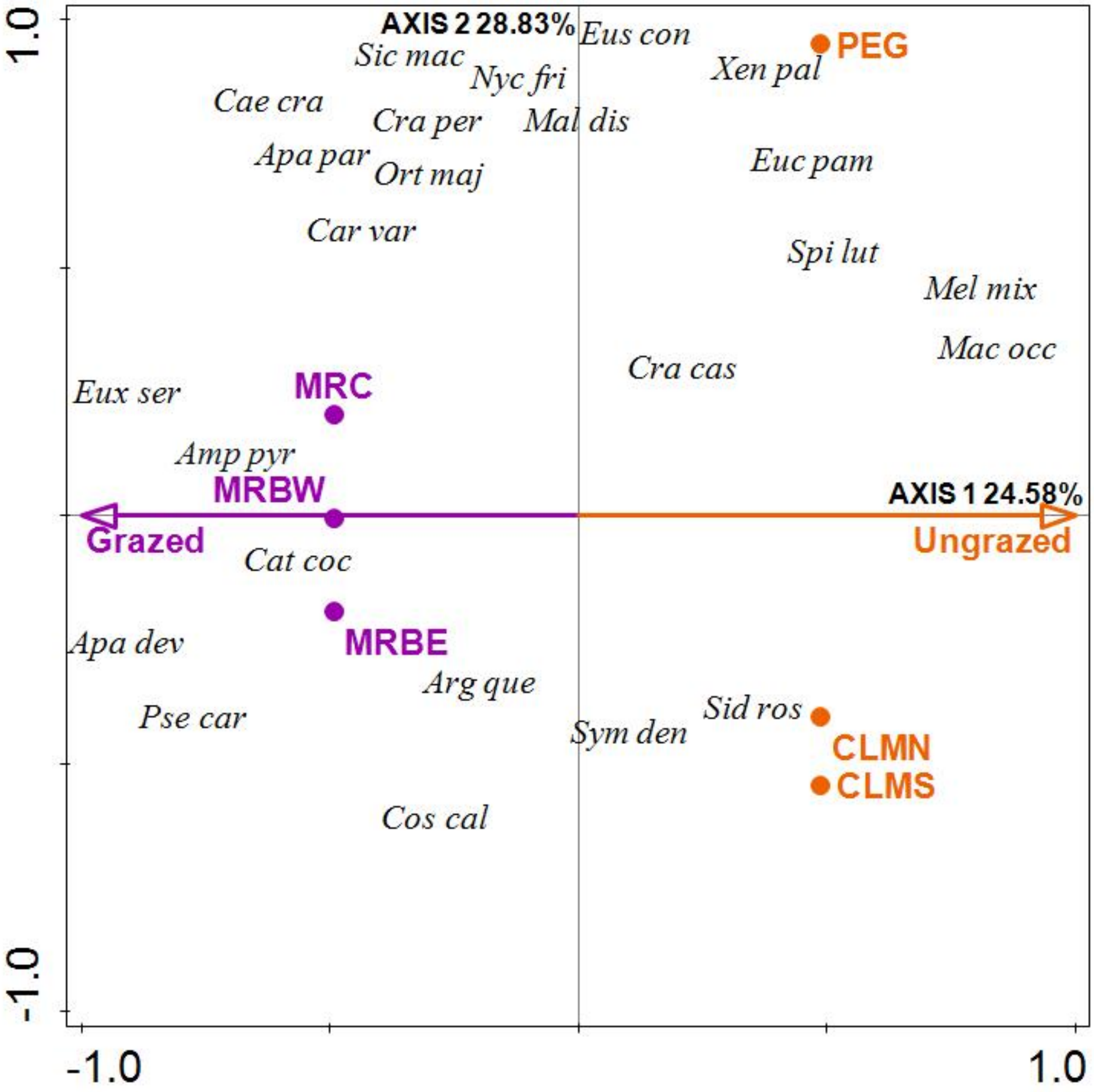

Figure 13. Redundancy analysis triplot of moth species that explained ≥1% of the variation. Species acronyms listed in Appendix 3 and 4. Significance of axis 1 = 24.58% and axis 2 = 28.83%. Purple represents the grazed treatment, and orange represents the ungrazed treatment. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

### 4.4.7 Feeding guild analysis

Chi-square analysis was used to determine differences in moth feeding guilds between grazed and ungrazed sites. The results of Chi-squared analysis (Table 21, Figure 14) indicate that there was a significant difference between the treatments in terms of feeding guild composition. Several guilds, including Tree ($x^2$ = 5.82, p = 0.016), Shrub ($x^2$ = 2.15, p = 0.007), Shrub/Ground ($x^2$ = 12.96, p = <0.001), and Generalist ($x^2$ =

101.587, p = <0.001), had significantly different abundances between the grazed and ungrazed treatments. There were significantly more Tree feeders, Shrub feeders, and Generalists in the ungrazed treatment, while there were significantly more Shrub/Ground feeders in the grazed treatment.

Table 21. Number of moth individuals found in each guild. Guilds Tree, Tree/Shrub, Shrub, Tree/Ground, Shrub/Ground and Ground are specialist guilds. Ground feeding specialists include herb, grass, moss and lichen feeding moths.

| | **Tree** | **Tree/ Shrub** | **Shrub** | **Tree/ Ground** | **Shrub/ Ground** | **Ground** | **General** |
|---|---|---|---|---|---|---|---|
| Grazed | 330 | 168 | 13 | 8 | 68 | 180 | 46 |
| Ungrazed | 395 | 196 | 31 | 5 | 32 | 178 | 206 |
| Total | 725 | 364 | 44 | 13 | 100 | 358 | 252 |
| $x^2$ | 5.82 | 2.15 | 7.364 | 0.692 | 12.96 | 0.011 | 101.587 |
| df | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| p-value | **0.016** | 0.142 | **0.007** | 0.405 | **<0.001** | 0.916 | **<0.001** |

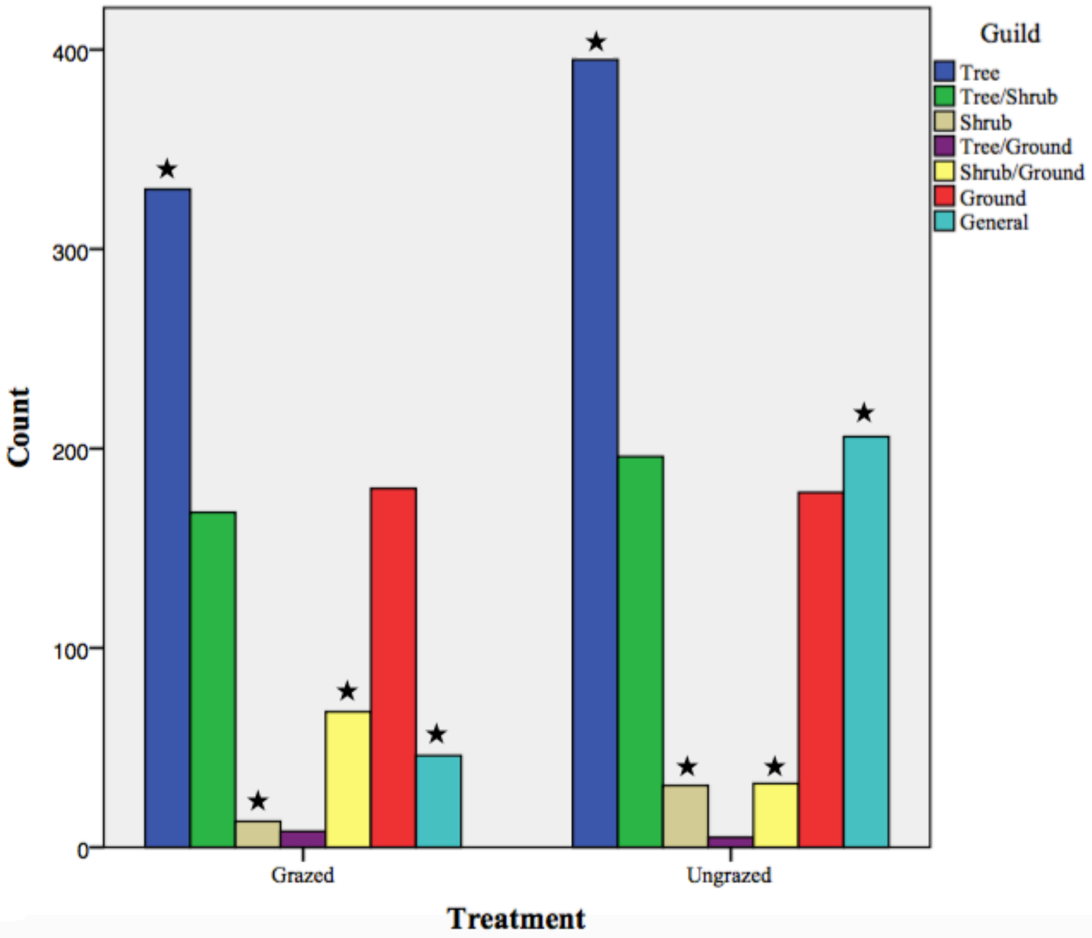

Figure 14. Number of individuals in each moth feeding-guild by treatment. Guilds are Tree, Tree/Shrub, Shrub, Tree/Ground, Shrub/Ground and Ground are specialist guilds. Ground feeding specialists include herb, grass, moss and lichen feeding moths. Stars (★) indicate significant guilds at p=0.05.

# Chapter 5

# Discussion

## 5.1 Summary

Alvars are globally rare ecosystems that support a unique and diverse community, including rare species of plants and animals, and therefore alvars make an important contribution to local and global biodiversity (Eriksson & Rosen 2008) however little is known about Manitoba's alvars both in terms of their ecology and the impacts of human activities. Alvars are important to the study of ecology to develop our understanding of the mechanisms that support their high species richness (Rusch 1988).

Alvars located in Manitoba contain unique rock formations, such as inland limestone cliffs and caves, which are known hotspots for biodiversity, especially rare plants and mosses (MAI 2012). The dominant land uses in the Interlake area are agriculture and mining, and both activities threaten the extent and quality of alvars in the area. Of particular concern is grazing of alvars leased by ranchers for grazing their livestock (Titlyanova et al. 1988, Eriksson & Rosen 2008, and MAI 2012). Grazing has been shown to have both positive and negative impacts on alvars ecosystems, by removing encroaching shrubs and trees but also damaging the plant community and the soil (Eriksson & Rosen 2008, Catling 2016).

Manitoba's alvars are listed as endangered under the Endangered Species and Ecosystems Act (2014) however to date no legally protected zones or management plans have been put into place for the long-term protection and maintenance of alvar ecosystems. To determine which site(s) should be prioritized for protection, I have investigated differences between grazed and ungrazed sites with a focus on their physical characteristics, and the plant and Lepidopteran community composition. Previous studies have inventoried and classified alvar plant communities, however to date no research has been done to inventory the Lepidopteran community in Manitoba's alvars. To determine the effects of livestock grazing on alvars, I have compared grazed alvars to alvars that have not been grazed by measuring certain physical characteristics, as well as plant and Lepidopteran community composition as explanatory variables to test for differences at the site level and between groups of grazed or ungrazed sites (termed treatments).

Information on the effects of grazing will be useful to land managers as they designate the boundaries of protected zones and determine the best management practices to prescribe for alvars in general.

The plant community observed in the Interlake alvars studied was consistent with previous descriptions by Bouchard (1997) and Eriksson & Rosen (2008), which found that alvars are rich communities dominated by shrubs, herbs and grasses, mosses and lichens, with very few trees (<60%, Reschke et al. 1999). Within the alvars I studied, I observed a combination of tall grass prairie and boreal forest species occupying the same habitat that was consistent with studies by Stephenson (1983) and Catling (2016). The total richness of the plant community observed in the alvars surveyed was 113 species from 35 families. For comparison, tall grass prairie ecosystems are considered rich ecosystems and contain 80-102 species (Markham & Sheffield 2014) and boreal spruce ecosystems can contain upwards of 150 species (Capar 2003 and Ryan 2005). Though rare and threatened species of plants have been previously observed in alvars in Manitoba (MAI 2012) results from the surveys based on centrally placed transects used in this study did not record the previously mentioned rare or threatened plant species. Many of these rare species occupy niches in specific limestone formations that were not present in the open alvar areas sampled within transects. Ungrazed sites had significantly more plant species than grazed sites, and a rich plant community may support a more diverse community of insects and other insectivores.

Monitoring of invertebrate communities can be used to predict potential impending ecological change because they are vulnerable to anthropogenic activities (Kremen et al. 1993, New 2004) and Lepidoptera have been previously established as useful indicators in Canadian alvars (Bouchard 1997). Changes to the Lepidopteran community may have cascading effects on insectivorous animals and insect predators and parasites (Hammond & Miller 1998) or reflect changes in the plant community and thus provide signals that disturbances such as grazing may be changing alvar communities.

Over two field seasons (2016 and 2017), the butterfly surveys recorded 1,557 individuals comprising 36 species and five families. This indicates a diverse and abundant butterfly community when compared to the butterfly community in the Burnt Lands alvars of Ontario, where surveys recorded 35 species but only 408 individuals

(Taylor & Catling 2011). There were four species that occurred only once, in my study and there were four species that were highly abundant and recorded over 100 times. Muller. The species that were only recorded once were the large marble *Euchloe ausonides,* pink-edged sulphur *Colias interior,* Harris' checkerspot *Chlosyne harrisii,* and American painted lady *Vanessa virginiensis*. The most common butterfly species (in descending order of abundance) were Aphrodite fritillary *Speyeria aphrodite* Fabr, Common wood nymph *Cercyonis pegala* Fabr, Silvery blue *Glaucopsyche lygdamus* Doub, and Common ringlet *Coenonympha tullia* There was no significant difference in the number of individuals, species richness, rarefied species richness, and diversity indices, including evenness and dominance between treatments for butterflies while Indicator Species Analysis (ISA) and Redundancy Analysis (RDA) showed a separation of species between grazed and ungrazed alvars.

Over two field seasons (2016 and 2017), moth surveys recorded 3,698 individuals from 137 species and 11 families. This maybe compared with the results of Grigoras' (2012) study of moths in Manitoba forest habitat, which recorded 9,986 individuals from 256 species. Forty-two of the species recorded in my study occurred only once, while four of the species were highly abundant and occurred over 100 times (in descending order of abundance): *Pyla aequivoca* Hein, *Pandemis canadana* Kear, *Malacosoma disstria* Hubner, and *M. occiduaria*. The most abundant family by a large margin was the *Noctuidae*, having more than twice the number of individuals in comparison to the second most abundant family. There was no significant difference in the number of individuals, species richness, diversity, evenness and dominance between sites or treatments for moths, while ISA and RDA showed a separation of species between grazed and ungrazed alvars.

## 5.2 Biodiversity

### 5.2.1 Plant biodiversity and community structure

Rich plant communities in Nordic alvars studied by Eriksson and Rosen (2008) supported a diverse community of animals, therefore it is important to consider the plant community as a factor in biodiversity protection. Most notably the encroachment of trees and shrubs into alvar habitat over time results in reduced biodiversity (Rusch 1988) and it is important to monitor these communities and use management strategies to prevent encroachment and subsequent biodiversity loss. There is a strong association in certain ecosystems between plants and insects (Summerville & Crist 2002) due to the extensive interactions that have occurred between these biotic groups over evolutionary time. The few previous studies of Manitoba's alvars (Hamel & Foster 2004, MAI 2012, and Catling 2016) have focused on the determining the extent of alvar vegetation in Manitoba and inventory and classification of the vegetation community, but have not examined disturbance impacts on the plant communities in a landscape level replicated approach.

Hamel & Foster (2004) surveyed the vegetation in the Clematis site (including the study sites CLMN and CLMS) but did not survey the northern alvar sites (MRC, MRBE, MRBW and PEG). The MAI report (2012) provided an inventory of alvar and alvar-like communities in Manitoba and determined which of these areas were considered true alvars, as well as providing a classification scheme for the vegetation communities in alvars. Catling (2016) focused on further classifying the alvar vegetation community types, but also included a rudimentary comparison of the vegetation community on two sides of a fence line. Catling (2016) located several alvars where on one side of the fence the habitat had been grazed by livestock, and found significant differences between grazed and ungrazed alvars in plant species composition (including diversity) and plant functional group composition. The present study encompasses considerably larger areas of alvar in comparison to Catling (2016) and focuses on grazing impacts over a large area within the centre of alvars. Catling (2016) focused on areas adjacent to the centres of alvars (fence line comparisons) and possible edge effects may have been present while this study focused mainly on open areas in the centre of alvars.

Maintaining biodiversity is an important goal for the conservation and protection of ecosystems and their vital functions (Kimmins 1997, Ober & Hayes 2010). One justification for the conservation of biodiversity is that diversity promotes stability and Tilman and Downing (1994) studied this relationship in grasslands. In their study, Tilman and Downing (1994) found that more diverse communities of plants were resilient, meaning they were more resistant to drought and recover more fully after drought, and therefore were more stable over the long-term. Grazing generally results in a vegetation structure that is less dense than that of ungrazed areas, however Rusch (1988) found that there was no significant difference in species richness between the treatments in alvars. In this study there was a significant difference in plant species richness between the sites and between the treatments. Ungrazed sites had significantly more species of plants than grazed sites in all three replicates and the most species were observed in PEG the site with the most tree and shrub encroachment. This indicated that higher richness does not necessarily correlate with the best quality alvar ecosystem, as the increase in richness may be attributed to an influx of undesirable, forest species. The lowest species richness was observed in a grazed site (MRBE). There was no significant difference between sites or treatments in plant community diversity indices. Plant species richness was greater in sites that were not exposed to the effects of cattle grazing, indicating that grazing may be having a negative effect on the richness of the plant community.

When studying alvar vegetation communities Catling (2016) found that there were significantly more trees with greater DBH in ungrazed areas, specifically *P. tremuloides* were more abundant in ungrazed areas as they are easily damaged by grazing activity. In this study distance between the nearest trees and transects was significantly greater in grazed sites, indicating that the grazed sites are less hospitable to tree species due to resource limitation or removal by grazing animals, and these results are consistent with the results of Catling (2016). The species that pose the greatest threat in terms of encroachment according to Stephenson (1983) are *P. tremuloides* and *P. glauca*. The primary tree species observed in this study were *P. tremuloides* and *Q. macrocarpa,* with the occasional *P. banksiana* or *P. glauca* present (though these species were not recorded in the transects). These results are consistent with studies that suggest cattle grazing may be an effective option for reducing the ability of trees to encroach into alvar meadows (Rusch 1988).

Catling (2016) reported that *J. horizontalis, D. fruticosa* and *A. uva-ursi,* were the primary shrubs observed in Manitoba's alvars and that shrubs decreased significantly in abundance in grazed alvar habitat. In this study the dominant shrub species in alvars were *D. fruticosa*, *J. horizontalis,* and *A. uva-ursi* (similar to Catling 2016), and these species were found to be more stongly associated to the ungrazed sites. However, I found there was no significant difference in overall percent cover of shrubs between sites or between treatments.

The overall level of invasive or introduced plant species in Manitoba's alvars was determined to be low by the MAI (2012). One pathway of introduction of non-native plant species into grazed alvars may be by supplemental cattle feed. Catling (2016) found that there was significantly higher plant species richness in grazed sites due to the addition of introduced species to the native vegetation. There were four introduced species recorded in the alvar sites surveyed for this study (Umbellate hawkweed *Heiracium umbellatum* L., sweet clover *Melilotus officinalis* Lamar., meadow Timothy grass *Phleum pratense* L. and Kentucky bluegrass *Poa pratensis* L.), however there was no significant difference in percent cover of introduced species between grazed and ungrazed sites. Catling (2016) found introduced species on the edges of grazed and ungrazed areas while in this study the centre of grazed and ungrazed areas were surveyed, where perhaps introduced species had not colonized the centre of alvars to the same degree as the edges.

Richness and abundance of lichens and mosses indicate healthy alvar habitats both in the Nordic alvars and in Manitoba (Rusch 1988, Caners 2012), however Leppik et al. (2013) found these species are susceptible to being damaged by livestock grazing. Catling (2016) found that grazing decreased the cover of bryophytes and lichens in alvars, and noted that lichens such as *Cladonia* spp. and mosses such as the rare moss *Tortella* spp. and common alvar species *A. abietina* are particularly susceptible to the damage. There was no significant difference in moss and lichen cover found between sites or between treatments in the alvar sites surveyed in this study.

### 5.2.2 Landscape diversity

The plant community showed a moderate degree of overlap when considering all sites over the landscape (beta diversity) when qualitative diversity was considered. In the qualitative assessment ungrazed sites shared an average of 63% of the plant species, grazed sites shared 74% of the plant species, and grazed and ungrazed sites shared on average 62% of the plant species. However when quantitative diversity is considered the degree of beta similarity between sites was reduced. When quantitative beta diversity of the plant community was calculated (combining presence/absence and percent cover estimates) the degree of similarity between grazed sites was 64% and 45% for ungrazed treatments. The degree of similarity between plant species in ungrazed and grazed plants was quite low at 29% indicating a clear effect of grazing on the plant community.

The qualitative similarity of the plant community was moderate among the grazed sites and higher among the ungrazed sites. Quantitative diversity was moderate among the grazed sites and lower among the ungrazed sites. Quantitative diversity of plants was notably low when compared between grazed and ungrazed sites, indicating that the plant communities do differ between the two treatments. The landscape results support the finding that the number of plant species in grazed alvars is less than those in ungrazed alvars. Results from the quantitative analysis also suggests that the plant community in grazed sites was more uniform in nature while it was more variable in the ungrazed sites. The mean similarity between ungrazed and grazed sites was low in the quantitative assessment, which was reflected in the plant species richness where grazed sites were less diverse. This was expected as grazing has been demonstrated to reduce plant diversity and encourage the dominance of less palatable species, especially when grazing pressure is high.

### 5.2.3 Cluster analysis

The site groupings indicated in the plant community cluster diagram align with the treatment groups, placing the grazed sites into one group distinct from the ungrazed sites based on the plant species relative abundances (percent cover). In the plant diagram the most similar sites were MRBW and MRC (grazed sites). The most similar ungrazed sites were CLMN and CLMS. In the beta assessment a similar situation exists for MRBW and MRC, and CLMN and CLMS in the qualitative analysis and for CLMN and CLMS in the quantitative assessment.

### 5.2.4 Soil assessment

Plant species are distributed on a gradient of environmental and soil characteristics including temperature, moisture, micronutrients, soil depth, and shade level (Kimmins 1997). Catling (2016) found that disturbance regime (grazing), exposed rock cover, soil depth, topography, and hydrology were the most important factors determining the distribution of vegetation in Manitoban alvars. In this study soil compaction was significantly higher in grazed sites, which could be expected as repeated trampling of the ground naturally leads to compaction of the soil over time, however there was no significant difference between grazed and ungrazed sites in the cover of exposed rock or soil depth. Increased soil compaction may affect vertical water distribution in plants and may indirectly increase the vulnerability of moth and butterfly larvae to desiccation in late summer if compaction is sufficient enough to cause plant stress (Royer et al. 2008).

Livestock grazing naturally contributes nutrient rich fertilizers to alvar soils, which may be beneficial as long as this does not lead to nutrient loading and an excess of one nutrient in the soil profile, such as nitrogen. Cattle dung is rich in nitrogen and "loading" of nitrogen may lead to a plant community dominated by nitrophilous ruderal species, which may outcompete characteristic alvar species and reduce plant diversity (Titlyanova et al. 1988). Nitrate is the form of nitrogen that is readily biologically available for use by plants (Hazelton et al. 2014). In this study the nitrate concentration was significantly different between sites and was significantly higher in grazed sites compared to ungrazed sites. The highest nitrate concentration was observed in site MRC, which also had the second lowest plant species richness of all the sites. This could indicate that site MRC may be experiencing a reduction in the number of plant species due to nitrogen loading in the soil, leading to conditions that are favourable to fewer species including those that favour nitrogen rich soils.

