The Classification of Alvar Vegetation in the Interlake Region of Manitoba, Canada

by

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"*Language adorns a science as clothes adorn the body. He who cannot do honour to his clothes must needs let them do honour to him. If elsewhere in the world only eloquent doctors had been allowed to write, less would be known than there is today*." Carl Linneaus 1745

Abstract

Alvars are globally rare rock barren ecosystems on limestone pavement. This thesis focused on the quantitative classification of vegetation of Manitoba alvars, the relationships between vegetation patterns and environmental factors and the effects of grazing on vegetation.

Vegetation plots were completed across twenty sites. Cluster analysis, indicator species analysis and PCA were used to describe eight vegetation types. A RDA revealed moisture regime, soil depth, bare rock cover and disturbance (grazing and browsing) are the most important factors affecting floristic composition.

Grazing effects were studied at two sites using paired plots on either side of a fenceline dividing grazed and ungrazed areas. PCA and RDA showed significant difference between vegetation compositions based on grazing. A partitioning of species richness and diversity by introduced and native species revealed that both sites experienced significant replacement by introduced species. Current grazing levels on Manitoba alvars are severely impacting the vegetation of this ecosystem.

Key words:

alvar, limestone pavement, disturbance, vegetation dynamics, species associations, plant ecology

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Chapter 1: Literature Review

1.1 Discovery and Definition

Alvar is a Swedish word meaning ‘unproductive land’ (Pärtel *et al.* 1999) and was first used by Carl von Linneaus in 1741 to describe this type of rock barren. Although alvars are similar to other rock barren ecosystems, such as cedar glades, Garry oak savannas and limestone pavements, they are unique ecosystems with specific environmental conditions and ecological processes (see section on *Similar Habitats* for further comparison). Alvars (Figure 1.1) are ecosystems with thin soils, occuring over limestone or dolomite bedrock in which some combination of drought, flooding, fire, frost heaving, wind erosion and/or grazing maintains a more or less open condition with sparse tree cover (<60%). These conditions create habitats that harbour unique plant species, or unique combinations of species. Due to their relative rarity, and increasing pressure for development, alvars have become the focus of numerous conservation efforts (Reschke *et al.* 1999; Brownell and Riley 2000; Cayouette *et al.* 2010; Manitoba Alvar Initiative 2012). As with most ecosystems, alvars can be difficult to categorize. However, they are typically characterized by the following attributes (also see Appendix 1):

1) temperate climate.
2) located above the glacial boundary.
3) predominantly limestone and dolomite (with shale, chert, sandstone, crystalline limestone and/or calcarenite) bedrock from the Ordovician, Silurian and Devonian periods occurs near the surface, possibly with intermittent patches of exposed rock.
4) flat topography.

5) soil cover is thin, usually less than 10cm, but sometimes up to 30cm, with deeper areas only occurring in cracks or depressions.
6) soils seasonally vary between highly saturated and highly xeric.
7) exposed cracks and grikes may be present in the bedrock but not with the frequency found in limestone barrens or limestone karst (see *Similar Habitats* section).
8) woody species such as trees and shrubs are mainly