The pH (or hydrogen ion concentration) was significantly different between sites and between treatments, with grazed sites having significantly higher pH indicating that these sites are significantly more basic (above 7.0-neutral) than the slightly acidic ungrazed sites (below 7.0). This may be attributed to the increased presence of coniferous shrub *J. horizontalis* in the CLMN and CLMS ungrazed sites, which could be contributing acidic needles to the soil. The pH of the soil dictates which plants will be able to become established and reproduce given the acid/basic nature of the soil (Hazelton et al. 2014). Cation exchange capacity (CEC) is related to the pH of the soil, as increase in CEC also increases the buffering capacity of the soil, or "the ability of the soil to resist changes in pH" (Hazelton et al. 2014) indicating environmental stability. In this study CEC was significantly different between sites, being highest in site CLMS and lowest in site PEG, but was not significantly different between treatments.

Increasing nutrient levels can lead to salinization of soils, which is loading of the nutrients sodium, calcium, potassium and magnesium, and salinized soils have a reduced ability to support plant growth (Hazelton et al. 2014). Calcium concentration was significantly different between sites, which was unexpected as all the alvar soils in Manitoba originate from calcium rich limestone and dolomite pavement, yet calcium was highest in the Clematis sites and lowest in PEG. The Clematis sites are located south of the other sites by ~70 km and these sites are located on bedrock that is a complex of limestone bedrock, with areas of strongly calcareous glacial til and limestone alluvium deposits (Government of Manitoba 2010), which were significantly higher in calcium compared to the northern sites. There was no significant difference in calcium concentration between treatments. Sodium concentration was significantly different both between sites and between treatments; concentration of sodium was higher in grazed sites and highest in site MRBE. Grazed sites had higher levels of sodium in the soil indicating the potential for the soil to become salinized in grazed alvar sites and negatively effect on the plant community. Concentrations of potassium and magnesium were not significantly different between sites, or between grazed and ungrazed treatment groups.

### 5.2.5 MRPP/ISA

Determining appropriate bioindicator species can be used to prevent biodiversity loss. Monitoring the species over time can be useful to implement adaptive management strategies if bioindicator species experience consistent declines over time (Noss 1990, Kremen 1993, Dengler 2009). Indicator species can also be used as indicators of diversity when abundances are compared to determine differences between grazing treatments (Dufrene & Legendre 1997). The multiple response permutation procedures (MRPP) for the plant community indicated that the grazing treatment does have a significant effect on the composition and abundance of plant species, which is consistent with the cluster and beta diversity results discussed previously. In the ISA results there were several plant species that approached the threshold of significance, however no species from these groups were equal to or less than $p = 0.05$, however several species scored high Indicator Values (IndVal) exceeding 94/100.

The plant species with high IndVal associated with ungrazed treatment sites in the ISA were mainly trees and shrubs, and some grasses and herbs, while the plant species with high IndVal associated with grazed sites were mainly grasses, herbs and moss. Trees such as trembling aspen *P. tremuloides* and bur oak *Q. macrocarpa,* and the shrub dwarf birch *Betula occidentalis* Hook. all had IndVal=100 and were indicative of the ungrazed treatment. *P. tremuloides* prefer open prairies and encroach into open areas (Johnson et al. 1995) but are easily damaged by livestock activity. *P. tremuloides* is an early colonizing tree species and indicates progress in forest succession, the transition of non-forested ecosystems into forested ones (Johnson et al. 1995). *B. occidentalis* is a riparian shrub species that needs moist conditions (Johnson et al. 1995) more likely to be found in ungrazed alvars that have less compacted soils able to conduct and hold water better than grazed soils. Shrub buffalo-berry *Shepherdia canadensis* Nutt., herb Seneca snakeroot *Polygala senega* L., and native grasses Porter's brome *Bromus porteri* Nash, and slender wheatgrass *Elymus trachycaulus* Gould also had IndVal=100 and were indicative of ungrazed alvar habitat. *S. canadensis* and *B. porteri* prefer open woodland and thicket habitat, so does *E. trachycaulum* which is often associated with aspen forests and is a shade tolerant grass (Johnson et al. 1995, United States Department of Agriculture 2018). The ungrazed sites had greater canopy cover due to the relative abundance of trees and may therefore support more shade-tolerant plant species.

There were fewer species associated with the grazed treatment in the results of the plant ISA. The species that were indicative of the grazed treatment with high IndVal were exclusively species of herbs, grasses and moss that prefer to grow in dry, open habitats. *M. lupulina* (IndVal=98.5) is a shade intolerant clover (USDA 2018), was only recorded in grazed sites which may have a less dense shrub canopy than the ungrazed sites allowing this species to grow in grazed sites. *M. lupulina* is also a nitrogen fixing species (USDA 2018) that is able to make nitrogen more biologically available in grazed sites and thus its presence maybe related to the higher levels of nitrogen in the soil. Dry grassland prairies and open, dry, boreal woodlands are the preferred habitat for prairie cinquefoil *Potentilla pensylvanica* L. (IndVal=98.6) and grazed soils were more compacted in this study which may have affected the ability of soils to to hold and conduct water.

*Geum triflorum* (IndVal=94.4) is a drought tolerant plant, intolerant to saline soils, and is an unpalatable species to grazing animals (USDA 2018). The presence of this species in grazed sites indicates that the soils, though significantly higher in calcium and sodium than ungrazed sites, are not salinized to the degree that would be a detriment to this plant species. The invasive species *P. pratensis* (IndVal=94.4) and the native prairie species Junegrass *Koeleria macrantha* Schult. (IndVal=90.6) are both grazing tolerant species that can withstand repeated grazing, making them more suited to the grazed habitat (Johnson et al. et al. 1995). *Abietinella abietina* (IndVal=94.2) prefers dry, calcareous soils and exposed rock areas in boreal forest, aspen parkland and prairie habitats. The soils in grazed sites had higher levels of calcium in the soil than did the ungrazed sites, which may favour species such as *A. abietina*.

### 5.2.6 RDA

Based on the RDA of the plant community, the ungrazed sites were grouped closer together than with the grazed sites and were separated from the grazed sites (beta analysis where ungrazed and grazed sites only had 29% similarity in the quantitative analysis). While the grazed sites are in a similar position on the first axis, on the second axis the grazed sites differ from each other and the sites were vertically separated. These results support a fairly important a difference between the plant assemblages between grazed and ungrazed sites in response to cattle removing palatable plants and trampling others, as well as increasing soil nitrogen concentration, which resulted in a less rich community of plants.

The RDA showed that increasing nitrate levels in the soil were significantly associated with the grazed sites. The grazed treatment was associated with *A. millefolium*, which prefers areas where there are patches of disturbed ground (Johnson et al. 1995) such as the patches of ground naturally disturbed by livestock grazing activities (Rusch 1988). *A. millefolium* is tolerant of drought conditions, intolerant of soil salinity, and is not-palatable to grazing animals hence the abundance of this species in grazed sites compared to the less disturbed, and more saline ungrazed sites (USDA 2018). Grazed sites were also associated with sedges from the genus *Carex* L., which are grass-like plants that prefer moist conditions and are not frequently browsed by cattle.

Three native prairie grasses were associated with the grazed treatment, Purple-oat grass *Schizachne purpurascens* Swallen*,* Prairie dropseed *Sporobolus heterolepis* A. Gray, and Tufted hair grass *Deschampsia caespitosa* P. Beauv. *D. caespitosa* is a tough and rigid grass species that is unpalatable to cattle (Johnson et al. 1995, USDA 2018). *D. caespitosa* is also a competitive species that spreads readily into disturbed areas, such as the grazed sites, and may outcompete trees for resources (USDA 2018). Several other species associated with the grazed treatment are also unpalatable or inedible to livestock animals. Several species associated with the grazed treatment in RDA also had high indicator values in the ISA, *G. triflorum, M. lupulina*, *K. macrantha, P. pensylvanica, P. pratensis,* and *A. abietina,* which were discussed previously.

Also several species of plants were strongly associated with the ungrazed treatment sites, such as *P. tremuloides*, *B. occidentalis*, *P. senega* and reindeer lichen *Cladina spp.*, which also had high indicator values of the ungrazed treatment in the ISA. Although a large number of plants are clustered around the ungrazed treatment sites, for this discussion I will focus on the species that explained the most variation in the RDA and the species most associated with the ungrazed treatment. Big bluestem *Andropogon gerardii* Vitm. is a native prairie grass species that is highly palatable to grazing animals (USDA 2018), explaining the greater abundance of this species in ungrazed sites compared to grazed sites. *A. gerardii* is recommended for use controlling soil erosion (USDA 2018), and is therefore a benefit to the ecosystem, and this species is adapted to shallow soils like those found in alvars. Shrub bearberry *A. uva-ursi* forms a thick mat of ground cover in suitable boreal forest-like habitats, like the ungrazed alvars, and also stabilizes the soil (USDA 2018). Similarly, *F. virginiana* will also form complete ground cover, and has a fibrous root system to aid soil stability (UTBG 2012, USDA 2018). All three of these species contribute to soil stability, makes them more resilient and prevents erosion.

Purple prairie clover *Dalea purpurea* Vent. and Pale vetchling *Lathyrus ochroleucus* Hook. are highly palatable wildflower species that prefer open and rocky habitat and are frequently removed by livestock in grazed areas, which also may lead these species to be more prevalent in the ungrazed treatment (Johnson et al. 1995, USDA 2018). Bastard toadflax *Comandra umbellata* L. prefers dry open woodlands and requires a diversity of plants nearby, as it is a semi-parasitic species that robs resources from the root networks of nearby plants (Johnson et al. 1995). The ungrazed sites had greater species richness, and may have provided more host plants for *C. umbellata* to parasitize.

## 5.3 Butterfly assessment

### 5.3.1 Differences between sites and treatments

Contrary to my initial hypotheses, butterfly assemblages were not significantly different when measured using species richness, rarefied species richness and diversity indices, including evenness and dominance, between sites or between grazed and ungrazed treatments, while ISA and RDA showed a separation of species between grazed and ungrazed alvars.

Though plant species richness was significantly lower in the grazed sites compared to the ungrazed sites, there was no significant difference in butterfly species richness between the treatments. This differs from my initial hypothesis that livestock grazing activities would significantly impact butterfly diversity using all of the various measures tested in this study and there would be a broad response to changes in the plant community, such as damage or removal of larval/nectar plants.

### 5.3.2 Landscape diversity

The butterfly community showed a relatively high degree of beta similarity between sites (60 to 80%) when qualitative similarity was calculated. The quantitative similarity was high among the ungrazed sites (77%) and moderate among the grazed sites (68%). Quantitative diversity was lower (40 to 70%) between sites. The quantitative similarity was moderate among the ungrazed sites (52%) and higher among the grazed sites (65%). The average quantitative beta similarity score between grazed and ungrazed sites was 47%. The trends in butterfly similarity between sites were similar to those found in plants between sites although for the plants grazed and ungrazed sites the quantitative similarity score was only 29%, whereas it was much higher for the butterfly species. As with the plants grazed sites seemed to have less variability in the presence/abundance of butterfly species than the ungrazed sites.

### 5.3.3 Cluster analysis

The cluster analysis placed the grazed sites into one group distinct from the ungrazed sites, based on the butterfly species relative abundances. The grouping patterns of the butterfly and plant cluster diagrams were relatively similar, but there were several differences. In the plant cluster diagram the most similar sites (most closely linked) were MRBW and MRC (grazed sites), while in the butterfly diagram CLMN and CLMS (ungrazed) were the most closely linked sites. The clustering in the plant community among the grazed sites showed a higher degree of similarity in comparison to the ungrazed sites while the clustering in the butterfly community among the grazed was similar to that found in the grazed sites for plants. Sites CLMN and CLMS were very similar in the ungrazed treatment. This is reflected in the amount of information remaining on the axis where the next grouping of PEG to the ungrazed group is created. Note that though CLMN and CLMS are more similar in terms of butterfly species abundance, the association of these two sites with PEG is actually lower than that found in the plant community.

### 5.3.4 MRPP/ISA

The MRPP for the butterfly community indicated that grazing treatment does have a significant effect on the composition of this community, which is consistent with the cluster analysis. The ISA results indicated that there were many butterfly species that approached the threshold of significance, however no species from these groups were equal to or less than $p = 0.05$, however several species scored moderately high Indicator Values (IndVal) exceeding 70/100.

Northern blue *Plebejus idas* L. (IndVal=89.2) was associated with ungrazed sites and feeds on heathers from the family Ericaceae, such as *A. uva-ursi,* and legumes from the family Fabaceae, such as *L. ochroleucus* (ISU 2018), both of which were more associated with the ungrazed treatment. Larvae of the hoary elfin *Callophrys polios* Cook & Wats. (IndVal=78.2) feed on *A. uva-ursi*, which was abundant in the ungrazed alvar sites (Government of Canada, 2014, ISU 2018), explaining the association of *C. polios* with the ungrazed treatment. The Viceroy *Limenitis archippus* Cramer (IndVal=70.4) was associated with the grazed treatment, larvae of this species feed on the foliage of the genera *Salix* (willows) and *Populus* (cottonwoods), such as *P. tremuloides,* both of which were also associated to the ungrazed treatment (Government of Canada 2014, ISU 2018). Conversely adult *L. archippus* butterflies feed on nectar from various wildflower sources, and many species of wildflowers were associated with the ungrazed treatment.

The specific larval host plants used by the common alpine *Erebia epipsodea* Butler (IndVal=81.8) are not known, but it is suspected they feed on *Carex* sedges and grasses (ISU 2018). Sedges and a number of native grass species were more associated with the grazed treatment, which may explain why this species may be more abundant in the grazed sites. Larvae of the greenish blue *Plebejus saepiolus* Bois. (IndVal=75.7) feed on a variety of clovers including *Trifolium repens* and *Trifolium hybridum* (Government of Canada 2014)*,* both of which had greater percent cover in the grazed sites, and *M. lupulina* was significantly associated with the grazed sites. Larvae of the Cabbage white *Pieris rapae* L. (IndVal=72.1) consume cabbage and related cruciferous plants, and adults take nectar from an array of plants including dandelion *Taraxacum officinale* Weber, red clover *Trifolium pratense* L., mustards from the genus *Brassicaceae*, asters from the genus *Asteraceae*, and mints from the genus *Lamiaceae* (ISU 2018). Several asters were associated with the grazed sites including *A. millefolium*, Gallardia *Gallardia aristata* Pursh, and species from the genera *Antennaria* and *Arnica*, all of which are food resources for adult *P. rapae,* which may explain their prevalence in grazed sites.

### 5.3.5 Rarefaction

Richness of species is dependent on sample size and survey effort, which is especially important when using attractant traps to sample populations of smpling mobile species, thus rarefaction was used to standardize the species richness estimates at a minimum number of individual observations for each site. Comparing rarefied species richness is more accurate than comparison of simple species richness when sample sizes or survey effort may differ (multiple surveyors or multiple traps). Rarefaction analysis of butterflies indicated three overlapping groups of sites based on the expected species richness at 180 individual observations using the 95% confidence interval. While there was no significant difference between the sites for rarefied species richness each group contained one grazed and one ungrazed site (MRBE & PEG, MRC & CLMN, and MRBW & CLMS). The rarefaction analysis of butterflies did not indicate a significant difference between sites or treatments of rarefied species richness. The rarefaction curves for all sites did not completely flatten out at the maximum level of diversity for each site during the sampling period indicating there was room for more species to occur although the rate of increase was quite similar between sites.

### 5.3.6 RDA

The ordination triplot produced in the RDA of butterfly species was similar to the previous triplot based on plant species, where nitrate levels were also significant and associated with the grazed treatment. The grazed sites were quite dissimilar, while the ungrazed sites grouped closely together. While the grazed sites are in a similar position on the first axis, on the second axis the butterfly assemblages in the grazed sites differ widely from each other. The spread of the butterfly species along the first axis showed separation between butterfly species most associated with the grazed and ungrazed sites.

There were several species of butterflies associated with the ungrazed treatment sites, such as *P. idas*, *C. polios, G. lygdamus*, *S. atlantis*, and *S. cybele*. and *C. polios* and these associations with the ungrazed treatment were similar to those found in the ISA analysis. Larval food plants for *G. lygdamus* are species from the family Fabaceae, especially species of the genera *Lathyrus* and *Vicia,* including *L. ochroleucus*, which was also associated with ungrazed sites (Government of Canada 2014). *S. atlantis* and *S.cybele* larvae feed on violets, Genus *Viola* (ISU 2018). Adult *G. lygdamus,* as well as *S. atlantis* and *S.cybele* adults feed on nectar from asters from family *Asteraceae* (ISU 2018), such as the upland white aster *Solidago ptarmicoides,* which was associated with ungrazed sites. *P. cocyta*, and *P. canadensis* were more associated with the ungrazed sites than the grazed sites. *P. cocyta* larvae feed on species in the family *Asteraceae* (Government of Canada 2014), and as mentioned only one aster species, *S. ptarmicoides,* was associated with the ungrazed sites. Larvae of *P. canadensis* prefer to feed from trees, including species of *Salix* and *Populus* (Government of Canada 2014), which were both associated with the ungrazed treatment sites and they appear to utilize both alvar treatments. *Papilio canadensis* is also a strong flyer and avid nectar feeder and could easily move between grazed and ungrazed sites even if they are several kilometres apart (Klassen et al. 1989).

On the positive side of the first axis are several species closely associated with the grazed treatment. The species located near site MRBW in the upper right were *T. lineola*, and *C. philodice*. Larvae of *T. lineola* and *C. philodice* feed on grasses, and their preferred host is *P. pratense* a species that was found in greater abundance in the grazed sites, though they will also eat Couch grass (*Agropyron repens*)(Government of Canada 2014). Both species are also associated with various forage crops and are often abundant in agricultural areas in Manitoba (Klassen et al. 1989). Site MRBE had the highest nitrate levels and had a group of species associated with it in the RDA, including *E. epipsodea*, *P. saepiolus*, *V. cardui*, *C. tullia*, *B. bellona* Fabr., and *H. comma assiniboia* Lyman. Two species associated to the grazed sites in RDA, *E. epipsodea* and *P. saepiolus,* were previously associated with the grazed treatment in ISA. *Vanessa cardui* larvae feed on a wide variety of plants, including asters *Asteraceae,* especially thistles from genus *Cirsium* and wormwoods from the genus *Artemisia* (Government of Canada 2014). Though two asters were associated with the grazed treatment, *A. millefolium* and *G. aristata,* only one Drummond's thistle *Cirsium drummondii* Torr. & A. Gray was recorded and this was in an ungrazed site. Plains wormwood *Artemisia campestris* L. was found in greater abundance in the grazed sites compared to the ungrazed sites, explaining the association of *V. cardui* with the grazed treatment. Larvae of *C. tullia* feed on many species of grasses, but their preferred food source is invasive grass *P. pratensis* (Government of Canada 2014)*,* which was also associated with the grazed sites. *B. bellona* feed on violets (*Viola*) as larvae (ISU 2018), however the percent cover of violets was similar between the two treatments in the raw data. Larvae of *H. comma assiniboia* are known to feed on *P. pratensis,* which was associated with the grazed treatment, but also feed on *A. gerardii,* which was associated to the ungrazed treatment. *C. alexandra* is located in the lower right near site MRC, and larvae of this species prefer to feed on a wide variety of legumes, such as *M. lupulina* a clover species associated with the grazed treatment.

## 5.4 Moth assessment

### 5.4.1 Differences between sites and treatments

The moth assemblages were not significantly different in species richness, rarefied species richness and diversity indices, including evenness and dominance between sites or between treatments, while ISA and RDA showed a separation of species between grazed and ungrazed alvars.

Though plant species richness was significantly lower in the grazed sites compared to the ungrazed sites, there was no significant difference in moth species richness between the treatments. This differs from my initial hypothesis that livestock grazing activities would significantly impact moth diversity using using all of the various measures tested in this study and there would be a broad response to changes in the plant community, such as damage or removal of larval/nectar plants.

### 5.4.2 Landscape diversity

The moth community showed a low/moderate degree of beta similarity between sites (41 to 53%) using qualitative similarity. The qualitative similarity was moderate among the grazed sites (50%) and moderate among the ungrazed sites (46%). Quantitative similarity was also low (32 to 62%) between sites. The quantitative similarity was moderate among the ungrazed sites (49%) and moderate among the grazed sites (49%). The quantitative beta similarity score between grazed and ungrazed sites averaged 46%. The trends in moth similarity suggested that moth species seem to be less similar between sites compared to plants and butterflies although there does not appear to be as large a difference between the moth assemblages between grazed and ungrazed sites. The quantitative beta similarity of site MRBE was notably low when compared to all other sites, with the exception of MRC. This may have indicated that the moth community of site MRBE is more unique in comparison to other sites.

### 5.4.3 Cluster analysis

The cluster groupings indicated in the moth community was inconsistent with the treatment groups, suggesting more overlap in the moth community than the plants and butterflies between grazed and ungrazed treatments. The two most closely linked sites were MRC (grazed) and PEG (ungrazed) shared a considerable amount of species. Sites MRBW (grazed), CLMN, and CLMS (ungrazed) were subsequently linked to the first two sites creating one large group in the cluster diagram. Site MRBE was placed in its own separate group, indicating less overlap with the moth community found in other sites. This reinforced the low level of beta similarity of the moth community between site MRBE and the other sites observed in landscape diversity analysis.

### 5.4.4 MRPP/ISA

The MRPP for the moth community indicated that grazing treatment did not have a significant effect on the composition of this community, which is consistent with the cluster analysis results. The ISA results indicated several moth species that approached the threshold of significance, no species from these groups were equal to or less than $p = 0.05$. Though not statistically significant several species scored moderately high Indicator

Values (IndVal) exceeding 70/100. Of these moth species with moderately high IndVal five of the six of them were association to the grazed treatment: *Proxenus miranda* Grote (IndVal=100), *E. servitus* (IndVal=72.4), *A. devastator*, *P. carneola* (IndVal=80.6), and *Argyrostrotis anilis* Drury (IndVal=75). Larvae of *P. miranda* feed on a wide variety of plants, including species found in alvars *T. officinale* and *F. virginiana,* however these specific plants were associated with the ungrazed treatment. The larval hosts of *E. servitus* and *A. anilis* are unknown. *A. devastator* larvae feed on a variety of grasses and herbaceous plants (ISU 2018). Larvae of *P. carneola* prefer to feed on species of goldenrod from the genus *Solidago* (and two other genera not recorded in alvars) (ISU 2018). This suggests moth species may be travelling from further away from their feeding habitat than butterflies, which were more associated with the plants found in alvars.

Only one species was associated with the ungrazed sites *M. mixta* (IndVal=74.8), and the larval host species are unknown (ISU 2018), though likely to be a variety of grasses. Several potential host grasses were associated to the ungrazed treatment, including *B. porteri, E. trachycaulus,* and *A. gerardii.* Overall while a number of species of moths were more associated with the grazed treatment in the ISA there was no clear indication of relationships with the larval host plants. This may be in part related to the fact that in Manitoba many of the larval host plants are unknown or host plant data is derived from areas outside the province.

### 5.4.5 Rarefaction

The rarefaction analysis of moths indicated two distinct (non-overlapping) groups of sites based on expected species richness at 200 individual observations using the 95% confidence interval. There was a significant difference sites in rarefied species richness between the sites and the two sites with the greatest rarefied richness of moths were grazed sites. The group of sites with the highest estimated rarefied species richness contained MRBE and MRC, suggesting that grazed sites may have higher levels of species richness of moths than the ungrazed sites. The sites with lower rarefied species richness were MRBW (grazed), CLMN, CLMS, and PEG (ungrazed). The rate of increase for species richness in alvar sites produced different rarefaction curves, for two of the grazed sites the rate of increase was high, while the rate of increase for all three ungrazed sites was more moderate. This may indicate different associations of moth species between sites.

### 5.4.6 RDA

The ordination triplot produced in the RDA of moth species was different in configuration compared to the previous two triplots based on plant and butterfly species data. In the triplot the treatment groupings are different in that the grazed sites show much more species overlap than the ungrazed sites (with the axes changed in orientation). The grazed sites are closer to each other than to the ungrazed sites, indicating similarity in terms of moth community composition in the grazed sites, with the ungrazed sites being more dissimilar. The second (vertical) axis accounts for slightly more of the variation explained in comparison to the first axis in the RDA, thus the overall spread of moth species between all sites is less clumped. The ungrazed sites CLMN and CLMS are grouped together on one side of the first axis from PEG, indicating that site PEG was dissimilar to the other ungrazed sites in terms of moth community composition. Although the diversity indices, species richness and rarefaction results were not significant the RDA suggests a more complex relationship between moth associations and sites.

There were several species of moths grouped near the grazed sites on the negative side of the first axis, such as *E. servitus*, *A. devastator*, *P. carneola*, *A. pyramidoides*, *C. cocctya* Grote, and to a lesser extent, *C. calami* Harvey, and *A. quercifoliana* Fitch. The associated larval host plants for *E. servitus*, *A. devastator*, and *P. carneola* are discussed in the ISA section where the ISA shows some associated with the grazed sites. Larvae of *C. coccinata* and *C. calami* feed on species of oak Genus *Quercus,* including *Q. macrocarpa* (ISU 2018). *C. calami* is also predaceous and will eat other caterpillars. *A. pyramidoides* and *A. quercifoliana* larvae prefer to feed in the leaves of many types of trees and shrubs, including alvar species such as *Q. macrocarpa* and wild raspberry *Rubus idaeus* L. (ISU 2018). Though *C. coccinata* and *A. pyramidoides* were associated with the grazed sites, their host species were only recorded in the ungrazed sites. *Q. macrocarpa* was present in the grazed sites, but not recorded by the transects, therefore any suggested association of these moth species with oak would not be highlighted in the RDA.

This may be instructive from the perspective that the distribution of trees both on the perimeter and within alvars may have an important influence on moth activity. Also because larger moths (and butterflies) may fly over longer distances, the distribution of treed habitat outside an alvar may also influence species richness. A landscape study of other habitats surrounding alvars in Manitoba may prove to be useful in explaining the association of the larger moth species with alvar treatments. No effort was made to divide moths and butterflies into size categories, which can predict mobility (Burke et al. 2011). A next step on this research would be to analyze butterfly and moth association with treatments using the criteria developed by Burke et al. (2011) whereby smaller less mobile species would be assessed separately than larger, more mobile species.

In the RDA a group of species is located above the grazed sites, indicating these species were associated both with MRC and MRBW and also the ungrazed site PEG, including: *C. crassiuscula*, *A. parthenice*, *C. variolaria*, *S. macularia*, *C. persicana*, *O. majuscula* and *N. frigidana*. Larvae of *C. crassiuscula* prefer to feed on hosts such as clover, grasses, and lupines, and grazed and ungrazed sites were both associated with several species of grass and clover. *A. parthenice* larvae prefer to feed on plants from the *Asteraceae* family, especially *T. officinale* and thistles, such as *C. drummondi. O. majuscula* are generalists that feed on a wide variety of plants including *T. officinale,* various grasses, and species from the genera *Salix.* Larvae of *N. frigidana* feed predominantly on *Salix,* but will also feed on species of the genus *Populus* (ISU 2018). Larvae of *C. variolaria* and *S. macularia* feed on the leaves of species from the genera *Populus,* and *Salix* (ISU 2018)*,* which were both associated with the ungrazed treatment. These species are also likely to be found in the grazed alvar sites, explaining the positions of *N. frigidana, C. variolaria* and *S. macularia* in the triplot. *C. persicana* larvae are tree generalists that feed on a wide variety of trees (over 40 species), including species from the genera *Betula, Pinus, Picea,* and *Salix* (ISU 2018)*,* and there were significantly more trees in the ungrazed sites, especially PEG. In the previous RDA's of plants and butterflies, the two groupings of species around the grazed and ungrazed treatments clearly indicated that these communities were different from one another, however with the moths there is more crossover of species between grazed sites and site PEG.

There were also a number of moth species associated exclusively with the ungrazed sites. Site PEG in the upper right is associated with species *E. confusaria*, *X. pallorana*, *E. pampina*, and *S. lutra*. Larvae of *E. confusaria* feed on species of the *Asteraceae* family, including species of goldenrods (ISU 2018), such as *S. simplex* and *S. ptramicoides*, which were both associated with the ungrazed treatment. *X. pallorana* larvae feed primarily on alfalfa *Medicago sativa* L. (not found in alvars) and *M. officinalis*, which was more abundant in ungrazed sites, especially site PEG. Larvae of *E. pampina* feed on the leaves of species from the genera *Prunus* (ISU 2018), which was not recorded by the transects but has been previously observed in Manitoba alvars (MAI 2012). *S. lutra* larvae are tree and shrub generalists that feed on many species of plants, including species from the genera *Betula, Populus,* and *Salix* (ISU 2018) all of which were associated with the ungrazed sites.

Two species are located in the lower right associated with ungrazed sites CLMN and CLMS, *S. rosea*, and *S. dentata*. The larval host plants of *S. rosea* are *T. officinale, S. canadensis,* and species from the genera *Ribes* and *Salix* (ISU 2018), all of which had greater percent cover in the ungrazed sites. Larvae of *S. dentata* feed on bog laurel *Kalmia polifolia* Wangenh. and species from the genus *Vaccinium* (ISU 2018), neither of which are known to be found in Manitoba alvars. They may feed on other plants in alvars or come from nearby habitats as they are both relatively large moths and would have the ability to sly into alvars from adjacent habitats. Two additional species associated to the ungrazed treatment were *M. mixta* (discussed previously) and *M. occiduaria*, the larvae of which feed on a variety of shrubs and trees, including trees from the genera *Populus* and *Salix,* and shrub *D. fruticosa* (ISU 2018). *Populus* and *Salix* were both associated to the ungrazed treatment, and *D. fruticosa* was found in greater abundance in the ungrazed sites.

### 5.4.7 Feeding guild analysis

Feeding guilds are a commonly used way of determining interactions between the plant community and the Lepidopteran community (Lewinsohn 2005). Specialized species rely on fewer food resources but use these resources efficiently, while generalized species are flexible and consume a wide range of food resources (Leps et al. 1998). Specialized species depend on just one or a few host plants and if these plants decline the species will decline in response (Shaffers 2008). Analysis of moth feeding guilds indicated that there was a significant difference in the distribution of individuals among the guilds between grazed and ungrazed treatments. The guilds showing a significant response between the treatments included the Tree, Shrub, Shrub/Ground, and Generalist guilds, with a higher proportion of Shrub/Ground feeders in grazed sites and a higher proportion of Tree and Shrub feeders, and Generalists in ungrazed sites.

The most abundant species contained in the Shrub/Ground feeding guild were *C. crassiuscula*, and *A. parthenice*. *C. crassiuscula* was particularly abundant specializing in grasses, and herbs, specifically legumes (*Fabaceae*) such as clover and lupines (Iowa State University, 2018). Grasses and non-native clovers were abundant in the grazed sites that would create favourable conditions for species *C. crassiuscula*. *A. parthenice* larvae feed on plants in the *Asteraceae* family of herbs specifically feeding on dandelion *T. officinale* Weber and thistles, such as *C. drummondii* (ISU, 2018). While *T. officinale* was more abundant in the ungrazed sites, there may have been other host plant species more abundant in grazed sites that *A. parthenice* larvae were utilizing.

The two most abundant species in the Tree guild were *P. aequivoca* and *M. disstria*, which were two of the most abundant moth species in the study, and these species are more associated with the ungrazed treatment likley due to the greater abundance of trees available in the ungrazed sites. *M. disstria* feeds on a variety of trees including species found in ungrazed alvars, such as *Populus, Quercus,* and *Salix* (ISU, 2018). The Shrub guild contained species *S. dentata* and *E. confusaria,* whose food preferences were both discussed previously, and were associated to the ungrazed sites.

The most abundant species contained in the Generalist feeding guild were *M. occiduaria*, *S. lutra*, *X. pallorana*, *C. persicana* Fitch, and *S. limboundata*. Ungrazed sites had greater richness of species of plants than the grazed sites. Larvae of *M. occiduaria* feed on broad-leaved trees and shrubs, and similarly larvae of *S.lutra* feed on *P. tremuloides*, birch species, buffalo-berry *S. canadensis*, and a host of other trees and shrubs (ISU, 2018). The shrub *S. canadensis* was recorded exclusively in the ungrazed sites and the ungrazed treatment had a greater abundance of trees and shrubs as well as having trees in closer proximity to the alvar habitat than in the grazed treatment, which may explain the increased occurrence of these generalist species. *X. pallorana* larvae consume primarily sweet clover *M. officinalis* and *M. sativa*, but also feeds on other herbs, shrubs, and trees (ISU 2018). Larvae of *C. persicana* feed on greater than forty species of trees and larvae of *S. limboundata* feed on various fruit -producing trees and shrubs, as well as herbs white clover *M. officinalis* and *T. officinale* (ISU 2018). As mentioned previously, ungrazed sites had greater abundance of *T. officinale* explaining the increased abundance of *S. limboundata*. Sweet clover *M. officinalis* was more abundant in the ungrazed treatment, in particular site PEG had high percent cover of clover to support an abundance *X. pallorana* and *S. limboundata*.

### 5.5 Management recommendations

Before the settlement of Europeans, western Canadian grasslands were often subjected to short but intense periods of grazing by migrating herds of animals several years apart, and today seasonal, domestic, livestock grazing simulates the previous natural grazing systems (Bailey et al. 2010). A holistic and integrated management approach is recommended to preserve alvar meadow areas and enlarge existing fragments, given the tendency for alvar to occur as a mosaic with forested habitat, alvars are vulnerable to encroachment and eventual forestation (Eriksson & Rosen 2013, Leppik et al. 2013). Critical factors for consideration in the management of rangeland plants are drought, herbivory, maintenance of plant growth, and the quality of the soil. Grazing has been demonstrated as an effective management strategy for preventing the encroachment of trees and shrubs into alvar habitat (Eriksson & Rosen 2008), and also appears to be effective in Manitoban alvars, though there is evidence of reduced plant species richness and soil compaction in the grazed sites.

Soils in grazed sites also had increased levels of nitrate and sodium, both of which may have negative effects when present in excess in the soil. Highly nitrogenous sites may favour nitrophilous species that may come to dominate the plant community, and loading of sodium (and calcium) leads to soil salinization, which limits the plant growth, and these factors may be related to the lower plant richness (Titlyanova et al. 1988). Grazing should be managed to maintain vegetative cover and thereby protect the soil, and help to perpetuate the native grassland plant species (Bailey et al. 2010). Spring, early summer, and times of drought are when the plant community is most vulnerable to negative effects of grazing so grazing should be deferred until mid-summer or after the drought period has ended (Bailey et al. 2010). The intensities of grazing given for the grazed sites in Chapter 3 were each estimated at a similar, low level (1.23-1.29 AUM/hectare) and further research is necessary to determine the effects of various, specific levels of grazing intensity (i.e. comparison of low, medium and high grazing intensity treatments) including more of the grazing alvars present in Manitoba's Interlake. Increasing the number of grazed replicates may clarify differences between grazing intensities in plant species diversity indices, besides richness.

It is important to take into account the depth of the soil when determining if grazing is appropriate as relatively thin and thick soils respond differently to grazing. Alvars with thicker soils are at higher risk to transition into woodland, as they develop a thicker organic layer at the surface and this is more likely to take place in the ungrazed treatment due to the potential for additional organic matter deposition. Rosen (1988) and Reschke et al. (1999) identified the more forested edges of the habitat and areas of relatively thick and resource rich soils as the most susceptible parts of alvars to shrub and tree encroachment. I sampled alvar soils from the centre of the habitat away from edges and there was no significant difference in soil depth between grazed and ungrazed sites. Alvar areas with thin soils, like the areas I sampled, are susceptible to disturbances such as grazing and are vulnerable to compaction and erosion caused by grazing according to Leppik et al. (2013). In my study, grazed alvars had significantly higher soil compaction than the ungrazed sites, and the compacted soils may reduce the ability of tree and shrub species to establish and reproduce but may indirectly lower plant diversity. This may be an important factor to consider when planning alvar management as sites with the highest soil compaction may require a period of rest from grazing during peak plant reproductive season to allow the soil and plant community to recover from the effects of grazing.

Prevention of tree and shrub encroachment may be achieved using livestock grazing that is carefully controlled and at a low level of intensity (Hammond & Miller 1998). Rotational grazing regimes with short grazing periods and long recovery periods are preferred for alvar ecosystems as it allows cattle to remove the encroaching plants and also for the native vegetation to regenerate (Catling 2016). Rotational grazing can be compatible with butterfly conservation as it maintains native plant species diversity in the resting phases to allow recovery from the effects of grazing, although the capacity for restoration may be highly variable among sites and the actual seasonal grazing period is critical to determine (Dana 1997). Grazing may be implemented rotationally to encourage plant cover of native forb (nectar) species with foliage heights between 25 and 40 cm (10 and 16 in) that encourage butterfly activities (Dana 1997). There appears to be more of a separation in the butterfly species than the moth species between grazed and ungrazed alvars sites. This may indicate that butterflies were more dependent on the open grassland meadow areas of alvars where as moths by comparison were more dependent on the surrounding forested or agricultural habitats. Butterfly species were more affected by changes in plant species composition in alvar meadows than moth species, most likely due to their increased dependence on nectar bearing plants. Therefore efforts to conserve butterflies in these areas should focus on maintaining alvar meadows, whereas conservation of alvar moths would require further research into the other habitats that make up the mosaic landscape around alvars.

A beneficial effect of grazing is the creation of small, disturbed patches of ground surface that represent available habitats for regenerating plants (Leppik et al. 2013) and these types of patches can be generated artificially when grazing animals are not present. If grazing is not appropriate or not sufficient to prevent the encroachment of trees and shrubs, then mechanical vegetation clearing may be necessary (Eriksson & Rosen 2008). Rosen (1988) recommends this clearing be done using chainsaws only, and does not advocate the use of heavy machinery and tractors in alvars. Clearing may be made more effective by also scraping away small patches of topsoil to create open niches for plant regeneration (Leppik et al. 2013). Some types of alvars may also benefit from regular moderate fires to maintain their open character, if it is not maintained by grazing alone (Reschke et al. 1999), however any burning should be treated with caution, by burning small portions of the habitat to create a mosaic of seral stages to maximize plant diversity (Catling 2009).

### 5.6 Limitations

Obtaining accurate estimates of species diversity is highly dependent on the sampling effort, as assemblages must be exhaustively sampled otherwise diversity may be over or underestimated (Magurran 2004). The Pollard-Yates method used by Brown and Boyce (1998) and Thomas (1983) typically employed transects from 1-3 km in length. Due to the nature of alvar occuring as part of a mosaic within a forested landscape, it was often not an option to use the recommended length of transects as the sites were limited in size, especially in the heavily treed PEG site. The placement of transects prevented sampling of edges in this study that could have also had an effect on the diversity measurements especially in the large compared to the smaller alvars.

Butterfly counts using the Pollard-Yates sampling method may be compared from year to year to observe changes to butterfly abundance and composition (Brown et al. 1998). The abundance of butterflies recorded in year one of this study was fairly low thus the sampling effort in the second year was increased (2017). The sampling effort for butterflies and perhaps for moths for monitoring alvar communities as a bioindicator tool in the future should remain at the same or greater frequency and duration as the sampling schedule in 2017, which could more accurately reflect the species found in alvars (Appendix 5). Rarefaction analysis showed that some sites were still accumulating species throughout the sample period and that more intense sampling may show greater differences in fauna between treatments (although it is probably impossible to sample all potential Lepidopteran species found in alvars in the short time frame of this study). I did not compare Lepidopteran diversity between the years in the present study, however it is worth noting there was less sampling effort for butterflies in 2016 than in 2017 due to time constraints related to intensively sampling the vegetation community in 2016. A comparison of diversity between years may provide a better estimate of resources needed to obtain a more complete assessment of the Lepidopteran fauna.

Moths were sampled using traps hung in trees and left unsupervised for approximately ten days at a time. Occasionally there were interruptions in sampling effort during the moth trapping periods when the traps were knocked down by wildlife (bears), or wind, or as in one case, filled with forest tent caterpillars. Also, suitable locations of traps were limited due to the lack of trees in alvar habitat. Traps were hung in different species of trees, though the majority of the traps were hung in oak trees. These deviations in trapping effort were recorded and these events occurred in the sites at random but may account for some variation in relative moth species abundances, though it is likely that these deviations had limited effects on the results as traps were replicated within sites. I also recommend inquiry into the size and/or mobility categories of moths and if these groups experience significant effects due to grazing, as it is possible smaller moths may be more sucestible due to their limited mobility compared to larger moths.

There is no established record of grazing intensity on alvars in Manitoba, and the estimates of grazing intensity I was given only reflect recent grazing activities and the history of grazing in these areas is unclear. The intensities were estimated and may not be 100% accurate, and as livestock do not use all areas of the grazing area equally, it is likely that some areas of the habitat are grazed more intensely than other less intense grazed areas and this would not be reflected in the estimates given. It is recommended that there is cooperation with Manitoba Sustainable Development and the alvar grazing leaseholders to begin to keep regular records of grazing intensities in these areas, and to potentially determine a rough history of past grazing activities in alvars. Also, it is recommended that future research be done in more grazed alvars to determine grazing intensities with better accuracy and study effects of different intensity levels of grazing on alvar ecosystems, i.e. comparing replicates of low, moderate, and high intensity grazing treatments. This would provide a greater level of accuracy of the effects of various intensities of grazing.

# Chapter 6

# Conclusions

Alvars are unique and diverse ecosystems that contribute to global and local biodiversity, due to their high levels of species richness and characteristic blend of tall grass prairie and boreal forest species of plants and insects. Various land uses in the Interlake area of Manitoba threaten the extent and quality of the already endangered alvars, and little was known about the impacts of grazing in particular, which occurs on over 75% of Manitoban alvars (MAI 2012). Grazing has been demonstrated to have both benefits and costs to alvar ecosystems, grazing animals maintain alvars by preventing the encroachment of shrubs and trees, but also cause damage to plants and soils (Titlyanova et al. 1988, Eriksson & Rosen 2008, and Catling 2016). Manitoba's alvars are listed as endangered under the Endangered Species and Ecosystems Act (2014) and long-term management requires the establishment of protected zones and management plans. Priority sites to be designated as protected zones in the context of this study are those sites with abundant, diverse, unique communities of plants and Lepidopterans, which will depend on the nature of the underlying soil. This study has compared all three of these important, biotic aspects of the ecosystem between grazed and ungrazed alvar sites.

## 6.1 Environment

Environmental factors such as disturbance regime, soil depth, soil micronutrients, and amount of exposed pavement are important in determining the distribution of plant species in alvar ecosystems (Kimmins 1997, Catling 2016). Soils in grazed sites were significantly more compacted than soils in ungrazed sites as a result of repeated trampling by livestock and this can have a negative effect on Lepidopteran larvae (Royer et al. 2008). Grazed sites also had significantly higher soil nitrate concentration than ungrazed sites as a result of cattle dung being deposited in these sites, and this elevated nitrate concentration may explain some of the reduction in species richness in the grazed sites. Certain plants prefer habitat with a high concentration of nitrate and may outcompete other species leading to a net reduction in richness of plants and by extension insects depending on them, notably the grazed site with the highest nitrogen also had the lowest plant species richness.

Hydrogen ion concentration, or pH, was significantly higher or more basic in the grazed sites compared to the slightly acidic ungrazed sites, attributed to the greater abundance of *J. horizontalis* in the southern ungrazed sites, CLMN and CLMS (Clematis North and South). The pH is an important determining factor in the establishment and reproduction of many plant species (Hazelton et al. 2014). Cation exchange capacity (CEC) indicates the buffering capacity of the soil to resist changes in pH, and though CEC was significantly different between sites, it was not significantly different between treatments.

Salinization of soils occurs when nutrients sodium, calcium, potassium and magnesium are present in excess, and this reduces the capacity of the soils to support plant growth (Hazelton et al. 2014). Calcium concentration was significantly different between sites, being highest in site CLMS, but was not significantly different between treatments. Sodium concentration was significantly different both between sites and between treatments; concentration of sodium was higher in grazed sites and highest in site MRBE. Concentrations of potassium and magnesium were not significantly different between sites, or between grazed and ungrazed treatment groups. Salinization did not appear to be a major threat to Manitoban alvars regardless of grazing disturbance as plants that are sensitive to salinization are still found in grazed sites with elevated sodium.

### 6.2 Plants

Due to their important role of producing biomass and other resources such as nectar that animals depend on for food, shelter and reproduction, plants are key in the conservation of biodiversity (Eriksson and Rosen 2008). Tree and shrub encroachment into alvars poses a threat to characteristically open alvar ecosystems and may result in biodiversity loss (Rusch 1988), and in extreme cases even a complete shift of alvar into forest ecosystem. Plant communities with higher diversity function with greater stability, meaning they are more resilient, resisting drought conditions and recovering more quickly after drought (Tilman and Downing 1994). The plant community of alvars in Manitoba was rich and unique containing 113 tall grass prairie and boreal forest species that are not typically found together in one ecosystem. There were significantly more trees that were closer to the transects (smaller meadows) in the ungrazed alvar sites, however the cover of shrubs, herbs/grasses, and lichens/mosses were not significantly different between grazed and ungrazed sites. Ungrazed sites supported a variety of shade-tolerant plant species that were found much less frequently in the grazed sites, which may have contributed to these sites having greater species richness. Conditions in grazed alvars were preferred by species of invasive grasses, and shade intolerant, nitrogen-fixing, and grazing tolerant species.

Landscape diversity analysis revealed that the grazed sites were more homogenous than the ungrazed sites in both qualitative and quantitative beta diversity, and the grazed and ungrazed sites differed considerably in plant species presence and abundance. The sites, when clustered based on the plant community, were placed into two distinct groups with the grazed sites and ungrazed sites separated. The MRPP analysis indicated that grazing had a significant effect on the plant community composition, and in the ISA several species were strongly indicative (IndVal>94) of either the grazed or ungrazed treatment. There are some species that have potential as indicator species to separate out unique plants found in grazed versus ungrazed alvars.

The RDA showed a range of plant species that were grouped with either the grazed and ungrazed sites, and also showing that the ungrazed sites were more similar to each other in plant composition than the grazed sites were to each other. This indicates that livestock grazing activities may have had a significant impact on alvar plant communities, and also may lead to higher soil nitrate concentrations, which could further effect plant composition. The species with high IndVal in the ISA were also grouped with the two different treatments provides further opportunity to identify certain indicator plants related to treatment type.

### 6.3 Lepidopterans

Alvars with diverse plant communities may in turn support diverse communities of butterflies and moths by providing a variety of plants for use as larval hosts and adult nectar sources for these pollinating insects. Bioindicator species may be used as indicators of diversity (and used to present loss of diversity) when species abundances are compared to determine differences over time or between two types of management techniques (Dufrene & Legendre 1997), such as grazed and ungrazed. In the present study the Lepidopterans were assessed as bioindicators that may be extrapolated to indicate potential differences in diversity between grazed and ungrazed alvar communities (Bouchard 1997), as insects are sensitive to ecological change (Kremen et al. 1993, New 2004) and provide an important food resource to many animals (Hammond & Miller 1998). Thirty-six species of butterflies and 137 species of moths were recorded in the surveys, however there was no significant difference in Lepidopteran diversity between grazed and ungrazed sites when measured using species diversity indices. Multivariate analysis highlighted a number of species that showed stronger associations with either grazed or ungrazed sites and could potentially be used as indicator species in further studies in the future.

Landscape diversity analysis results indicated that while grazed and ungrazed sites shared many of the same species, the actual abundances and presence of species were different between the grazed and ungrazed sites. The cluster analysis of butterfly species placed the grazed sites into one group distinct from the ungrazed sites. Overall grouping patterns of the butterflies were less strong between treatments than those found in the plant assessment. The MRPP analysis indicated that the effect of grazing on butterfly community composition was significant between grazed and ungrazed sites.

The RDA showed that the grazed and ungrazed sites contained different Lepidopteran species groups and that the ungrazed sites were more similar to each other than the grazed sites were to each other. Soil nitrate concentration was significant in the distribution of butterfly species and was strongly associated with the grazed sites. Species with high IndVal in the ISA were also important in the RDA, as well as several additional species being associated to each treatment. Ungrazed sites were associated with butterfly species that feed on wildflowers from the genera *Lathyrus* and *Vicia*, and some *Asteraceae,* including *S. ptarmicoides*, in addition to the previously mentioned, trees, shrubs, and forbs. Grazed sites were associated with butterfly species that feed on native and invasive grasses, legumes such as *M. lupulina,* asters from the family *Asteraceae*, and wormwoods from genus *Artemisia,* which were more associated with the grazed sites than the ungrazed sites. Ungrazed sites supported a community of butterflies that depends more on boreal woodland plant species, while grazed sites supported butterflies that depended more on prairie forb and grass species.

Rarefied species richness of moths was significantly greater in the grazed sites, and was highest in sites MRBE (Marble Ridge B East) and MRC (Marble Ridge C). The trends in moth landscape diversity indicated that moth communities appear to be more unique between sites in comparison to the plant and butterfly diversity as the moth assemblages in grazed and ungrazed sites, and site MRBE (Marble Ridge B East) was particularly unique. The cluster analysis based on the moth species did not place the grazed sites into one group distinct from the ungrazed sites, but rather placed all the sites except one into one large group. Analysis with MRPP also did not detect a significant difference in the moth community between grazed and ungrazed sites. The moth community did not respond in the same way to grazing as the plants and butterflies, which both significantly responded to livestock grazing activities. More research into the moth fauna utilizing alvars is needed to better understand how moths are interacting with grazing in alvars. RDA suggested that the grazed and ungrazed sites were different from each other when considering the moth community, and that the grazed sites were more similar to each other than the ungrazed sites were to each other.

The analysis of moth feeding guilds indicated that there was a significant difference in the distribution of individuals among the guilds between grazed and ungrazed treatments. The primary guilds that were significantly different between the treatments were the Tree, Shrub, Shrub/Ground, and Generalist guilds, with a higher proportion of Shrub/Ground feeders in grazed sites and a higher proportion of Tree and Shrub feeders, and Generalists in ungrazed sites. Ungrazed sites had greater richness of species of plants than the compared grazed sites, indicating this was a preferable habitat condition for generalist species that require a broad range of plants, and also had a greater level of tree and shrub encroachment to support Tree and Shrub specialist moth species. The ungrazed sites provided an abundance of shrubs and species of herbs and grasses, and this may explain the higher proportion of generalists in these sites.

## 6.4 Management

Natural alvar grasslands were historically maintained by periodic, intense periods of grazing and a seasonal grazing regime that simulates these natural conditions is recommended in alvars that are being actively grazed (Bailey et al. 2010). The main goal for alvar conservation is the preservation, and enlargement of extant alvar fragments (Eriksson & Rosen 2013, Leppik et al. 2013), which are vulnerable to encroachment by forest species, leading to forestation. Alvars that are not grazed may require some management intervention to prevent them from becoming forested, especially the northern Peguis site, as they contained significantly greater densities of trees and other forest plant species, and species of Lepidopterans that feed on these plants.

The intensity of grazing in the alvar sites surveyed in this study could be considered to be at a relatively low level (averaging ~1.25 AUM/hectare compared to Oland, Sweden at ~1 AUM/hectare), with a relatively small number of cattle being grazed seasonally in these sites. Though the level of grazing was low it had significant impacts on the soil, evident from the higher soil compaction, and sodium and nitrate concentrations in the grazed sites. However, these soil impacts do not seem to have strongly affected the overall biotic community when considering plants and Lepidopterans as indicators. Therefore, the introduction of seasonal cattle grazing into ungrazed alvars at a low level of intensity may be beneficial to reduce the level of encroachment of trees and shrubs, such as *P. tremuloides* and *Salix*, and encourage the establishment of more native grasses and prairie plant species. The Peguis site may be a good candidate site to test this management strategy of introduced grazing to a ungrazed area, as Peguis showed the highest level of forest encroachment. Soil quality should be monitored in all grazed alvars to prevent soil compaction or sodium/nitrate concentrations from reaching sufficiently high levels to have significant negative impacts on the plant community.

In areas where grazing is not feasible, mechanical clearing may be employed to remove encroaching species but this should only be done by chainsaw operators on foot as the soils are susceptible to extensive damage from heavy machinery (Rosen 1988). Ungrazed alvars may benefit from additional management efforts such as the scraping away of small patches of the soil surface (Leppik et al. 2013) or carefully controlled burning to allow for the removal of encroaching forest species and reestablishment of early successional prairie species (Reschke et al. 1999, Catling 2016). Vehicle and even foot traffic in alvars may cause damage to soils, and should be limited to established tracks and trails in alvars that make popular destinations for naturalists, hunters and other visitors.

Though the level of grazing intensity was low in the grazed alvar sites, the plant community was significantly different from the ungrazed sites, with grazed sites having significantly lower species richness than ungrazed sites. The increase in richness in the ungrazed sites may be attributed to the presence of trees and other shade-tolerant species, in addition to the prairie plant species also found in grazed sites, or to the removal of palatable species of plants from grazed areas. Plant species richness in grazed sites may be increased by allowing the grazed sites to rest by delaying the beginning of the grazing season until mid-summer whenever possible to allow the plant community to reproduce unimpeded and to discontinue grazing of alvars during drought periods (Bailey et al. 2010). Grazing did not have a significant effect on the amount of ground cover of plants in the alvars studied, and it is important that the plant cover is monitored and maintained as it prevents damage to the bare soil (Bailey et al. 2010).

While seasonal grazing is an acceptable management strategy, rotational grazing regimes may be implemented to mitigate the effects of grazing on the alvar plant community (Catling 2016). Rotational grazing involves increasing the network of fences in alvar pastures so the animals can be penned into smaller sections of the habitat, which they rotate through removing encroaching plants in the active section and giving the native plant community plenty of time to regenerate in the remaining sections. This grazing strategy is also compatible with the conservation of butterfly populations as it encourages native plant species diversity and a variety of larval host and nectar-producing plants (Dana 1997). Moths appear to be less dependent on the plants that are found in the vicinity of where they were trapped, and the moth communities were not significantly different between the grazed and ungrazed alvar sites, indicating they were less affected by grazing than the butterflies. This indicated that moths may be travelling into alvars from surrounding habitats, while butterflies either as larvae or adults in alvars may be more associated with the plants.

## 6.5 Summary

Conservation of Manitoba's alvars is important because these fragile ecosystems contribute to local and global biodiversity, and they are threatened both by natural processes and anthropogenic management. If alvars are not managed appropriately they will be subject to encroachment by shrubs and trees, and if they are managed too intensely their fragile soils may be damaged and the alvar community may not recover. Alvars contain a unique combination of prairie and forest species and ideal alvar communities exhibit a balance of species from these two different ecosystems. Grazing, which effects three quarters of Manitoba alvars, appeared to influence plant diversity and also Lepidopteran diversity (although the effects were less pronounced). In this study grazed and ungrazed communities showed some differences in plant and butterfly diversity while impacts on moth diversity were less clear. There appears to be differences in physical factors such as nitrate/sodium concentration and compaction, which may help dictate this difference.

The best management strategies for the conservation of rich communities of plants and Lepidopterans in Manitoba's alvars are to use low intensity, seasonal, or, if physically and financially feasible, rotational livestock grazing. This strategy is useful for the maintenance and enlargement of existing alvar fragments, allowing livestock animals to more uniformly remove encroaching plants from alvars, encouraging the establishment of native prairie plants, and allowing the plant community time to regenerate while not being actively grazed.

Grazing should be deferred until mid-summer in alvar pastures because this allows the plant community to establish during the spring and early summer, to provide a rich community of plants to support pollinators, such as Lepidopterans. All grazed alvars should be subject to regular soil tests to monitor the levels of compaction, nitrate and sodium, as these variables can be damaging to the plant community when in excess. Alvars are susceptible to forest encroachment due to being located adjacent to forest ecosystems, and if grazing is not feasible these areas will require additional management to reduce encroaching, including mechanical clearing (by chainsaw operators on foot), and carefully controlled burning.

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## Appendix 1: List of potential alvar plants and invasive species

Appendix 1a. Vegetation species found in Manitoba's Interlake alvars with conservation status ranks. G ranks are the global conservation status and the S ranks are the subnational conservation status.

| **Species Common Name** | **Binomial Nomenclature** | **Grank** | **Srank** |
|---|---|---|---|
| Common Yarrow | *Achillea millefolium* | G5 | S5 |
| Glade Onion | *Allium stellatum* | G5 | S5 |
| Ragweed sp. | *Ambrosia spp.* | | |
| Pussytoes sp. | *Antennaria sp.* | | |
| Aster sp. | *Symphyothrichum sp.* | | |
| Porter's Chess | *Bromus porteri* | G5 | S3 |
| Harebell | *Campanula rotundifolia* | G5 | S5 |
| Sedge sp. | *Carex sp.* | | |
| Poverty Oat Grass | *Danthonia spicata* | G5 | S5 |
| Shrubby Cinquefoil | *Dasiphora fruticosa ssp. floribunda* | G5 | S5 |
| Tufted Hairgrass | *Deschampsia caespitosa* | G5 | S5 |
| Spikerush sp. | *Eleocharis sp.* | | |
| Slender Wild Rye | *Elymus trachycaulum* | G5 | S5 |
| Northern Bedstraw | *Galium boreale* | G5 | S5 |
| Prairie-smoke | *Geum triflorum* | G5 | S4 |
| Broadleaf Gumweed | *Grindela squarrosa* | G5 | S5 |
| Dudley's Rush | *Juncus dudleyi* | G5 | S5 |
| Creeping Juniper | *Juniperus horizontalis* | G5 | S5 |
| Prairie Junegrass | *Koelaria macrantha* | G5 | S5 |
| Pepper-grass sp. | *Lepidum sp.* | | |
| Hoary Puccoon | *Lithospermum canescens* | G5 | S5 |
| Meadow Timothy | *Phluem pratense* | | |
| Annual bluegrass | *Poa annua* | | |
| Kentucky Bluegrass | *Poa pratensis* | G5 | S5 |
| Tansy Cinquefoil | *Potentilla bipinnatifida* | G5 | S5 |
| Fanleaf Cinquefoil | *Potentilla gracillis* | G5 | S4 |
| Pennsylvania Cinquefoil | *Potentilla pensylvanica* | G5 | SU |
| Cinquefoil sp. | *Potentilla sp.* | | |
| Prickly Rose | *Rosa acicularis* | G5 | S5 |
| White Heath Aster | *Symphyotrichum ericoides* | G5 | S4 |
| Vetch sp. | *Vicia sp.* | | |
| Pale-Goat Chickory | *Agoseris glauca* | G5 | S5 |
| Wild Onion | *Allium textile* | G5 | S3 |
| Saskatoon Serviceberry | *Amelanchier alnifolia* | G5 | S5 |
| Big Bluestem | *Andropogon gerardii* | G5 | S5 |
| Canada Anemone | *Anemone canadensis* | G5 | S5 |

| | | | |
|---|---|---|---|
| Long-fruit Anemone | *Anemone cylindrica* | G5 | S5 |
| Hudson's Bay Anemone | *Anemone multifida* | G5 | S5 |
| Spreading Dogbane | *Apocynum androsaemifolium* | G5 | S5 |
| Western Hairy Rockcress | *Arabis hirsuta* | G5 | S5 |
| Rockcress sp. | *Arabis sp.* | | |
| Bearberry | *Arctostaphylos uva-ursi* | G5 | S5 |
| Pacific Wormwood | *Artemisa campestris* | G5 | S5 |
| White Sagebrush/Prairie sage | *Artemisia ludoviciana* | G5 | S5 |
| Spring Birch | *Betula occidentalis* | G5 | S4S5 |
| Bog Birch | *Betula pumila* | G5 | S5 |
| Field Chickweed | *Cerastium arvense* | G5 | S5 |
| Drummond's Thistle | *Cirsium drummondi* | G5 | S4 |
| Thistle sp. | *Cirsium sp.* | | |
| Umbellate Bastard Toad-flax | *Commandra umbellata* | G5 | S5 |
| American Hazelnut | *Corylus americana* | G5 | S4 |
| Lady's Slipper | *Cypripedium sp.* | | |
| Purple Prairie Clover | *Dalea purpurpea* | G5 | S4 |
| Philedelphia Fleabane | *Erigeron philadelphicus* | G5 | S5 |
| Rough Fescue | *Festuca altaica/hallii* | G4 | S3 |
| Virginia Strawberry | *Fragaria virginiana* | G5 | S5 |
| Great Blanket-flower | *Gaillardia aristata* | G5 | S4 |
| Sunflower sp. | *Helianthus sp.* | | |
| Richardson's Alumroot | *Heuchera richardsonii* | G5 | S5 |
| Umbellate Hawkweed | *Hieracium umbellatum* | G5 | S5 |
| Common Juniper | *Juniperus communis* | G5 | S5 |
| Strap-style Gayfeather | *Liatris ligulistylis* | G5 | S4 |
| Wood Lily | *Lilium philadelphicum* | G5 | S4 |
| Prairie Flax | *Linum lewisii* | G5 | S5 |
| Mountain Honeysuckle | *Lonicera dioica* | | |
| Starflower Solomon's-plume | *Maianthemum stellatum* | G5 | S5 |
| Wild Bergamot | *Monarda fistulosa* | G5 | S5 |
| Prairie Goldenrod | *Oligoneuron album* | G5 | S4 |
| Prairie Goldenrod | *Oligoneuron rigidum* | G5 | S5 |
| Yellow Owl's-clover | *Orthocarpus luteus* | G5 | S4 |
| White-grained Mountain-ricegrass | *Oryzopsis asperifolia* | G5 | S5 |
| Large Indian Breadroot | *Pediomelum esculenta* | G5 | S4 |
| Hood's Phlox | *Phlox hoodii* | G5 | S3 |
| White Spruce | *Picea glauca* | G5 | S4 |
| Bluegrass sp. | *Poa sp.* | | |
| Seneca Snakeroot | *Polygala senega* | G4G5 | S4 |
| Trembling Aspen | *Populus tremuloides* | G5 | S5 |
| Tall Cinquefoil | *Potentilla arguta* | G5 | S5 |

| | | | |
|---|---|---|---|
| Fire Cherry | *Prunus pensylvanica* | G5 | S5 |
| Choke Cherry | *Prunus virginiana* | G5 | S5 |
| Bur Oak | *Quercus macrocarpa* | G5 | S5 |
| Black-eyed Susan | *Rudbeckia hirta* | G5 | S5 |
| Willow | *Salix sp.* | | |
| Maryland Black-snakeroot | *Sanicula marilandica* | G5 | S5 |
| Canada Buffaloberry | *Shepherdia canadensis* | G5 | S5 |
| Strict Blue-eyes-grass | *Sisyrinchium montanum* | G5 | S5 |
| Hairy Goldenrod | *Solidago hispida* | G5 | S5 |
| Missouri Goldenrod | *Solidago missouriensis* | G5 | S5 |
| Field Goldenrod | *Solidago nemoralis* | G5 | S5 |
| Snowberry sp. | *Symphoricarpos sp.* | | |
| Smooth Blue Aster | *Symphyothrichum laeve* | G5 | S5 |
| Common Dandelion | *Taraxacum officinale* | G5 | |
| Veined Meadowrue | *Thalictrum venulosum* | G5 | S5 |
| Northern Poison-oak | *Toxicodendron rydbergii* | G5 | S5 |
| White Camas | *Zigadenus elegans* | G5 | S5 |
| Heartleaf Alexanders | *Zizia aptera* | G5 | S5 |
| Golden Alexanders | *Zizia aurea* | G5 | S5 |
| Rough Bentgrass | *Agrostis scabra* | G5 | S5 |
| Creeping Bentgrass | *Agrostis stellatum* | G5 | |
| Milkweed sp. | *Asclepias sp.* | | |
| Paper Birch | *Betula papyrifera* | G5 | S5 |
| Fleabane sp. | *Erigeron sp.* | | |
| Twinflower | *Linnaea borealis* | G5 | S5 |
| Wild Lily-of-the-Valley | *Maianthemum canadense* | G5 | S5 |
| Black Medic | *Medicago lupulina* | | |
| American Crow-wheat | *Melampyrum lineare* | G5 | S5 |
| Jack Pine | *Pinus banksiana* | G5 | S5 |
| Silverweed | *Potentilla anserina* | G5 | S5 |
| Smooth Sumac | *Rhus glabra* | G5 | S4 |
| Canadian Gooseberry | *Ribes oxyacanthoides* | G5 | S5 |
| Common Red Raspberry | *Rubus idaeus* | G5 | S5 |
| Smooth Herbaceous Greenbrier | *Smilax herbacea* | G5 | |
| Goldenrod sp. | *Solidago sp.* | | |
| Downy Arrow-wood | *Viburnum rafinquesianum* | G5 | S4 |
| American Purple Vetch | *Vicia americana* | G5 | S5 |
| Awnless Brome | *Bromus inermis* | G5 | |
| Goosefoot sp. | *Chenopodium sp.* | | |
| Spike-oat | *Helichtotrichon hookeri* | G5 | S4 |
| Gastony's Cliffbrake | *Pellaea gastonyi* | G2G3 | S1 |
| Western Dwarf Cliffbrake | *Pellaea glabella* | G5 | S2 |
| Dense Spikemoss | *Selaginella densa* | G5 | S3 |

|  |  |  |  |
|---|---|---|---|
| Violet sp. | *Viola sp.* |  |  |
| Wheatgrass | *Agropyron sp.* |  |  |
| Arnica sp. | *Arnica sp.* |  |  |
| Woodland strawberry | *Fragaria vesca* | G5 | S4S5 |
| Felwort | *Gentianella amarella* | G5 | S5 |
| Pale Vetchling | *Lathyrus ochroleucus* | G4G5 | S4S5 |
| Honeysuckle sp. | *Lonicera sp.* |  |  |
| Sweet-clover | *Melilotus officinalis* | G5 | SE |
| Northern Rice Grass | *Oryzopsis pungens* | G5 | S5 |
| Purple Locoweed | *Oxytropis lambertii* | G5 | S3S4 |
| Slender Beardtongue | *Penstemon gracilis* | G5 | S4 |
| Poa sp. | *Bluegrass sp.* |  |  |
| Prairie Crocus | *Pulsatilla patens* | G5 | S4 |
| Prairie Buttercup | *Ranunculus rhomboideus* | G5 | S4 |
| Blackcurrant sp. | *Ribes sp.* |  |  |
| Rose sp. | *Rosa sp.* |  |  |
| Stiff Goldenrod | *Solidago rigida* | G5 | S5 |
| Spear grass | *Hesperostipa comata* | G5 | S4 |
| Dandelion sp. | *Taraxacum sp.* |  |  |
| Meadow Rue sp. | *Thalictrum sp.* |  |  |
| Tall Bitter Fleabane | *Trimophra elata* | G4 | S4 |
| Spring Vetch | *Vicia sativa* | G5 | SE |
| Abietinella Moss | *Abietinella abietina* | G4G5 | S4S5 |
| Aulacomnium Moss | *Aulacomnium palustre* | G5 | S4S5 |
|  | *Barbula convoluta* | G5 | SU |
|  | *Brachythecium campestre* | G4G5 | S4S5 |
| Brachythecium Moss | *Brachythecium salebrosum* | G5 | S4S5 |
| Campylium Moss | *Campylium polygamum* | G5 | S4S5 |
|  | *Ceratodon purpureus* | G5 | S4S5 |
| Waxyleaf Moss | *Dicranum polysetum* | G5 | S4S5 |
| Elegant Beaked Moss | *Eurhynchium pulchellum* | G5 | S4S5 |
| Feathermoss | *Pleurozium schreberi* | G5 | S4S5 |
|  | *Tortella fragilis* | G5 | S4S5 |
| Twisted Moss | *Tortella tortuosa* | G5 | S4S5 |
| Common Green Bryum Moss | *Bryum psuedotriquetrum* | G5 | S4S5 |
|  | *Bryum sp.* |  |  |
|  | *Didymodon rigidulus* | G5 | S4S5 |
| Tortula Moss | *Tortula ruralis* | G5 |  |
|  | *Brachythecium sp.* |  |  |
| Extinguisher Moss | *Encalypta procera* | G4G5 | S4S5 |
|  | *Grimmia teretinervis* | G3G5 |  |
| Hedwig's Fringeleaf Moss | *Hedwigia ciliata* | G5 |  |
| Stairstep Moss | *Hylocomium splendens* | G5 | S4S5 |

| | | | |
|---|---|---|---|
| Sanionia Moss | *Sanionia uncinata* | G5 | S4S5 |
| | *Tortula norvegica* | G5 | |
| Don's Small Limestone Moss | *Seligeria donniana* | G4G5 | S1S2 |
| Reindeer Lichen sp. | *Cladina sp.* | | |
| Cup Lichen sp. | *Cladonia sp.* | | |
| | *Cephaloziella rubella* | G5 | |
| Hyaline Liverwort | *Athalamia hyaline* | G5 | |
| Inflated Scalewort | *Frullania inflata* | G5 | |
| Fragrant Macewort | *Mannia fragrans* | G5 | |
| | *Mannia sibirica* | | S1 |

Adapted from MAI (2012) and Hamel & Foster (2004).

Appendix 1b. Invasive vegetation species in Manitoba’s alvars

| Species Common Name | Binomial Nomenclature |
|---|---|
| Timothy Grass | *Phleum pretense* |
| Kentucky Bluegrass | *Poa pratensis* |
| Annual Bluegrass | *Poa annua* |
| Garden's Bird's-foot trefoil | *Lotus corniculatus* |
| Awnless Brome | *Bromus inermis* |
| Creeping Bentgrass | *Agrostis stolonifera* |
| Canada Bluegrass | *Poa compressa* |
| Rough Fruited Cinquefoil | *Potentilla recta* |
| Common Mullein | *Verbascum thapsus* |
| Ox-eye Daisy | *Chrysanthemum leucanthemum* |
| Hawkweed | *Hieracium sp.* |
| White Sweet Clover | *Melilotus alba* |
| Buckthorn | *Rhamnus cathartica* |

Adapted from MAI (2012) and Reschke et al. (1999)

## Appendix 2: Early and later summer 2016 plant percent cover by site

Appendix 2a: Early summer 2016 plant species number of stems (trees only) and percent cover by sites. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| Family | Scientific Name | Code | Auth. | MRBE | MRBW | MRC | CLMN | CLMS | PEG |
|---|---|---|---|---|---|---|---|---|---|
| Salicaceae | Populus tremuloides | Pop tre | Michx. | 0 | 0 | 0 | 0 | 1 | 65 |
| Fagaceae | Quercus macrocarpa | Que mac | Michx. | 0 | 0 | 0 | 5 | 0 | 4 |
| Rosaceae | Dasiphora fruticosa | Das fru | Rydb. | 139 | 292.75 | 70 | 281 | 368 | 60 |
|  | Amelanchier alnifolia | Ame aln | Nutt. | 4 | 5 | 12 | 7 | 14 | 70 |
|  | Rosa acicularis | Ros aci | Lindl. | 10 | 20 | 14 | 10 | 19 | 11 |
|  | Rubus idaeus | Rub ida | L. | 0 | 0 | 0 | 15 | 0 | 3 |
| Pinaceae | Picea glauca | Pic gla2 | Voss | 0 | 0 | 0 | 0 | 6 | 1 |
| Cupressaceae | Juniperus communis | Jun com | L. | 11 | 6 | 19 | 7 | 35 | 45 |
|  | Juniperus horizontalis | Jun hor | Moen. | 123 | 60 | 180 | 747 | 226 | 0 |
| Betulaceae | Betula occidentalis | Bet occ | Hook. | 0 | 0 | 0 | 152 | 40 | 6 |
| Salicaceae | Salix sp. | Sal spp |  | 3 | 16 | 1 | 32 | 6 | 24 |
| Grossulariaceae | Ribes oxyacanthoides | Rib oxy | L. | 0 | 0 | 0 | 1 | 0 | 2 |
| Apocynaceae | Apocynum androsaemifolium | Apo and | L. | 0 | 1 | 0 | 19 | 0 | 5 |
| Elaeagnaceae | Shepherdia canadensis | She can | Nutt. | 0 | 0 | 0 | 6 | 4 | 31 |
| Caprifoliaceae | Lonicera dioica | Lon dio | L. | 2 | 0 | 40 | 2 | 6 | 0 |
|  | Symphoricarpos sp. | Sym spp |  | 0 | 59 | 1 | 1 | 7 | 11 |
|  | Populus tremuloides | Pop tre2 | Michx. | 0 | 0 | 0 | 38 | 134 | 107 |
|  | Quercus macrocarpa | Que mas | Michx. | 0 | 0 | 0 | 14 | 5 | 14 |
| Asteraceae | Artemisia campestris | Art cam | L. | 0 | 12 | 0 | 0 | 1 | 0 |
|  | Artemisia ludoviciana | Art lud | Nutt. | 0 | 0 | 0 | 1 | 1 | 0 |
|  | Achillea millefolium | Ach mil | L. | 90 | 99 | 74 | 7 | 27 | 105 |
|  | Antennaria sp. | Ant spp |  | 2 | 148 | 156 | 17 | 36 | 25 |
|  | Symphyothrichum sp. | Sym sps |  | 83 | 16 | 1 | 1 | 21 | 14 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cirsium drummondii | Cir dru | Torr.& A.Gray | 0 | 0 | 0 | 1 | 0 | 0 |
| | Cirsium sp. | Cir spp | | 0 | 0 | 0 | 0 | 0 | 2 |
| | Agoseris glauca | Ago gla | Raf. | 0 | 4 | 7 | 2 | 1 | 25 |
| | Erigeron philadelphicus | Eri phi | L. | 0 | 3 | 0 | 3 | 0 | 2 |
| | Gaillardia aristata | Gal ari | Pursh | 50 | 0 | 8 | 5 | 17 | 0 |
| | Tragopogon dubius | Tra dub | Scop. | 0 | 0 | 2 | 0 | 0 | 0 |
| | Helianthus sp. | Hel spp | | 0 | 1 | 0 | 1 | 1 | 0 |
| | Hieracium umbellatum | Hie umb | L. | 1 | 1 | 0 | 0 | 0 | 0 |
| | Rudbeckia hirta | Rud hir | L. | 3 | 9 | 3 | 5 | 32 | 2 |
| | Solidago sp. | Sol spp | | 1 | 0 | 1 | 2 | 0 | 6 |
| | Solidago simplex | Sol sim | Kunth | 1 | 9 | 5 | 24 | 38 | 57 |
| | Solidago missouriensis | Sol mis | Nutt. | 0 | 0 | 0 | 1 | 0 | 0 |
| | Solidago rigida | Sol rig | L. | 0 | 0 | 0 | 1 | 3 | 0 |
| | Solidago ptarmicoides | Sol pta | B. Boivin | 1 | 9 | 4 | 28 | 25 | 146 |
| | Symphyotrichum laeve | Sym lae | A. & D. Love | 1 | 0 | 0 | 0 | 0 | 0 |
| | Taraxacum officinale | Tax off | Wigg. | 0 | 0 | 3 | 1 | 0 | 0 |
| | Erigeron sp. | Eri spp | | 10 | 8 | 5 | 0 | 0 | 8 |
| | Arnica sp. | Arn spp | | 3 | 2 | 3 | 0 | 0 | 0 |
| | Erigeron elatus | Eri ela | Greene | 0 | 0 | 0 | 0 | 0 | 1 |
| | Allium textile | All tex | Nelson &Mac. | 0 | 0 | 0 | 1 | 0 | 2 |
| Campanlaceae | Campanula rotundifolia | Cam rot | L. | 54 | 19 | 15 | 11 | 31 | 16 |
| Rubiaceae | Galium boreale | Gal bor | L. | 59 | 59 | 54 | 45 | 45 | 66 |
| Rosaceae | Geum triflorum | Geu tri | Pursh | 51 | 267 | 235 | 5 | 27 | 6 |
| | Fragaria virginiana | Fra vir | Miller | 10 | 2 | 10 | 14 | 32 | 129 |
| | Potentilla norvegica | Pot nor | L. | 0 | 0 | 0 | 1 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Potentilla recta | Pot gra | L. | 0 | 30 | 3 | 0 | 0 | 0 |
| | Potentilla pensylvanica | Pot pen | L. | 32 | 3 | 13 | 1 | 0 | 0 |
| | Potentilla arguta | Pot arg | Pursh | 3 | 1 | 0 | 0 | 6 | 47 |
| Boraginaceae | Lithospermum canescens | Lit can | Lehm. | 0 | 3 | 1 | 12 | 9 | 19 |
| Fabaceae | Vicia sp. | Vic spp | | 0 | 0 | 0 | 8 | 0 | 0 |
| | Medicago lupulina | Med lup | L. | 6 | 52 | 133 | 0 | 0 | 3 |
| | Dalea purpurea | Dal pur | Vent. | 0 | 3 | 3 | 3 | 61 | 0 |
| | Vicia americana | Vic ame | Muhl. | 0 | 20 | 27 | 2 | 18 | 46 |
| | Lathyrus ochroleucus | Lat och | Hook. | 0 | 5 | 2 | 1 | 4 | 36 |
| | Melilotus officinalis | Mel off | Lamar. | 0 | 0 | 0 | 0 | 1 | 30 |
| | Vicia sativa | Vic sat | L. | 0 | 3 | 0 | 0 | 8 | 13 |
| | Trifolium hybridum | Tri hyb | L. | 0 | 1 | 5 | 0 | 0 | 0 |
| | Trifolium pratense | Tri pra | L. | 0 | 10 | 24 | 0 | 0 | 35 |
| | Thermopsis rhombifolia | The rho | Nutt. | 0 | 0 | 22 | 0 | 0 | 0 |
| Ranunculaceae | Anemone canadensis | Ane can | L. | 0 | 2 | 0 | 0 | 1 | 30 |
| | Anemone multifida | Ane mul | Poiret | 0 | 2 | 8 | 2 | 5 | 12 |
| | Pulsatilla patens | Pul pat | Pritzel | 0 | 0 | 0 | 2 | 0 | 0 |
| Brassicaceae | Arabis hirsuta | Ara his | L. Scopoli | 0 | 3 | 0 | 1 | 0 | 0 |
| Ericaceae | Arctostaphyloc uva-ursi | Arc uva | L. Sprengel | 0 | 0 | 0 | 463 | 425 | 304 |
| Caryophyllaceae | Cerastium arvense | Cer arv | L. | 13 | 26 | 4 | 0 | 1 | 0 |
| Santalaceae | Commandra umbellata | Com umb | L. | 3 | 1 | 2 | 10 | 9 | 55 |
| Orchidaceae | Cypripedium sp. | Cyp spp | | 0 | 0 | 0 | 1 | 0 | 0 |
| Saxifragaceae | Heuchera richardsonii | Heu ric | R. Brown | 2 | 1 | 5 | 1 | 6 | 8 |
| Liliaceae | Lilium philadelphicum | Lil phi | L. | 0 | 0 | 0 | 2 | 0 | 7 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Asparagaceae | Maianthemum stellatum | Mai ste | Link | 0 | 0 | 4 | 0 | 0 | 0 |
| | Maianthemum canadense | Mai can | Desf. | 0 | 0 | 0 | 0 | 0 | 24 |
| Lamiaceae | Monarda fistulosa | Mon fis | L. | 0 | 0 | 18 | 13 | 52 | 29 |
| | Scutellaria galericulata | Scu gal | L. | 0 | 0 | 0 | 0 | 1 | 0 |
| | Prunella vulgaris | Pru vul | L. | 0 | 16 | 0 | 0 | 0 | 0 |
| Polygalaceae | Polygala senega | Pol sen | L. | 0 | 0 | 0 | 57 | 16 | 14 |
| | Zizia aptera | Ziz apt | Fern. | 0 | 1 | 0 | 1 | 15 | 30 |
| | Zizia aurea | Ziz aur | W. Koch | 25 | 1 | 3 | 0 | 0 | 26 |
| Iridaceae | Sisyrinchium montanum | Sis mon | Greene | 1 | 4 | 0 | 6 | 2 | 7 |
| | Thalictrum venulosum | Tha ven | Trel. | 1 | 9 | 4 | 4 | 1 | 59 |
| Violaceae | Viola sp. | Vio spp | | 7 | 9 | 7 | 5 | 10 | 5 |
| Poaceae | Bromus porteri | Bro por | Nash | 0 | 0 | 0 | 0 | 0 | 2 |
| | Deschampsia caespitosa | Des cae | P. Beauv. | 16 | 44 | 21 | 7 | 25 | 3 |
| | Elymus trachycaulus | Ely tra | Gould | 21 | 3 | 12 | 1 | 12 | 19 |
| | Koeleria macrantha | Koe mac | Schult. | 59 | 103 | 92 | 0 | 13 | 10 |
| | Phleum pratense | Phl pra | L. | 0 | 14 | 4 | 0 | 0 | 6 |
| | Poa pratensis | Poa pra | L. | 29 | 57 | 14 | 1 | 5 | 0 |
| | Andropogon gerardii | And ger | Vitm. | 0 | 1 | 0 | 22 | 30 | 1 |
| | Agrostis scabra | Agr sca | Wild. | 0 | 1 | 14 | 0 | 0 | 0 |
| | Muhlenbergia richardsonis | Muh ric | Rydb. | 0 | 0 | 0 | 9 | 0 | 0 |
| | Sporobolus heterolepis | Spo het | A.Gray | 26 | 34 | 101 | 80 | 7 | 22 |
| | Spartina alterniflora | Spa alt | Loisel. | 0 | 10 | 0 | 1 | 4 | 0 |
| | Schizachne purpurascens | Sch pur | Swallen | 10 | 3 | 8 | 1 | 9 | 0 |
| | Elymus canadensis | Ely can | L. | 0 | 0 | 0 | 1 | 1 | 0 |
| | Calamagrostis canadensis | Cal can | P. Beauv. | 0 | 2 | 0 | 0 | 0 | 0 |
| Cyperaceae | Carex sp. | Car spp | | 294 | 133 | 204 | 62 | 43 | 82 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Eleocharis sp. | Ele spp | 0 | 22 | 0 | 0 | 0 | 0 |
| Thuidiaceae | Abietinella abietina | Abi abi | 201 | 55 | 284 | 16 | 17 | 0 |
| Aulacomniaceae | Aulacomnium palustre | Aul pal | 0 | 0 | 0 | 0 | 0 | 157 |
| Cladoniaceae | Cladina sp. | Cla spp | 0 | 1 | 30 | 274 | 156 | 55 |
|  |  | Cup lic | 9 | 3 | 2 | 0 | 111 | 13 |
|  |  | Sca lic | 484 | 82 | 98 | 0 | 319 | 45 |
|  |  | Lea lic | 37 | 17 | 7 | 0 | 2 | 8 |
|  |  | Cru lic | 0 | 15 | 0 | 0 | 0 | 0 |

Appendix 2b: Late summer 2016 plant species percent cover by sites. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| **Scientific Name** | **Code** | **Auth.** | **MRBE** | **MRBW** | **MRC** | **CLMN** | **CLMS** | **PEG** |
|---|---|---|---|---|---|---|---|---|
| Artemisia campestris | Art cam | L. | 0 | 1 | 0 | 0 | 0 | 0 |
| Achillea millefolium | Ach mil | L. | 100 | 29 | 45 | 2 | 9 | 26 |
| Antennaria sp. | Ant spp |  | 24 | 80 | 51 | 6 | 25 | 40 |
| Symphyotrichum ericoides | Sym eri | Nesom | 42 | 7 | 0 | 2 | 1 | 0 |
| Erigeron philadelphicus | Eri phi | L. | 0 | 0 | 0 | 0 | 1 | 2 |
| Gaillardia aristata | Gal ari | Pursh | 12 | 0 | 2 | 0 | 0 | 6 |
| Liatris ligulistylis | Lia lig | Schum. | 0 | 32 | 3 | 0 | 0 | 6 |
| Rudbeckia hirta | Rud hir | L. | 0 | 0 | 0 | 0 | 2 | 2 |
| Solidago sp. | Sol spp |  | 0 | 0 | 0 | 0 | 1 | 0 |
| Solidago rigida | Sol rig | L. | 2 | 2 | 0 | 3 | 9 | 5 |
| Solidago ptarmicoides | Sol pta | B. Boivin | 0 | 0 | 1 | 4 | 1 | 62 |
| Symphyotrichum laeve | Sym lae | A.&D. Love | 0 | 0 | 0 | 2 | 0 | 1 |
| Taraxacum officinale | Tax off | Wigg. | 2 | 0 | 0 | 8 | 13 | 26 |
| Erigeron sp. | Eri spp |  | 2 | 10 | 9 | 0 | 0 | 2 |
| Arnica sp. | Arn spp |  | 0 | 0 | 1 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Allium textile | All tex | Nelson &Macbr. | 4 | 0 | 1 | 2 | 1 | 3 |
| Campanula rotundifolia | Cam rot | L. | 22 | 4 | 7 | 7 | 6 | 6 |
| Galium boreale | Gal bor | L. | 13 | 17 | 28 | 14 | 18 | 39 |
| Geum triflorum | Geu tri | Pursh | 61 | 73 | 123 | 3 | 1 | 6 |
| Fragaria virginiana | Fra vir | Miller | 0 | 1 | 5 | 7 | 26 | 47 |
| Fragaria vesca | Fra ves | L. | 0 | 0 | 0 | 0 | 0 | 5 |
| Potentilla norvegica | Pot nor | L. | 2 | 0 | 0 | 0 | 0 | 0 |
| Potentilla recta | Pot gra | L. | 0 | 16 | 0 | 0 | 0 | 0 |
| Potentilla pensylvanica | Pot pen | L. | 15 | 0 | 1 | 0 | 0 | 0 |
| Potentilla arguta | Pot arg | Pursh | 1 | 0 | 4 | 0 | 2 | 8 |
| Lithospermum canescens | Lit can | Lehm. | 0 | 0 | 0 | 2 | 2 | 17 |
| Medicago lupulina | Med lup | L. | 10 | 11 | 46 | 1 | 0 | 0 |
| Dalea purpurea | Dal pur | Vent. | 0 | 0 | 0 | 4 | 39 | 0 |
| Vicia americana | Vic ame | Muhl. | 0 | 6 | 17 | 1 | 11 | 11 |
| Lathyrus ochroleucus | Lat och | Hook. | 0 | 0 | 8 | 1 | 6 | 24 |
| Melilotus officinalis | Mel off | Lamar. | 1 | 3 | 0 | 1 | 1 | 5 |
| Vicia sativa | Vic sat | L. | 0 | 0 | 0 | 0 | 0 | 1 |
| Oxytropis lambertii | Oxy lam | Pursh | 0 | 0 | 0 | 0 | 0 | 2 |
| Trifolium hybridum | Tri hyb | L. | 0 | 6 | 5 | 0 | 0 | 0 |
| Trifolium pratense | Tri pra | L. | 0 | 0 | 13 | 0 | 0 | 0 |
| Thermopsis rhombifolia | The rho | Nutt. | 0 | 0 | 10 | 0 | 0 | 0 |
| Anemone canadensis | Ane can | L. | 0 | 0 | 0 | 0 | 0 | 3 |
| Anemone multifida | Ane mul | Poiret | 0 | 3 | 0 | 2 | 1 | 3 |
| Arabis hirsuta | Ara his | L. Scopoli | 0 | 0 | 0 | 1 | 0 | 0 |
| Arabis sp. | Ara spp | | 10 | 0 | 0 | 0 | 0 | 0 |
| Arctostaphyloc uva-ursi | Arc uva | L. Sprengel | 0 | 20 | 0 | 138 | 209 | 147 |
| Cerastium arvense | Cer arv | L. | 3 | 4 | 0 | 1 | 1 | 45 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Commandra umbellata | Com umb | L. | 2 | 0 | 1 | 9 | 6 | 12 |
| Cypripedium sp. | Cyp spp | | 0 | 0 | 0 | 0 | 0 | 2 |
| Heuchera richardsonii | Heu ric | R. Brown | 1 | 4 | 2 | 2 | 0 | 1 |
| Maianthemum canadense | Mai can | Desf. | 0 | 0 | 0 | 0 | 0 | 8 |
| Monarda fistulosa | Mon fis | L. | 0 | 0 | 0 | 0 | 0 | 1 |
| Scutellaria galericulata | Scu gal | L. | 0 | 0 | 3 | 9 | 18 | 18 |
| Prunella vulgaris | Pru vul | L. | 0 | 1 | 0 | 0 | 0 | 1 |
| Polygala senega | Pol sen | L. | 0 | 0 | 0 | 13 | 3 | 29 |
| Sanicula marilandica | San mar | L. | 0 | 0 | 0 | 0 | 0 | 15 |
| Zizia aptera | Ziz apt | Fern. | 1 | 0 | 0 | 0 | 2 | 11 |
| Zizia aurea | Ziz aur | W. Koch | 0 | 0 | 0 | 1 | 0 | 1 |
| Thalictrum venulosum | Tha ven | Trel. | 0 | 7 | 3 | 0 | 0 | 12 |
| Toxicodendron rydbergii | Tox ryd | Greene | 0 | 0 | 0 | 0 | 0 | 3 |
| Viola sp. | Vio spp | | 10 | 7 | 4 | 5 | 10 | 4 |
| Bromus porteri | Bro por | Nash | 0 | 0 | 0 | 2 | 8 | 17 |
| Danthonia spicata | Dan spi | P. Beauv. | 0 | 0 | 0 | 0 | 0 | 1 |
| Deschampsia caespitosa | Des cae | P. Beauv. | 28 | 72 | 11 | 0 | 0 | 0 |
| Elymus trachycaulus | Ely tra | Gould | 20 | 0 | 3 | 0 | 0 | 0 |
| Koeleria macrantha | Koe mac | Schult. | 12 | 25 | 5 | 3 | 0 | 5 |
| Phleum pratense | Phl pra | L. | 0 | 27 | 0 | 0 | 0 | 9 |
| Andropogon gerardii | And ger | Vitm. | 0 | 0 | 1 | 4 | 33 | 0 |
| Agrostis scabra | Agr sca | Wild. | 2 | 12 | 0 | 0 | 0 | 6 |
| Sporobolus heterolepis | Spo het | A.Gray | 58 | 15 | 14 | 6 | 1 | 1 |
| Schizachne purpurascens | Sch pur | Swall. | 3 | 10 | 13 | 4 | 4 | 3 |
| Elymus canadensis | Ely can | L. | 0 | 0 | 0 | 0 | 0 | 2 |
| Carex sp. | Car spp | | 57 | 22 | 26 | 2 | 2 | 10 |

**Appendix 3: Moth species recorded during 2016 and 2017 sampling**

| Family | MONA # | PATT # | Scientific Name | Code | Common Name | Auth. |
|---|---|---|---|---|---|---|
| Erebidae | 8803 | 930795 | Catocala relicta | Cat rel | White Underwing Moth | Wlk. |
| Noctuidae | 9878 | 932524 | Lithomoia germana | Lit ger | Goldenrod Brindle Moth | Morris. |
| Noctuidae | 9952 | 932609 | Eucirroedia pampina | Euc pam | Scalloped Swallow Moth | Gn. |
| Erebidae | 8801 | 930792 | Catocala ilia | Cat ili | Ilia Underwing Moth | Cramer |
| Erebidae | 8805 | 930797 | Catocala unijuga | Cat uni | Once-married Underwing Moth | Wlk. |
| Erebidae | 8851 | 930837 | Catocala coccinata | Cat coc | Scarlet Underwing Moth | Grt. |
| Noctuidae | 9382 | 932350 | Apamea devastator | Apa dev | Glassy Cutworm | Brace. |
| Noctuidae | 9261 | 931477 | Acronicta impressa | Acr imp | Impressed Dagger Moth | Wlk. |
| Noctuidae | 10055 | 931911 | Sympistis dentata | Sym den | Toothed Apharetra Moth | Grt. |
| Noctuidae | 10280 | 932872 | Polia purpurissata | Pol pur | Purple Arches Moth | Grt. |
| Noctuidae | 9578 | 932664 | Hyppa xylinoides | Hyp xyl | Common Hyppa Moth | Gn. |
| Noctuidae | 11029 | 933680 | Abagrotis alternata | Aba alt | Greater Red Dart Moth | Grt. |
| Noctuidae | 10944 | 933572 | Xestia smithii | Xes smi | Smith's Dart Moth | Snell. |
| Noctuidae | 9638 | 931544 | Amphipyra pyramidoides | Amp pyr | Copper Underwing Moth | Gn. |
| Erebidae | 8196 | 930246 | Apantesis parthenice | Apa par | Parthenice Tiger Moth | Kirby |
| Erebidae | 8536 | 930612 | Calyptra canadensis | Cal can | Canadian Owlet Moth | Belt. |
| Erebidae | 8129 | 930335 | Pyrrharctia isabella | Pyr isa | Isabella Tiger Moth | J. Smith |
| Erebidae | 8175 | 930247 | Apantesis virguncula | Apa vir | Little Virgin Tiger Moth | Kirby |
| Noctuidae | 10268 | 932908 | Sideridis maryx | Sid mar | Maroonwing Moth | Gn. |
| Erebidae | 8267 | 930440 | Cisseps fulvicollis | Cis ful | Yellow-collared Scape Moth | Hubner |
| Noctuidae | 9580 | 932667 | Hyppa brunneicrista | Hyp bru |  | Smith |
| Noctuidae | 9193 | 931412 | Raphia frater | Rap fra | Brother Moth | Grt. |
| Geometridae | 6796 | 931226 | Campaea perlata | Cam per | Pale Beauty Moth | Gn. |
| Geometridae | 6279 | 930725 | Macaria occiduaria | Mac occ |  | Pack. |
| Noctuidae | 9815 | 932672 | Cosmia calami | Cos cal | American Dun-bar Moth | Harv. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Noctuidae | 9549 | 932674 | Enargia decolor | Ena dec | Pale Enargia Moth | Wlk. |
| Noctuidae | 9456 | 932446 | Amphipoea interoceanica | Amp int | Interoceanic Ear Moth | Smith. |
| Noctuidae | 9364 | 932314 | Apamea sordens | Apa sor | Bordered Apamea Moth | Hufn. |
| Noctuidae | 10447 | 932947 | Leucania commoides | Leu com | | Gn. |
| Noctuidae | 10446 | 932945 | Leucania multilinea | Leu mul | Many-lined Wainscot Moth | Wlk. |
| Noctuidae | 10854 | 933439 | Euxoa servitus | Eux ser | Slave Dart Moth | Sm. |
| Noctuidae | 10951 | 933630 | Pseudohermonassa tenuicula | Pse ten | Morrison's Sooty Dark Moth | Morris. |
| Noctuidae | 10585 | 933136 | Orthodes majuscula | Ort maj | Rustic Quaker Moth | Herr. |
| Erebidae | 8738 | 930923 | Caenurgina crassiuscula | Cae cra | Clover Looper Moth | Haworth |
| Noctuidae | 10368 | 933016 | Lacinipolia meditata | Lac med | Thinker Moth | Grt. |
| Noctuidae | 10066.1 | 931823 | Sympistis dinalda | Sym din | | Smith |
| Erebidae | 8764 | 930956 | Argyrostrotis anilis | Arg ani | Short-lined Chocolate Moth | Drury |
| Geometridae | 6941 | 931384 | Eusarca confusaria | Eus con | Confused Eusarca Moth | Hubner |
| Noctuidae | 9431 | 932625 | Parastichtis suspecta | Par sus | | Hubner |
| Noctuidae | 10307 | 932889 | Trichordestra lilacina | Tri lil | Aster Cutworm Moth | Harv. |
| Noctuidae | 10954 | 933627 | Agnorisma bugrai | Agn bug | Collared Dart Moth | Kocak |
| Noctuidae | 10702 | 933320 | Euxoa divergens | Eux div | Divergent Dart Moth | Wlk. |
| Erebidae | 8731 | 930929 | Euclidia cuspidea | Euc cus | Toothed Somberwing Moth | Hubner |
| Noctuidae | 9249 | 931467 | Acronicta increta | Acr inc | Southern Oak Dagger Moth | Morris. |
| Noctuidae | 9333 | 932319 | Apamea lignicolora | Apa lig | Wood-colored Apamea Moth | Gn. |
| Geometridae | 6728 | 911153 | Euchlaena effecta | Euc eff | Effective Euchlaena Moth | Wlk. |
| Noctuidae | 10449 | 932948 | Leucania insueta | Leu ins | | Gn. |
| Torticidae | 3595 | 620250 | Pandemis canadana | Pan can | Green Aspen Leaftier Moth | Kear. |
| Torticidae | 3635 | 620300 | Choristoneura rosaceana | Cho ros | Oblique-banded Leafroller Moth | Harris |
| Crambidae | 5275 | 801197 | Herpetogramma pertextalis | Her per | Bold-feathered Grass Moth | Leder. |
| Crambidae | 4956 | 801432 | Anania extricalis | Aan ext | | Gn. |
| Torticidae | 3623 | 620282 | Argyrotaenia | Arg que | Yellow-winged Oak Leafroller | Fitch |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | quercifoliana | | | |
| Noctuidae | 10462 | 932966 | Leucania pseudargyria | Leu pse | False Wainscot | Gn. |
| Torticidae | 3682 | 620357 | Clepsis persicana | Cle pers | White-triangle Tortrix Moth | Fitch |
| Crambidae | 5408 | 800847 | Catoptria latiradiellus | Cat lat | Three-spotted Crambus Moth | Wlk. |
| Torticidae | 3637 | 620302 | Choristoneura conflictana | Cho con | Large Aspen Tortrix Moth | Wlk. |
| Torticidae | 3693 | 620372 | Xenotemna pallorana | Xen pal | | Robin. |
| Erebidae | 8397 | 930551 | Palthis angulalis | Pal ang | Dark-spotted Palthis Moth | Hubner |
| Torticidae | 2743 | 930528 | Apotomis capreana | Apo cap | | Clem. |
| Torticidae | 2823 | 620591 | Olethreutes fasciatana | Ole fas | | Clem. |
| Noctuidae | 10301 | 932883 | Spiramater lutra | Spi lut | Otter Spirameter Moth | Gn. |
| Noctuidae | 10926 | 933554 | Spaelotis clandestina | Spa cla | Clandestine Dart Moth | Harris |
| Noctuidae | 9647 | 932266 | Proxenus miranda | Pro mir | Miranda Moth | Grt. |
| Noctuidae | 10803 | 933411 | Euxoa velleripennis | Eux vel | Fleece-winged Dart Moth | Grt. |
| Noctuidae | 9361 | 932362 | Melanapamea mixta | Mel mix | | Grt. |
| Lasiocampidae | 7698 | 870014 | Malacosoma disstria | Mal dis | Forest Tent Caterpillar Moth | Hubner |
| Noctuidae | 8975 | 931142 | Nycteola frigidana | Nyc fri | Frigid Owlet Moth | Wlk. |
| Pyralidae | 5824 | 800390 | Pyla aequivoca | Pyl aeq | | Hein. |
| Noctuidae | 9284 | 932207 | Anterastria teratophora | Ant ter | Gray Marvel Moth | Herr. |
| Erebidae | 8089 | 930204 | Hypoprepia miniata | Hyp min | Scarlet-winged Lichen Moth | Kirby |
| Erebidae | 8090 | 930205 | Hypoprepia fucosa tricolor | Hyp fuc | Painted Lichen Moth | Hubner |
| Geometridae | 7010 | 910676 | Nematocampa resistaria | Nem res | Horned Spanworm Moth | Herr. |
| Erebidae | 8322 | 930469 | Idia americalis | Idi ame | American Idia Moth | Gn. |
| Pyralidae | 5655 | 800153 | Acrobasis tricolorella | Acr tri | Destructive Pruneworm Moth | Grt. |
| Erebidae | 8114 | 930294 | Virbia laeta | Vir lae | Joyful Holomelina Moth | Guer. |
| Geometridae | 7371 | 910214 | Xanthorhoe iduata | Xan idu | | Gn. |
| Erebidae | 8052 | 930226 | Crambidia pura | Cra pur | Pure Lichen Moth | Barnes &Mcdu. |
| Geometridae | 6678 | 911099 | Cabera variolaria | Car var | Vestal Moth | Gn. |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Geometridae | 6912 | 911352 | Sicya macularia | Sic mac | Sharp-lined Yellow Moth | Harris |
| Noctuidae | 9053 | 932205 | Pseudeustrotia carneola | Pse car | Pink-barred Lithacodia Moth | Gn. |
| Geometridae | 6292 | 910712 | Macaria exauspicata | Mac exa |  | Wlk. |
| Noctuidae | 10490 | 932773 | Orthosia revicta | Ort rev | Subdued Quaker Moth | Morris. |
| Erebidae | 8445 | 930566 | Hypena abalienalis | Hyp aba | White-lined Bomolocha Moth | Wlk. |
| Geometridae | 7159 | 910567 | Scopula limboundata | Sco lim | Large Lace-border Moth | Haworth |
| Geometridae | 6583 | 911001 | Iridopsis ephyraria | Iri eph | Pale-winged Gray Moth | Wlk. |
| Erebidae | 8123 | 930306 | Virbia ferruginosa | Vir fer | Rusty Holomelina Moth | Wlk. |
| Crambidae | 5343 | 800931 | Crambus perlella | Cra per | Immaculate Grass-veneer Moth | Scop. |
| Crambidae | 5464 | 800821 | Urola nivalis | Uro niv | Snowy Urola Moth | Drury |
| Noctuidae | 7931 | 930019 | Gluphisia septentrionis | Glu sep | Common Gluphisia Moth | Wlk. |
| Pyralidae | 5524 | 800086 | Hypsopygia costalis | Hyp cos | Clover Hayworm Moth | Fabr. |
| Erebidae | 8384.1 | 930536 | Renia flavipunctalis | Ren fla | Yellow-spotted Renia Moth | Geyer |
| Noctuidae | 10370 | 933017 | Lucinipolia lustralis | Luc lus |  | Grt. |
| Noctuidae | 9212 | 931433 | Acronicta grisea | Acr gri | Gray Dagger Moth | Wlk. |
| Noctuidae | 10292 | 932874 | Melanchra adjuncta | Mel adj | Hitched Arches Moth | Gn. |
| Noctuidae | 8007 | 930100 | Schizura unicornis | She uni | Unicorn Caterpillar Moth | Smith |
| Geometridae | 7188 | 910022 | Dysstroma walkerata | Dys wal | Orange-spotted Carpet Moth | Pear. |
| Noctuidae | 10910 | 933223 | Anicla tepperi | Ani tep |  | Smith |
| Geometridae |  |  | Unknown Geometridae | Unk Geo |  |  |
| Pyralidae |  |  | Unknown Pyralidae | Unk Pyr |  |  |
| Noctuidae |  |  | Unknown Noctuid | Unk Noc |  |  |
|  |  |  | Unknown Micro | Unk Mic |  |  |
| Sphingidae | 7822 | 890141 | Smerinthus cerisyi | Sme cer | One-eyed Sphinx | Kirby |
| Notodontidae | 7985 | 930003 | Clostera albosigma | Clo alb | Sigmoid Prominent | Fitch |
| Sphingidae | 7821 | 890140 | Smerinthus jamaicensis | Sme jam | Twin-spotted Sphinx | Drury |
| Erebidae | 8817 | 930804 | Catocala briseis | Cat bri | Briseis Underwing | Edwar. |
| Erebidae | 8689 | 931023 | Zale lunata | Zal lun | Lunate Zale Moth | Drury |

| | | | | | | |
|---|---|---|---|---|---|---|
| Erebidae | 8262 | 930435 | Ctenucha virginica | Cte vir | Virginia Ctenucha | Esper |
| Noctuidae | 10265 | 932908 | Sideridis rosea | Sid ros | Rosewing | Harv. |
| Geometridae | 6982 | 911432 | Prochoerodes lineola | Pro lin | Large Maple Spanworm | Goeze |
| Noctuidae | 9257 | 931474 | Acronicta impleta | Acr imp | Yellow-haired Dagger Moth | Wlk. |
| Noctuidae | 10299 | 932881 | Lacanobia subjuncta | Lac sub | Speckled Cutworm | Grt. &Robin. |
| Noctuidae | 8939 | 931225 | Syngrapha alias | Syn ali | | Otto. |
| Noctuidae | 9229 | 931445 | Acronicta hasta | Acr has | Speared Dagger Moth | Gn. |
| Noctuidae | 9369 | 932347 | Apamea inficita | Apa inf | Lined Quaker Moth | Wlk. |
| Erebidae | 8194 | 930242 | Apantesis phyllira | Apa phy | Phyllira Tiger | Drury |
| Geometridae | 7048 | 910629 | Nemoria mimosaria | Nem mim | White-fringed Emerald | Gn. |
| Drepanidae | 6237 | 850005 | Pseudothyatira cymatophoroides | Pse cym | Tufted Thyatirid | Gn. |
| Noctuidae | 10659 | 933521 | Agrotis volubilis | Agr vol | Voluble Dart | Harv. |
| Geometridae | 7388 | 910231 | Xanthorhoe ferrugata | Xan fer | Red Twin-Spot | Cler. |
| Geometridae | 6837 | 911269 | Probole alienaria-amicaria | Pro ali | Alien Probe | Herr. |
| Geometridae | 7169 | 910578 | Scopula inductata | Sco ind | Soft-lined Wave | Gn. |
| Nolidae | 8983 | 931121 | Meganola minuscula | Meg min | Confused Meganola | Zeller |
| Erebidae | 8051 | 930225 | Crambidia casta | Cra cas | Pearly-winged Lichen | Pack. |
| Noctuidae | 8896 | 931178 | Diachrysia aereoides | Dia aer | Dark-spotted Looper | Grt. |
| Noctuidae | 8924 | 931234 | Anagrapha falcifera | Ana fal | Celery Looper | Kirby |
| Noctuidae | 10968 | 933584 | Xestia badicollis | Xes bad | Northern Variable Dart | Grt. |
| Noctuidae | 9241 | 931458 | Acronicta fragilis | Acr fra | Fragile Dagger Moth | Gn. |
| Noctuidae | 10300 | 932882 | Lacanobia grandis | Lac gra | Grand Arches Moth | Gn. |
| Noctuidae | 10674 | 933501 | Feltia subgothica | Fel sub | Subgothic Dart Moth | Haworth |
| Erebidae | 8043 | 930217 | Manulea bicolor | Man bic | Bicolored Moth | Grt. |
| Geometridae | 6621 | 911060 | Melanolophia signataria | Mel sig | Signate Melanolophia Moth | Wlk. |
| Geometridae | 7187 | 910021 | Dysstroma truncata | Dys tru | Marbled Carpet Moth | Hufn. |
| Geometridae | 7640 | 910481 | Lobophora nivigerata | Lob niv | Powdered Bigwing Moth | Wlk. |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Noctuidae | 10999 | 933567 | Aplectoides condita | Apl con |  | Gn. |
| Geometridae |  |  | Euputhecia spp. | Eup spp |  |  |
| Crambidae |  |  | Zanclognatha spp. | Zan spp. |  |  |
| Noctuidae | 9351 | 932307 | Apamea alia | Apa ali |  | Gn. |
| Torticidae |  |  | Unknown Torticidae | Unk tor |  |  |
| Geometridae | 6290 | 910733 | Macaria loricaria | Mac lor |  | Ever. |
| Noctuidae | 10304 | 932886 | Trichordestra legitima | Tri leg | Striped Garden Caterpillar | Grt. |
| Noctuidae | 9681.1 | 932234 | Elaphria alapallida | Ela ala | Pale-winged Midget Moth | Pogue &Sull. |
| Geometridae | 6819 | 911251 | Metanema inatomaria | Met ina | Pale Metanema Moth | Gn. |
| Noctuidae | 10651 | 933516 | Agrotis venerabilis | Agr ven | Venerable Dart Moth | Wlk. |
| Torticidae | 3695 | 620390 | Sparganothis sulfureana | Spa sul | Sparganothis Fruitworm Moth | Clem. |

## Appendix 4: Moth abundances by trap

Appendix 4a: Moth abundances by trap 2016

| | MRBW | MRBE | MRBW | CLMN | MRBE | CLMN | PEG | CLMS | MRC | PEG | CLMS | MRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **11** | **12** | **9** | **8** | **14** | **13** | **2** | **1** | **4** | **20** | **3** | **18** |
| Catocala relicta | | 2 | | | | | | | 1 | | | |
| Lithomoia germana | | 1 | | | 1 | | | | 2 | | | |
| Eucirroedia pampina | | | | 1 | | | | | 1 | 4 | | |
| Catocala ilia | | | | | 1 | | | 1 | | | | |
| Catocala unijuga | 1 | | | | | | | 1 | | | | |
| Catocala coccinata | | | | | | | | 2 | | | | |
| Apamea devastator | 2 | | | | 4 | | | | | | | |
| Acronicta impressa | 1 | | | | 1 | | 1 | | | | 3 | |
| Sympistis dentata | | | | 4 | | 2 | | | | | 1 | 2 |
| Polia purpurissata | | 1 | | | | | | | | | | 1 |
| Hyppa xylinoides | | | | 1 | 3 | | | | | | | |
| Abagrotis alternata | | 1 | | | 1 | | | | | | | |
| Xestia smithii | | 1 | | | 1 | | 1 | | | 2 | | |
| Amphipyra pyramidoides | | 9 | | | 7 | | 1 | | | | | 1 |
| Apantesis parthenice | | | | | | | | | | 1 | | 2 |
| Calyptra canadensis | | 1 | | | | | | | | | | |
| Pyrrharctia isabella | | | | | | | 1 | | | | | |
| Apantesis virguncula | | | | | | | 2 | | | 1 | | |
| Sideridis maryx | | | | | | | | 2 | | | 1 | |
| Cisseps fulvicollis | | | | | | | | | | 1 | | |
| Hyppa brunneicrista | | | | 1 | | | | | | | | |
| Raphia frater | 1 | | | | 1 | 1 | 1 | | 1 | | | |
| Campaea perlata | | | | | | | | | 1 | 1 | | |

| Scientific Name | MRBW 11 | MRBE 12 | MRBW 9 | CLMN 8 | MRBE 14 | CLMN 13 | PEG 2 | CLMS 1 | MRC 4 | PEG 20 | CLMS 3 | MRC 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Enargia decolor | | | | | | | | | 1 | | | |
| Amphipoea interoceanica | | | | | 1 | | | | | | | |
| Apamea sordens | | | | | 1 | | | | 1 | | | |
| Leucania commoides | 2 | | | 1 | | | | 1 | 2 | | | 1 |
| Leucania multilinea | | | 1 | | | | | | | | | 1 |
| Euxoa servitus | 1 | 2 | | | 5 | | | 2 | | | | |
| Pseudohermonassa tenuicula | | | | 1 | | | | | | | | |
| Orthodes majuscula | | | | | 5 | | | | | 1 | | |
| Caenurgina crassiuscula | 4 | 1 | 1 | 3 | 1 | | 4 | | 4 | 2 | | 2 |
| Lacinipolia meditata | | | | | | | | | | | | 1 |
| Sympistis dinalda | | | | 1 | | | | | | | | 2 |
| Argyrostrotis anilis | | | | | | | | | | | 1 | |
| Eusarca confusaria | | | | | | | 2 | | | 4 | | 1 |
| Parastichtis suspecta | | | | | | | | | | 1 | | |
| Trichordestra lilacina | | | | | 1 | | | | | | | |
| Agnorisma bugrai | | 2 | | | | | | | | | | |
| Euxoa divergens | 1 | | | | | | | 1 | 1 | 1 | | |
| Euclidia cuspidea | | | | | | | | | | | | 1 |
| Acronicta increta | | | | | 1 | | | | | | | |
| Apamea lignicolora | | | | | 1 | | | | | | | 1 |
| Euchlaena effecta | | | | | | | | | | 2 | | |
| Leucania insueta | | 1 | | | | | | | | | | |
| Pandemis canadana | 15 | 2 | 6 | 15 | 10 | 20 | 10 | 5 | 9 | 8 | 26 | 34 |
| Choristoneura rosaceana | | | | | | | | | | | 1 | |
| Herpetogramma pertextalis | | 1 | | | | | | | 1 | | | 2 |

| | MRBW | MRBE | MRBW | CLMN | MRBE | CLMN | PEG | CLMS | MRC | PEG | CLMS | MRC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | | **11** | **12** | **9** | **8** | **14** | **13** | **2** | **1** | **4** | **20** | **3** | **18** |
| Leucania pseudargyria | | | | | | | | | 1 | | | 1 | |
| Clepsis persicana | | 2 | | 2 | | 2 | | 3 | | 1 | 1 | | |
| Catoptria latiradiellus | | | | | | | | | | | 1 | | |
| Choristoneura conflictana | | | 1 | | | | | | | | 1 | | |
| Xenotemna pallorana | | | 2 | | | 1 | 2 | | | 4 | | 1 | |
| Palthis angulalis | | | | | | | | | | | 2 | | |
| Apotomis capreana | | | 1 | | | 3 | | | | | | | |
| Olethreutes fasciatana | | 1 | | | | | | | | | | | |
| Spiramater lutra | | 3 | | | | | 3 | | | | | | |
| Spaelotis clandestina | | | | | | | | | | | 1 | | |
| Proxenus miranda | | | 1 | | 1 | | | | 1 | | | | |
| Euxoa velleripennis | | 1 | | | 2 | | | | | | | | |
| Melanapamea mixta | | 1 | | | 1 | 1 | 19 | 1 | | 1 | 2 | 2 | |
| Malacosoma disstria | 38 | 6 | 25 | 5 | 1 | 2 | 12 | 0 | 4 | 51 | 9 | 17 | |
| Nycteola frigidana | 2 | 1 | 1 | | 3 | | 4 | | | 2 | | | |
| Pyla aequivoca | 5 | 4 | 24 | 20 | 7 | 42 | 10 | 1 | 7 | 18 | 4 | 15 | |
| Anterastria teratophora | | | | | | | | | | | 1 | | |
| Hypoprepia miniata | | | | 1 | | | | | | | | | |
| Hypoprepia fucosa tricolor | | | 1 | 1 | | | | | | | | 2 | |
| Nematocampa resistaria | 1 | | | | | | | | | | | | |
| Idia americalis | 1 | 1 | | 2 | | | | | | 1 | | 4 | |
| Acrobasis tricolorella | | 1 | | | | | | | | | | | |
| Virbia laeta | | 1 | | | | | | | | 1 | | | |
| Xanthorhoe iduata | | | 1 | | 1 | | | | | 1 | | 1 | |
| Crambidia pura | | 1 | | 1 | | | 2 | | | | 2 | 1 | |

| Scientific Name | MRBW 11 | MRBE 12 | MRBW 9 | CLMN 8 | MRBE 14 | CLMN 13 | PEG 2 | CLMS 1 | MRC 4 | PEG 20 | CLMS 3 | MRC 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pseudeustrotia carneola |  | 3 |  |  | 1 |  |  |  |  |  |  | 1 |
| Macaria exauspicata |  | 1 |  | 1 |  | 1 | 1 |  | 1 |  |  |  |
| Orthosia revicta |  |  |  | 1 |  |  |  |  |  | 1 |  |  |
| Hypena abalienalis |  |  |  |  |  |  | 1 |  |  |  |  |  |
| Scopula limboundata |  |  | 1 |  |  |  | 1 |  | 1 | 3 |  | 2 |
| Iridopsis ephyraria |  | 3 |  |  |  |  |  |  |  |  |  |  |
| Virbia ferruginosa |  |  |  |  |  |  |  |  |  |  | 1 | 1 |
| Crambus perlella |  |  |  |  |  |  |  | 1 | 1 |  |  | 2 |
| Urola nivalis |  | 1 |  |  |  |  |  |  |  |  |  |  |
| Gluphisia septentrionis |  |  | 1 |  |  |  |  |  |  |  |  |  |
| Hypsopygia costalis |  |  |  | 1 |  |  |  |  |  |  | 1 |  |
| Renia flavipunctalis |  |  |  |  |  | 1 |  |  |  | 1 |  |  |
| Lucinipolia lustralis |  |  |  | 1 |  |  |  |  |  |  |  |  |
| Acronicta grisea | 1 |  |  |  |  | 1 |  |  |  |  |  |  |
| Melanchra adjuncta |  |  |  |  |  |  |  |  |  |  |  |  |
| Schizura unicornis |  | 1 |  |  |  |  |  |  |  |  |  |  |
| Dysstroma walkerata |  |  |  |  | 1 |  |  |  |  |  |  |  |
| Anicla tepperi |  |  |  |  |  |  |  |  |  |  | 2 |  |
| Unknown Geometridae |  |  | 1 | 1 |  |  | 1 |  |  |  |  | 1 |
| Unknown Pyralidae |  | 5 |  |  | 2 | 1 |  |  |  |  |  |  |
| Unknown Noctuid |  |  |  |  |  |  | 1 |  | 2 |  |  | 1 |
| Unknown Micro | 73 | 91 | 35 | 26 | 42 | 59 | 49 | 4 | 119 | 153 | 64 | 193 |

Appendix 4b: Moth abundances by trap 2017

| | MRBE | CLN | MRBW | PEG | CLS | MRC | MRBE | MRBW |
|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Catocala relicta | | | | | | | | |
| Eucirroedia pampina | 1 | | | 2 | | | | |
| Catocala unijuga | | | | | | | | |
| Catocala coccinata | | | | | | | | 3 |
| Apamea devastator | | | 1 | | | | 2 | |
| Acronicta impressa | | | 1 | | | | | |
| Sympistis dentata | | | | | | 1 | | 1 |
| Hyppa xylinoides | | | | | | | | |
| Xestia smithii | | | 1 | | | 2 | 1 | 1 |
| Amphipyra pyramidoides | | | | | | | | |
| Apantesis parthenice | | | | 1 | | 3 | | |
| Calyptra canadensis | | | | | | | | |
| Sideridis maryx | | | | | | 2 | | |
| Raphia frater | | | | | | | | |
| Campaea perlata | | | | | | | | |
| Macaria occiduaria | | 2 | | | 3 | 5 | | |
| Cosmia calami | 1 | | | | | | | 9 |
| Amphipoea interoceanica | | | | | | 1 | | |
| Leucania commoides | | | 1 | | | | | |
| Leucania multilinea | | | | | | | | |
| Euxoa servitus | 1 | | | 1 | | 7 | 6 | 2 |
| Orthodes majuscula | 1 | | | | | 1 | | 1 |
| Caenurgina crassiuscula | | | 1 | 3 | | | 6 | 3 |
| Sympistis dinalda | | | | | | | | |
| Argyrostrotis anilis | 1 | | | | | | | 1 |

| MRBW 9 | CLN 10 | MRBE 11 | CLN 12 | PEG 13 | CLS 15 | MRC 17 | PEG 18 | CLS 19 | MRC 20 |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | 1 |  |  |  |  |
|  |  |  | 2 |  |  |  | 2 |  |  |
|  |  |  |  | 1 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 4 |
|  | 1 | 1 |  |  |  |  |  |  | 1 |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  | 1 |  |  |  |  |  | 1 |
|  |  |  |  |  |  |  | 2 |  | 1 |
|  |  |  | 1 | 1 |  |  | 3 |  | 1 |
|  |  |  |  |  |  | 1 |  |  |  |
| 1 |  |  |  |  |  |  |  |  | 1 |
| 1 |  |  |  |  |  |  |  |  |  |
|  |  |  | 1 |  |  |  |  |  |  |
|  | 1 |  |  | 2 |  |  | 1 |  |  |
|  |  |  |  | 1 |  |  | 2 |  |  |
| 1 | 8 |  | 11 | 28 |  |  | 18 | 32 | 4 |
| 1 | 5 |  | 4 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |
| 1 | 1 |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | 1 |  |
| 1 |  |  |  | 2 |  |  |  |  | 1 |
|  |  | 1 |  | 2 |  |  | 3 |  |  |
| 15 | 2 | 3 |  | 5 |  | 1 | 9 | 2 | 13 |
|  |  |  |  | 1 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |

| **Scientific Name** | **MRBE 1** | **CLN 2** | **MRBW 3** | **PEG 4** | **CLS 5** | **MRC 6** | **MRBE 7** | **MRBW 8** |
|---|---|---|---|---|---|---|---|---|
| Eusarca confusaria | | | | | | | | |
| Parastichtis suspecta | | | | | | | | |
| Trichordestra lilacina | | | | | | | 1 | |
| Agnorisma bugrai | | | | 2 | | 2 | | |
| Euxoa divergens | | | | | | | | |
| Euclidia cuspidea | | | | | | | | |
| Acronicta increta | | | | | | | | |
| Apamea lignicolora | | | | | | | | |
| Euchlaena effecta | 1 | | | | | | | |
| Leucania insueta | | | | | | | | |
| Pandemis canadana | 2 | 7 | 7 | 2 | | 2 | | 8 |
| Choristoneura rosaceana | 1 | | | | | | | |
| Anania extricalis | | | | 3 | | | | 1 |
| Argyrotaenia quercifoliana | 3 | | | | | | | 1 |
| Clepsis persicana | | | | | | | | |
| Xenotemna pallorana | | 1 | | | | | | |
| Apotomis capreana | | | 1 | | | 1 | 2 | |
| Spiramater lutra | | 1 | | | 1 | 1 | 1 | |
| Melanapamea mixta | | | | 2 | | 2 | | |
| Malacosoma disstria | | | | | 2 | | | |
| Nycteola frigidana | | | 2 | | | 1 | | 3 |
| Pyla aequivoca | 2 | 11 | 3 | 14 | | 8 | 2 | 7 |
| Hypoprepia miniata | | | | | | | | |
| Hypoprepia fucosa tricolor | | | | | | | | |
| Nematocampa resistaria | | | | | | | | |

| MRBW 9 | CLN 10 | MRBE 11 | CLN 12 | PEG 13 | CLS 15 | MRC 17 | PEG 18 | CLS 19 | MRC 20 |
|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | 9 | | |
| | | | | | | | 1 | | |
| | | | | | | | | | |
| | | | | | 1 | | | | |
| 2 | | | 1 | | | | | 1 | |
| | | | | | | | | | 1 |
| | | | | 1 | | | | | |
| | | | 1 | | | | | | |
| | | | | 1 | | | | | |
| | | | | | | | | 1 | |
| 12 | 15 | 5 | 1 | 18 | 7 | 2 | 7 | 7 | 1 |
| | | | | | 1 | | | | |
| 3 | 6 | | | 1 | | | | 1 | |
| | | | | | 1 | | 2 | | |
| | | 1 | 1 | | 1 | | | | 2 |
| | | | | 2 | | 1 | 2 | | |
| | | | 1 | | 1 | | | | |
| | 1 | | 2 | 7 | | | 1 | | |
| | 12 | 1 | | 26 | 2 | | 2 | 4 | |
| | | | | | | | | | |
| | 1 | 2 | | 11 | 1 | 1 | 1 | | 1 |
| 6 | 39 | 4 | 3 | 11 | 3 | 4 | | 28 | 16 |
| | | | | | | | 1 | | |
| 1 | | | | | | | 1 | | |
| 1 | | | | | | | | | |

| Scientific Name | MRBE 1 | CLN 2 | MRBW 3 | PEG 4 | CLS 5 | MRC 6 | MRBE 7 | MRBW 8 |
|---|---|---|---|---|---|---|---|---|
| Idia americalis | | | | | | | | |
| Xanthorhoe iduata | | 1 | | 1 | | | | |
| Crambidia pura | | | 6 | 1 | | | 4 | |
| Cabera variolaria | | | | | | | | |
| Sicya macularia | | | | | | | | 1 |
| Pseudeustrotia carneola | 3 | | | | 1 | | | 1 |
| Macaria exauspicata | | 1 | | 1 | | | | |
| Scopula limboundata | 1 | | | 2 | | | | |
| Virbia ferruginosa | | | | 1 | | | | |
| Crambus perlella | | | | 2 | | 1 | | |
| Gluphisia septentrionis | | | | | | | | |
| Lucinipolia lustralis | 3 | | | 3 | | | 1 | |
| Melanchra adjuncta | | | | | | | | 1 |
| Dysstroma walkerata | | | | | | | | |
| Unknown Geometridae | 1 | | | | | | | |
| Unknown Pyralidae | 1 | 1 | | | 1 | 1 | | |
| Unknown Noctuid | 1 | | | | | 3 | 3 | 1 |
| Unknown Micro | 38 | 21 | 22 | 25 | | 62 | 35 | 48 |
| Smerinthus cerisyi | | | | | | | | |
| Clostera albosigma | | | | | | | | |
| Smerinthus jamaicensis | | | | 1 | | | | |
| Catocala briseis | | | 1 | | | | | |
| Zale lunata | | | | 1 | | | | |
| Ctenucha virginica | 1 | | | | | | 1 | |
| Sideridis rosea | | 1 | | | | | | |

| **MRBW 9** | **CLN 10** | **MRBE 11** | **CLN 12** | **PEG 13** | **CLS 15** | **MRC 17** | **PEG 18** | **CLS 19** | **MRC 20** |
|---|---|---|---|---|---|---|---|---|---|
| 6 |  |  |  | 1 | 1 |  | 1 |  | 1 |
| 1 |  |  |  |  |  |  |  |  | 2 |
| 4 |  |  |  | 1 |  |  | 1 |  | 4 |
| 6 |  |  |  |  |  |  |  |  |  |
|  |  | 1 |  | 1 |  |  | 1 |  |  |
| 2 |  |  |  |  | 1 | 1 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  | 1 |  |  |  |  |  | 1 | 1 |  |
|  |  |  |  |  |  |  |  | 1 |  |
| 1 |  | 3 |  | 7 |  |  |  |  | 1 |
|  |  |  |  | 1 |  |  |  |  |  |
| 2 | 1 |  | 1 |  | 2 |  |  | 2 |  |
| 2 |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 1 |  |  | 1 |  |  |
|  | 1 |  |  |  |  | 1 |  |  |  |
|  |  |  |  | 1 |  |  |  |  |  |
|  | 8 |  | 2 | 6 |  |  | 2 | 2 | 3 |
| 189 | 33 | 8 | 28 | 37 | 60 | 20 | 149 | 72 | 85 |
| 1 |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  | 10 |  |  |  |  |  |  |  |  |

| Scientific Name | MRBE | CLN | MRBW | PEG | CLS | MRC | MRBE | MRBW |
|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Prochoerodes lineola |  |  |  |  |  |  |  |  |
| Acronicta impleta |  |  |  |  |  |  |  |  |
| Lacanobia subjuncta |  |  |  |  |  |  |  |  |
| Syngrapha alias |  |  |  |  |  |  |  |  |
| Acronicta hasta |  |  |  |  |  |  |  |  |
| Apamea inficita |  |  |  |  |  | 1 |  |  |
| Apantesis phyllira |  |  |  | 1 |  |  |  |  |
| Nemoria mimosaria |  |  |  |  |  |  |  |  |
| Pseudothyatira cymatophoroides |  |  |  |  |  |  |  |  |
| Agrotis volubilis | 1 |  |  |  |  |  |  |  |
| Xanthorhoe ferrugata |  |  |  |  |  |  | 1 |  |
| Probole alienaria-amicaria |  |  |  |  |  |  | 1 |  |
| Scopula inductata | 1 |  |  |  |  |  |  |  |
| Meganola minuscula |  |  |  |  |  |  |  |  |
| Crambidia casta |  |  |  | 1 |  |  |  |  |
| Diachrysia aereoides |  |  |  |  |  |  |  | 1 |
| Anagrapha falcifera |  |  |  |  |  |  |  |  |
| Xestia badicollis |  |  |  |  |  |  |  |  |
| Acronicta fragilis |  | 2 |  |  |  |  |  |  |
| Lacanobia grandis |  |  |  |  |  |  |  |  |
| Feltia subgothica |  |  |  | 1 |  | 1 |  |  |
| Manulea bicolor |  |  |  |  |  |  |  |  |
| Melanolophia signataria |  |  |  |  |  |  |  |  |
| Dysstroma truncata |  |  |  |  |  |  |  |  |

| MRBW 9 | CLN 10 | MRBE 11 | CLN 12 | PEG 13 | CLS 15 | MRC 17 | PEG 18 | CLS 19 | MRC 20 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 1 |
| | | | | 1 | | | | | |
| | 1 | | | | | | | | |
| | | | | 1 | | | | | |
| | 1 | | | | | | | | |
| | | | | | 1 | | | | |
| | | | | | | | | | |
| | | | | | | | | | 1 |
| | | 1 | | 1 | | | | | |
| | | | 1 | 1 | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| 1 | | | | | | | | | 1 |
| | | | 6 | 1 | | | | | 6 |
| | | | | | | | | | |
| | | | | | | | | | 1 |
| | 1 | | | | | | | | |
| | 1 | | | 1 | | | | | |
| | | | 1 | | | | | | |
| | | | | | | | | | 3 |
| | | | | | | | | | 1 |
| 1 | | | | | | | | | |
| | | | | | | | | | 2 |

| Scientific Name | MRBE 1 | CLN 2 | MRBW 3 | PEG 4 | CLS 5 | MRC 6 | MRBE 7 | MRBW 8 |
|---|---|---|---|---|---|---|---|---|
| Lobophora nivigerata | | | | | | | | |
| Aplectoides condita | | | | | | | | |
| Euputhecia spp. | | | | | | 1 | | |
| Zanclognatha spp. | | | | | | 1 | | |
| Apamea alia | | | | | | | | |
| Unknown Torticidae | | 1 | | | | | | |
| Macaria loricaria | | | | 1 | | 1 | | |
| Trichordestra legitima | 1 | | | | | | | 1 |
| Elaphria alapallida | | | | | | | | |
| Metanema inatomaria | | | | | | | | |
| Agrotis venerabilis | | | | | | | | |
| Sparganothis sulfureana | | | | | | 1 | | |

| MRBW 9 | CLN 10 | MRBE 11 | CLN 12 | PEG 13 | CLS 15 | MRC 17 | PEG 18 | CLS 19 | MRC 20 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 1 |
| | | | | 1 | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | 1 | | | | | | | | |
| | | | | 1 | | | | 1 | |
| | | | | | | | | 2 | |
| | | | 1 | 1 | | | | 1 | |
| | | | | | | | | | 1 |
| 1 | | | | | | | | | |
| | | | | | | | | | 1 |

## Appendix 5: Moth abundances by date

Appendix 5a: Moth abundances by date 2016

| Scientific Name | 10-Jun | 18-Jun | 22-Jun | 27-Jun | 03-Jul | 14-Jul | 22-Jul | 02-Aug | 12-Aug | 24-Aug | 02-Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Catocala relicta | | | | | | | | | | 2 | 1 |
| Lithomoia germana | | | | | | | | | | 1 | 3 |
| Eucirroedia pampina | | | | | | | | | | 1 | 5 |
| Catocala ilia | | | 2 | | | | | 2 | | | |
| Catocala unijuga | | | | | | | | | | | |
| Catocala coccinata | | | 2 | | | | | | | | |
| Apamea devastator | | | | | | | 2 | 2 | 2 | | |
| Acronicta impressa | | | | | | 1 | 3 | 1 | | | |
| Sympistis dentata | | | | | | | 3 | 5 | 1 | | |
| Polia purpurissata | | | | | | | | | 2 | | |
| Hyppa xylinoides | | | | | | | | 2 | 1 | 1 | |
| Abagrotis alternata | | | | | | | | 1 | | 1 | |
| Xestia smithii | | | | | | | | 1 | 1 | 3 | |
| Amphipyra pyramidoides | | | | | | | | | 11 | 7 | |
| Apantesis parthenice | | | | | | 1 | | 1 | 1 | | |
| Calyptra canadensis | | | | | | 1 | | | | | |
| Pyrrharctia isabella | | | | | | 1 | | | | | |
| Apantesis virguncula | | | | | | 3 | | | | | |
| Sideridis maryx | | 1 | 1 | | | 1 | | | | | |
| Cisseps fulvicollis | | | | | | 1 | | | | | |
| Hyppa brunneicrista | | 1 | | | | | | | | | |
| Raphia frater | | 2 | | 1 | | 2 | | | | | |
| Campaea perlata | | | | | | 2 | | | | | |
| Macaria occiduaria | | 1 | | | 5 | 31 | 4 | 4 | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cosmia calami | | | | | 3 | 2 | 1 | | | |
| Enargia decolor | | | | | | | | | | 1 |
| Amphipoea interoceanica | | | | | | | | 1 | | |
| Apamea sordens | 1 | | 1 | | | | | | | |
| Leucania commoides | | | | | 3 | 2 | 2 | | | |
| Leucania multilinea | | | | | 1 | | 1 | | | |
| Euxoa servitus | | | | | | | 1 | 7 | 2 | |
| Pseudohermonassa tenuicula | | | | | | | 1 | | | |
| Orthodes majuscula | | | | 1 | 4 | 1 | | | | |
| Caenurgina crassiuscula | | | | 1 | 9 | 5 | 6 | 1 | | |
| Lacinipolia meditata | | | | 1 | | | | | | |
| Sympistis dinalda | | | | | 3 | | | | | |
| Argyrostrotis anilis | 1 | | | | | | | | | |
| Eusarca confusaria | | | | | 7 | | | | | |
| Parastichtis suspecta | | | | | 1 | | | | | |
| Trichordestra lilacina | | | | | 1 | | | | | |
| Agnorisma bugrai | | | | | | | | | 2 | |
| Euxoa divergens | | | 1 | | 1 | | 1 | | 1 | |
| Euclidia cuspidea | | | 1 | | | | | | | |
| Acronicta increta | | | | | 1 | | | | | |
| Apamea lignicolora | | | | | 2 | | | | | |
| Euchlaena effecta | | | | | 2 | | | | | |
| Leucania insueta | | | 1 | | | | | | | |
| Pandemis canadana | 3 | | 17 | 48 | 80 | 9 | 5 | 3 | | |
| Choristoneura rosaceana | | | | 1 | | | | | | |
| Herpetogramma pertextalis | | | | 1 | 3 | | | | | |
| Anania extricalis | 2 | | 1 | 1 | 7 | | 3 | | | |
| Argyrotaenia quercifoliana | | 1 | 1 | 27 | 10 | | 3 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Leucania pseudargyria | 1 | | 1 | | | | | | |
| Clepsis persicana | | 1 | 4 | 5 | 2 | | | | |
| Catoptria latiradiellus | | | | | 1 | | | | |
| Choristoneura conflictana | 2 | | | | | | | | |
| Xenotemna pallorana | | | | | 9 | 1 | 1 | | |
| Palthis angulalis | | 2 | | | | | | | |
| Apotomis capreana | | | 2 | 1 | 1 | | | | |
| Olethreutes fasciatana | | | | | 1 | | | | |
| Spiramater lutra | 4 | | 1 | | 1 | | | | |
| Spaelotis clandestina | | | | 1 | | | | | |
| Proxenus miranda | | | 1 | 1 | 1 | | | | |
| Euxoa velleripennis | | | | | | | | | 3 |
| Melanapamea mixta | | | | 2 | 26 | | | | |
| Malacosoma disstria | | | 4 | 24 | 53 | | | | |
| Nycteola frigidana | | | | | 2 | 4 | 3 | | 4 |
| Pyla aequivoca | 17 | | 19 | 23 | 69 | 12 | 2 | 14 | |
| Anterastria teratophora | | 1 | | | | | | | |
| Hypoprepia miniata | | | | | | | 1 | | |
| Hypoprepia fucosa tricolor | | | | | 3 | | 1 | | |
| Nematocampa resistaria | | | | | 1 | | | | |
| Idia americalis | 1 | | | 1 | | 2 | 5 | | |
| Acrobasis tricolorella | | | 1 | | | | | | |
| Virbia laeta | | | | 1 | 6 | | | | |
| Xanthorhoe iduata | 2 | | 1 | | | 1 | | | |
| Crambidia pura | | | | 4 | 2 | | | | |
| Cabera variolaria | 1 | | 1 | | 5 | | | | |
| Sicya macularia | | | | | 22 | | | | |
| Pseudeustrotia carneola | 1 | | | 3 | 1 | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Macaria exauspicata | | | | | 3 | 2 | | | | | |
| Orthosia revicta | | | | | | | | 2 | | | |
| Hypena abalienalis | | 1 | | | | | | | | | |
| Scopula limboundata | | | | 1 | 2 | 5 | | | | | |
| Iridopsis ephyraria | | 1 | | | | 2 | | | | | |
| Virbia ferruginosa | | | | | | 2 | | | | | |
| Crambus perlella | | | | | 2 | 2 | | 1 | | | |
| Urola nivalis | | | | | | 1 | | | | | |
| Gluphisia septentrionis | | 1 | | | | | | | | | |
| Hypsopygia costalis | | | | | | 2 | | | | | |
| Renia flavipunctalis | | | | | | | 1 | 1 | | | |
| Lucinipolia lustralis | | | | | 1 | | | | | | |
| Acronicta grisea | | 1 | | | | | | | | | |
| Melanchra adjuncta | | | | | | | | 1 | | | |
| Schizura unicornis | | | | | | 1 | | | | | |
| Dysstroma walkerata | | | | | | | | | 1 | | |
| Anicla tepperi | | | | | 1 | 1 | | | | | |
| Unknown Geometridae | | | | | | 2 | 1 | 1 | | | |
| Unknown Pyralidae | | 3 | | 1 | | 1 | 2 | | 1 | | |
| Unknown Noctuid | | 1 | | 1 | 2 | 16 | 8 | 6 | 3 | 8 | |
| Unknown Micro | | 151 | | 49 | 81 | 443 | 31 | 90 | 28 | 4 | 2 |

Appendix 5b: Moth abundances by date 2017

| Scientific Name | 31-May | 08-Jun | 20-Jun | 29-Jun | 06-Jul | 13-Jul | 21-Jul | 31-Jul | 02-Aug | 10-Aug | 22-Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Catocala relicta | | | | | | | | | | | 1 |
| Eucirroedia pampina | | | | | | | | | | | 7 |
| Catocala unijuga | | | | | | | | 1 | | | |
| Catocala coccinata | | | | | | | | 4 | | 3 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Apamea devastator | | | | | | | | 6 |
| Acronicta impressa | | | | | | | | 1 |
| Sympistis dentata | | | | | | 2 | 2 | |
| Hyppa xylinoides | | | | | 1 | | 1 | 1 |
| Xestia smithii | | | | | | 1 | 4 | 6 |
| Amphipyra pyramidoides | | | | | | | | 1 |
| Apantesis parthenice | | | | | | 1 | 1 | 4 |
| Calyptra canadensis | | | | | | 1 | | |
| Sideridis maryx | | | 1 | 1 | | | | 1 |
| Raphia frater | 2 | | 1 | | 1 | | | |
| Campaea perlata | | | | 1 | 2 | 4 | | |
| Macaria occiduaria | | | 2 | 6 | 11 | 75 | 21 | 7 |
| Cosmia calami | | | | | 1 | 10 | | |
| Amphipoea interoceanica | | | | | | | 1 | 1 |
| Leucania commoides | | | | | 1 | 1 | 1 | |
| Leucania multilinea | | | | | | 1 | | |
| Euxoa servitus | | | | | | 1 | | 15 |
| Orthodes majuscula | | | | 1 | 3 | 5 | | |
| Caenurgina crassiuscula | 1 | | | | 8 | 29 | 3 | 16 |
| Sympistis dinalda | | | | | 1 | | | |
| Argyrostrotis anilis | | | 2 | 1 | | | | |
| Eusarca confusaria | | 1 | | 1 | 3 | 7 | | |
| Parastichtis suspecta | | | | | | 1 | | |
| Trichordestra lilacina | | | | | | 1 | | |
| Agnorisma bugrai | | | | | | | | 5 |
| Euxoa divergens | | | | 1 | 1 | 1 | 1 | |
| Euclidia cuspidea | 1 | | | | | | | |
| Acronicta increta | | | 1 | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Apamea lignicolora | | | | | | | 1 | | | |
| Euchlaena effecta | 1 | | 1 | | | | | | | |
| Leucania insueta | | | | | 1 | | | | | |
| Pandemis canadana | 9 | | 9 | | 38 | 21 | 18 | | 6 | 6 |
| Choristoneura rosaceana | | | | | 2 | | | | | |
| Anania extricalis | | | 1 | | 3 | 9 | 1 | | | 1 |
| Argyrotaenia quercifoliana | | | 2 | | 5 | | | | | |
| Clepsis persicana | | 1 | 1 | | 3 | | | | | |
| Xenotemna pallorana | | | | | 2 | 5 | 1 | | | |
| Apotomis capreana | | 2 | 3 | | | | | | 1 | |
| Spiramater lutra | 3 | 2 | 3 | | 9 | 1 | | | | |
| Melanapamea mixta | | | 4 | | 37 | 9 | 1 | | | |
| Malacosoma disstria | | | | | 2 | | | | | |
| Nycteola frigidana | | | | | 1 | | 7 | | 3 | 2 |
| Pyla aequivoca | 1 | 2 | 30 | | 23 | 46 | 27 | | 10 | 23 |
| Hypoprepia miniata | | | | | | | 1 | | | |
| Hypoprepia fucosa tricolor | | | | | | | 2 | | | |
| Nematocampa resistaria | | | | | | | 1 | | | |
| Idia americalis | | 1 | | | | 6 | 1 | | | 2 |
| Xanthorhoe iduata | 1 | 2 | 1 | | 1 | | | | | |
| Crambidia pura | | | | | | 2 | 3 | | | 16 |
| Cabera variolaria | | | | | | 6 | | | | |
| Sicya macularia | | | | | 1 | 1 | 2 | | | |
| Pseudeustrotia carneola | 1 | 2 | 3 | | 1 | | 1 | | | |
| Macaria exauspicata | | | 3 | | 7 | 4 | | | | |
| Scopula limboundata | | | 1 | | 1 | | 1 | | | |
| Virbia ferruginosa | | 1 | | | 1 | | | | | |
| Crambus perlella | | | | | 1 | | 2 | | 4 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gluphisia septentrionis | | | 1 | | | | | |
| Lucinipolia lustralis | | 2 | 6 | | 1 | 3 | | 4 |
| Melanchra adjuncta | | | | | 2 | 1 | | |
| Dysstroma walkerata | | 1 | | | 1 | | | |
| Unknown Geometridae | | 1 | | | 2 | | | |
| Unknown Pyralidae | 1 | 2 | | | | 1 | 1 | |
| Unknown Noctuid | 3 | 3 | 1 | 5 | 9 | 3 | | 7 |
| Unknown Micro | 92 | 132 | 82 | 124 | 94 | 159 | 24 | 186 |
| Smerinthus cerisyi | 1 | | | | | | | |
| Clostera albosigma | 1 | | | | | | | |
| Smerinthus jamaicensis | | | | 1 | | | | |
| Catocala briseis | | | | | | | 1 | |
| Zale lunata | | | | 1 | | | | |
| Ctenucha virginica | | 2 | | | | | | |
| Sideridis rosea | 1 | 2 | | | | | | |
| Prochoerodes lineola | | | | | | | 1 | |
| Acronicta impleta | 1 | | | | | | | |
| Lacanobia subjuncta | | | | 1 | | | | |
| Syngrapha alias | | | | | 1 | | | |
| Acronicta hasta | 1 | | | | | | | |
| Apamea inficita | | | | | | | 2 | |
| Apantesis phyllira | | | | | | | | 1 |
| Nemoria mimosaria | | 1 | | | | | | |
| Pseudothyatira cymatophoroides | | | | 2 | | | | |
| Agrotis volubilis | | | 1 | | 1 | | | 1 |
| Xanthorhoe ferrugata | | | | | | | | 1 |
| Probole alienaria-amicaria | | 1 | | | | | | |
| Scopula inductata | | | | 1 | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Meganola minuscula | 1 | 1 | | | | | |
| Crambidia casta | | | | | | | 14 |
| Diachrysia aereoides | | | | 1 | | | |
| Anagrapha falcifera | | | | | | | 1 |
| Xestia badicollis | | 1 | | | | | |
| Acronicta fragilis | | | | 1 | 3 | | |
| Lacanobia grandis | 1 | | | | | | |
| Feltia subgothica | | | | | | | 5 |
| Manulea bicolor | | | | | | | 1 |
| Melanolophia signataria | 1 | | | | | | |
| Dysstroma truncata | | | | | | | 2 |
| Lobophora nivigerata | 1 | | | | | | |
| Aplectoides condita | | | | 1 | | | |
| Euputhecia spp. | | | | | | 1 | |
| Zanclognatha spp. | | | | | | 1 | |
| Apamea alia | | | 1 | | | | |
| Unknown Torticidae | | | | 2 | | 1 | |
| Macaria loricaria | | | 2 | 2 | | | |
| Trichordestra legitima | | | 1 | 1 | 2 | 1 | |
| Elaphria alapallida | | 1 | | | | | |
| Metanema inatomaria | | 1 | | | | | |
| Agrotis venerabilis | | | | | | | 1 |
| Sparganothis sulfureana | | | | | | 1 | |

## Appendix 6: Butterfly species recorded during 2016 and 2017 sampling

| Family | PATT# | Scientific Name | Code | Common Name | Authority |
|---|---|---|---|---|---|
| Hesperiidae | 770047 | Thorybes pylades | Tho pyl | Northern Cloudywing | Scud. 1870 |
| | 770088 | Erynnis juvenalis | Ery juv | Juvenal's Duskywing | Fabr. 1793 |
| | 770113 | Pyrgus centaureae | Pyr cen | Northern Grizzled Skipper | Rambur 1842 |
| | 770159 | Thymelicus lineola | Thy lin | Essex/European skipper | Ochs. 1808 |
| | 770214 | Hesperia comma assiniboia | Hes com | Plains/Common Branded skipper | Lyman 1892 |
| | 770218 | Hesperia leonardus | Hes leo | Leonard's skipper | Harris 1862 |
| | 770232 | Polites peckius | Pol pec | Peck's skipper | Cramer 1775 |
| Papilionidae | 770301 | Papilio polyxenes | Pap pol | Black/American Swallowtail | Fabr. 1775 |
| | 770314 | Papilio canadensis | Pap can | Canadian Tiger Swallowtail | Roth. & Jordan 1906 |
| Pieridae | 770340 | Colias philodice | Col phi | Common/Clouded Sulphur | Godart 1819 |
| | 770341 | Colias eurytheme | Col eur | Orange Sulfur/Alfalfa | Bois. 1852 |
| | 770344 | Colias alexandra | Col ale | Queen Alexandra's Sulphur | Edwards 1863 |
| | 770351 | Colias nastes | Col nas | Labrador Sulphur | Bois. 1832 |
| | 770355 | Colias interior | Col int | Pink-edged Sulphur | Scud. 1862 |
| | 770392 | Pieris rapae | Pie rap | Small White | L. 1758 |
| | 770394 | Pontia protodice | Pon pro | Checkered White/Southern Cabbage | Bois. & LeCon. 1830 |
| | 770395 | Pontia occidentalis | Pon occ | Western White | Reak. 1866 |
| Lycaenidae | 770413 | Lycaena dorcas | Lyc dor | Dorcas/Cinquefoil Copper | W. Kirby 1837 |
| | 770432 | Satyrium titus | Sat tit | Coral Hairstreak | Fabr. 1793 |
| | 770467 | Callophrys polios | Cal pol | Hoary Elfin | Cook & Wats. 1907 |
| | 770511 | Cupido amyntula | Cup amy | Western Tailed Blue | Bois. 1852 |
| | 770540 | Glaucopsyche lygdamus | Gla lyg | Silvery Blue | Doub. 1841 |
| | 770544 | Plebejus idas | Ple ida | Idas/Northern Blue | L. 1761 |
| | 770546 | Plebejus melissa | Ple mel | Melissa Blue | W.H. Edwards 1873 |
| | 770548 | Plebejus saepiolus | Ple sae | Greenish Blue | Bois. 1852 |

| | | | | | |
|---|---|---|---|---|---|
| | 770556 | Agriades glandon rustica | Agr gla | Arctic Blue | Edwards 1865 |
| | 770588 | Danaus plexippus | Dan ple | Monarch | L. 1758 |
| Nymphalidae | 770593 | Limenitis arthemis | Lim art | White Admiral/Red-spotted Purple | Drury 1773 |
| | 770596 | Limenitis archippus | Lim arc | Viceroy | Cramer 1776 |
| | 770613 | Boloria bellona | Bol bel | Meadow Fritillary | Fabr. 1775 |
| | 770625 | Speyeria cybele | Spe cyb | Great Spangled Fritillary | Fabr. 1775 |
| | 770626 | Speyeria aphrodite | Spe aph | Aphrodite Fritillary | Fabr. 1787 |
| | 770636 | Speyeria atlantis | Spe atl | Atlantis Fritillary | W.H. Edwards 1862 |
| | 770677 | Aglais milberti | Agl mil | Milbert's Tortoiseshell | Godart 1819 |
| | 770672 | Vanessa virginiensis | Van vir | American Painted Lady | Drury 1773 |
| | 770673 | Vanessa cardui | Van car | Cosmopolitan Painted Lady | L. 1758 |
| | 770687 | Polygonia faunus | Pol fau | Green Comma | W.H. Edwards 1862 |
| | 770716 | Chlosyne gorgone | Chl gor | Gorgone Checkerspot | Hubner 1810 |
| | 770719 | Chlosyne harrisii | Chl har | Harris' Checkerspot | Scud. 1864 |
| | 770742 | Phyciodes cocyta | Phy coc | Northern Pearl Crescent | Cramer 1777 |
| | 770743 | Phyciodes batesii | Phy bat | Tawny Crescent | Reak. 1866 |
| | 770758 | Coenonympha tullia | Coe tul | Large Heath/Common Ringlet | Muller 1764 |
| | 770770 | Cercyonis pegala | Cer peg | Common Wood Nymph | Fabr. 1775 |
| | 770782 | Erebia epipsodea | Ere epi | Common Alpine | Butler 1868 |

## Appendix 7: Butterfly abundances by site

Appendix 7a: Butterfly abundances by site 2016. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| **Scientific Name** | **MRBE** | **MRBW** | **MRC** | **CLMN** | **CLMS** | **PEG** |
|---|---|---|---|---|---|---|
| Thorybes pylades | 0 | 0 | 0 | 1 | 0 | 1 |
| Erynnis juvenalis | 0 | 0 | 0 | 0 | 0 | 1 |
| Thymelicus lineola | 0 | 1 | 0 | 0 | 0 | 0 |
| Hesperia comma assiniboia | 10 | 4 | 6 | 0 | 0 | 17 |
| Hesperia leonardus | 0 | 1 | 0 | 0 | 0 | 1 |
| Polites peckius | 0 | 0 | 1 | 0 | 0 | 0 |
| Papilio polyxenes | 0 | 0 | 0 | 1 | 0 | 0 |
| Papilio canadensis | 2 | 1 | 0 | 1 | 0 | 8 |
| Colias philodice | 2 | 0 | 0 | 1 | 1 | 0 |
| Colias eurytheme | 2 | 3 | 0 | 1 | 1 | 1 |
| Colias alexandra | 0 | 0 | 5 | 0 | 0 | 0 |
| Colias nastes | 0 | 0 | 2 | 0 | 0 | 0 |
| Colias interior | 0 | 0 | 1 | 0 | 0 | 0 |
| Pieris rapae | 2 | 0 | 2 | 0 | 0 | 0 |
| Pontia protodice | 0 | 1 | 1 | 0 | 0 | 0 |
| Pontia occidentalis | 0 | 0 | 2 | 0 | 0 | 0 |
| Lycaena dorcas | 0 | 3 | 0 | 3 | 6 | 0 |
| Cupido amyntula | 0 | 0 | 0 | 0 | 0 | 1 |
| Glaucopsyche lygdamus | 6 | 5 | 0 | 1 | 1 | 20 |
| Plebejus idas | 0 | 0 | 0 | 3 | 3 | 0 |
| Plebejus melissa | 0 | 0 | 0 | 0 | 0 | 3 |
| Plebejus saepiolus | 0 | 6 | 0 | 1 | 0 | 0 |
| Agriades glandon rustica | 1 | 0 | 0 | 0 | 0 | 1 |
| Danaus plexippus | 0 | 0 | 0 | 0 | 1 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Limenitis arthemis | 5 | 2 | 1 | 3 | 4 | 2 |
| Limenitis archippus | 0 | 0 | 0 | 0 | 1 | 0 |
| Boloria bellona | 0 | 0 | 0 | 0 | 1 | 2 |
| Speyeria cybele | 0 | 1 | 11 | 20 | 26 | 4 |
| Speyeria aphrodite | 8 | 0 | 5 | 2 | 2 | 2 |
| Speyeria atlantis | 1 | 0 | 0 | 0 | 7 | 1 |
| Aglais milberti | 2 | 0 | 1 | 0 | 0 | 0 |
| Phyciodes cocyta | 10 | 1 | 0 | 3 | 1 | 20 |
| Phyciodes batesii | 12 | 2 | 9 | 6 | 2 | 1 |
| Coenonympha tullia | 10 | 27 | 7 | 4 | 2 | 0 |
| Cercyonis pegala | 4 | 5 | 5 | 3 | 4 | 3 |
| Erebia epipsodea | 13 | 21 | 2 | 0 | 0 | 2 |

Appendix 7b: Butterfly abundances by site 2017. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLMN/CLMS), and Peguis (PEG).

| **Common Name** | **MRBE** | **MRBW** | **MRC** | **CLMN** | **CLMS** | **PEG** |
|---|---|---|---|---|---|---|
| Northern Cloudywing | 1 | 0 | 2 | 1 | 1 | 0 |
| Juvenal's Duskywing | 0 | 0 | 0 | 0 | 1 | 0 |
| Northern Grizzled Skipper | 0 | 0 | 1 | 0 | 0 | 2 |
| Essex/European skipper | 0 | 4 | 0 | 0 | 0 | 2 |
| Plains/Common Branded skipper | 14 | 6 | 12 | 1 | 2 | 7 |
| Peck's skipper | 0 | 1 | 3 | 1 | 0 | 1 |
| Black/American Swallowtail | 2 | 0 | 0 | 1 | 0 | 0 |
| Canadian Tiger Swallowtail | 2 | 4 | 1 | 0 | 2 | 3 |
| Common/Clouded Sulphur | 1 | 6 | 0 | 0 | 0 | 0 |
| Queen Alexandra's Sulphur | 2 | 0 | 0 | 0 | 0 | 2 |
| Island Marble | 1 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Small White | 1 | 2 | 0 | 1 | 0 | 1 |
| Dorcas/Cinquefoil Copper | 16 | 18 | 9 | 5 | 7 | 6 |
| Coral Hairstreak | 0 | 0 | 0 | 2 | 0 | 1 |
| Hoary Elfin | 0 | 0 | 4 | 2 | 3 | 26 |
| Western Tailed Blue | 0 | 0 | 0 | 1 | 0 | 0 |
| Silvery Blue | 8 | 4 | 5 | 17 | 12 | 69 |
| Idas/Northern Blue | 0 | 1 | 0 | 11 | 3 | 2 |
| Greenish Blue | 6 | 6 | 24 | 0 | 1 | 2 |
| Monarch | 0 | 0 | 0 | 0 | 1 | 0 |
| White Admiral/Red-spotted Purple | 4 | 2 | 2 | 5 | 2 | 1 |
| Viceroy | 1 | 1 | 0 | 2 | 1 | 2 |
| Meadow Fritillary | 1 | 12 | 20 | 7 | 1 | 6 |
| Great Spangled Fritillary | 0 | 4 | 1 | 2 | 0 | 1 |
| Aphrodite Fritillary | 13 | 28 | 42 | 80 | 45 | 22 |
| Atlantis Fritillary | 2 | 1 | 1 | 2 | 7 | 10 |
| American Painted Lady | 0 | 0 | 1 | 0 | 0 | 0 |
| Cosmopolitan Painted Lady | 6 | 1 | 0 | 0 | 1 | 0 |
| Green Comma | 1 | 0 | 1 | 0 | 0 | 0 |
| Gorgone Checkerspot | 0 | 1 | 0 | 0 | 1 | 1 |
| Harris' Checkerspot | 1 | 0 | 0 | 0 | 0 | 0 |
| Northern Pearl Crescent | 7 | 1 | 3 | 4 | 4 | 26 |
| Tawny Crescent | 6 | 6 | 4 | 1 | 10 | 40 |
| Large Heath/Common Ringlet | 26 | 39 | 19 | 1 | 4 | 1 |
| Common Wood Nymph | 27 | 36 | 43 | 22 | 18 | 17 |
| Common Alpine | 6 | 9 | 16 | 0 | 0 | 5 |

Appendix 8: Extended environmental variables comparisons between sites. Site abbreviations: Marble Ridge B East and West (MRBE/MRBW), Marble Ridge C (MRC), Clematis North and South (CLN/CLS), and Peguis (PEG).

| | | | **Grazed (3)** | | | **Ungrazed (3)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Units** | **MRB-E** | **MRB-W** | **MRC** | **CLM-N** | **CLM-S** | **PEG** | **$F_{5,24}$** | **p-value[1]** |
| Nitrate | mg/kg | 13.48ab[2] | 10.33ab | 15.77b | 2.83a | 3.29ab | 2.30a | 4.06 | **0.008** |
| Phosphorus | mg/kg | 13.22 | 9.70 | 12.34 | 7.94 | 12.44 | 26.94 | 1.68 | 0.177 |
| Potassium | mg/kg | 171.00 | 161.00 | 209.40 | 182.40 | 261.20 | 211.40 | 1.25 | 0.316 |
| Sulphate | mg/kg | 9.61 | 6.25 | 10.23 | 7.16 | 7.35 | 6.47 | 1.98 | 0.118 |
| pH | na | 7.37ab | 7.52b | 7.37ab | 7.30ab | 6.75a | 6.98ab | 3.99 | **0.009** |
| EC | na | 0.84 | 1.13 | 1.28 | 0.97 | 1.25 | 0.66 | 2.39 | 0.068 |
| Organic Matter | % | 19.30 | 18.76 | 20.26 | 20.38 | 29.56 | 16.74 | 1.57 | 0.205 |
| Calcium | mg/kg | 6046ab | 6822ab | 5862ab | 7980ab | 8518b | 5176a | 2.95 | **0.033** |
| Magnesium | mg/kg | 1184.0 | 1200.0 | 1490.0 | 1410.8 | 2122.0 | 1225.4 | 2.59 | 0.052 |
| Sodium | mg/kg | 18.1b | 15.5ab | 11.2ab | 10.4a | 12.4ab | 9.7a | 3.97 | **0.009** |
| Total BS | % | 100.00 | 100.00 | 99.30 | 99.20 | 93.46 | 96.50 | 2.61 | 0.051 |
| BS Calcium | % | 74.7bc | 76.7bc | 68.9ab | 77.5c | 65.1a | 68.8ab | 7.13 | **<0.001** |
| BS Potassium | % | 1.06 | 0.92 | 1.32 | 0.92 | 0.98 | 1.46 | 3.20 | **0.024** |
| BS Magnesium | % | 24.0ab | 22.2ab | 29.0b | 20.7a | 27.3ab | 26.1ab | 3.79 | **0.011** |
| BS Sodium | % | 0.20b | 0.14a | 0.10a | 0.10a | 0.10a | 0.10a | 16.67 | **<0.001** |
| CEC | meq/100g | 40.46ab | 44.40ab | 42.52ab | 52.50ab | 65.60b | 37.42a | 3.06 | **0.028** |
| Soil Depth | cm | 6.20 | 6.79 | 9.54 | 8.54 | 5.30 | 11.09 | 1.14 | 0.432 |
| Litter Depth | cm | 0.78 | 0.60 | 0.93 | 0.74 | 0.39 | 0.39 | 0.47 | 0.786 |
| Soil Compaction | kg/cm2 | 2.46 | 2.54 | 2.94 | 2.18 | 1.86 | 1.99 | 1.68 | 0.272 |
| % Pavement | % | 1.70 | 8.80 | 4.70 | 5.85 | 1.50 | 0.00 | 1.75 | 0.256 |
| % Bare Ground | % | 8.45 | 10.90 | 6.20 | 11.05 | 2.80 | 16.30 | 1.16 | 0.426 |

[1] Significant differences highlighted in bold.

[2] Means in rows followed by the same letter are not significantly different ($p>0.05$). Tukey's post-hoc test.

* EC = Electrical Conductivity, BS = Base Saturation, CEC = Cation Exchange Capacity

## Appendix 9: Diversity index equations (Magurran 1988)

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Figure 1. Shannon Diversity equation

$$J'='\ \frac{H}{ln(S)}$$

Figure 2. Shannon Dominance equation

$$D = \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N - 1)}$$

Figure 3. Simpson’s Diversity equation

$$d = \frac{N_{\max}}{N}$$

Figure 4. Berger-Parker Dominance equation

$$\mathrm{C_N} = \frac{2jN}{(aN + bN)}$$

Figure 5. Sørenson’s Quantitative Beta Diversity equation

$$\mathrm{C}s = \frac{2j}{(a+b)}$$

Figure 6. Sørenson’s Qualitative Beta Diversity equation

**Appendix 10. Comparison of the results of the present study and Catling (2016)**

| Species | Catling (2016) | Rodgers (2018) |
|---|---|---|
| *Populous tremuloides* | Ungrazed | Ungrazed |
| *Juniperus horizontalis* | Ungrazed | Ungrazed |
| *Dasiphora fruticosa* | Ungrazed | Ungrazed |
| *Arctostaphylos uva-ursi* | Ungrazed | Ungrazed |
| *Potentilla pensylvanica* | Grazed | Grazed |
| *Poa alpine* | Grazed | |
| *Agrostis stolonifera* | Grazed | |
| *Poa pratensis* | Grazed | Grazed |
| *Cirsium arvense* | Grazed | |
| *Trifolium pratense* | Grazed | |
| *Erigeron asper* | Grazed | |
| *Sporobolus heterolepis* | Ungrazed | Grazed |
| *Solidago ptarmicoides* | Ungrazed | Ungrazed |
| *Carex crawei* | Ungrazed | Grazed |
| *Eleocharis elliptica* | Grazed | |
| *Symphiotrichum laeve* | Ungrazed | |
| *Galium boreale* | Ungrazed | |
| *Packera paupercula* | Ungrazed | |
| *Festuca hallii* | Ungrazed | |
| *Antennaria howellii* | Ungrazed | Grazed |
| *Comandra umbellata* | Ungrazed | Ungrazed |
| *Solidago rigida* | Ungrazed | |
| *Solidago nemoralis* | Ungrazed | |
| *Monarda fistulosa* | Ungrazed | Ungrazed |
| *Cypripedium parviflorum* | Ungrazed | |
| *Geum trifolium* | | Grazed |
| *Achillea millefolium* | | Grazed |
| *Medicago lupulina* | | Grazed |
| *Abietinella abietina* | | Grazed |
| *Betula occidentalis* | | Ungrazed |
| *Fragaria virginiensis* | | Ungrazed |
| *Cladina moss* | | Ungrazed |
| *Aulacomnium palustre* | | Ungrazed |
| *Polygala senega* | | Ungrazed |
| *Koeleria macrantha* | | Grazed |
| *Deschampsia caespitosa* | | Grazed |

## Appendix 11. Butterfly species, treatments, and host plant associations summarized from ISA and RDA

| Species | Group | Host Plants |
|---|---|---|
| *Plebejus ida* | Ungrazed | *A. uva-ursi, L. ochroleucus* |
| *Erebia epipsodea* | Grazed | *Carex spp, grasses* |
| *Callophrys polios* | Ungrazed | *A. uva-ursi* |
| *Plebejus saepiolus* | Grazed | *T. repens, T. hybridum, M. lupulina* |
| *Pieris rapae* | Grazed | *T. officinale, T. pratense, Asters* |
| *Limenitis archippus* | Ungrazed | *Salix, P. tremuloides, wildflowers* |
| *Speyeria atlantis* | Ungrazed | *Viola, Asters, S. ptarmicoides* |
| *Speyeria cybele* | Ungrazed | *Viola, Asters, S. ptarmicoides* |
| *Hesperia comma assiniboia* | Grazed | *P. pratensis, A. gerardii* |
| *Glaucopsyche lygdamus* | Ungrazed | *Vetches, Lahyrus and Vicia, Asters* |
| *Phycoides cocyta* | Ungrazed | *Asters, S. ptarmicoides* |
| *Papilio canadensis* | Ungrazed | *Salix, P. tremuloides, wildflowers* |
| *Thymelicus lineola* | Grazed | *P. pratensis, A. repens* |
| *Colias philodice* | Grazed | *P. pratensis, A. repens* |
| *Vanessa cardui* | Grazed | *Asters, thistle, A. campestris* |
| *Boloria bellona* | Grazed | *Viola* |
| *Coenonympha tullia* | Grazed | *P. pratensis* |
| *Colias alexandra* | Grazed | *M. lupulina* |

## Appendix 12. Moth species, treatments, and host plant associations summarized from ISA and RDA

| Species | Group | Host Plants |
|---|---|---|
| *Pronexus miranda* | Grazed | *T. officinale, F. virginiana* |
| *Apamea devastator* | Grazed | *Grass/herb generalist* |
| *Pseudeustrotia carneola* | Grazed | *Solidago* |
| *Argyrostrotis anilis* | Grazed | *Unknown* |
| *Melanapamea mixta* | Ungrazed | *B. porteri, E. trachycaulus, A. gerardii* |
| *Euxoa servitus* | Grazed | *Unknown* |
| *Spirameter lutra* | Ungrazed | *Salix, P. tremuloides, B. occidentalis* |
| *Orthodes majuscula* | Grazed | *Salix, grasses, T. officinale* |
| *Clepsis persicana* | Ungrazed | *Salix, B. occidentalis, Pinus, Picea* |
| *Amphipyra pyramidoides* | Grazed | *Q. macrocarpa, R. idaeus* |
| *Catocala coccinata* | Grazed | *Q. macrocarpa* |
| *Cosmia calami* | Grazed | *Q. macrocarpa* |
| *Argyrataenia quercifoliana* | Grazed | *Q. macrocarpa, R. idaeus* |
| *Euscara confusaria* | Ungrazed | *Asters, S. ptarmicoides, S. simplex* |
| *Xenotemna pallorana* | Ungrazed | *M. sativa, M. officinalis* |
| *Eucirroedia pampina* | Ungrazed | *Prunus* |
| *Sideridis rosea* | Ungrazed | *T. officinale, S. canadensis, Salix, Ribes* |
| *Sympstis denata* | Ungrazed | *Vaccinium, K. polifolia* |
| *Macaria occiduaria* | Ungrazed | *Salix, P. tremuloides, D. fruticosa* |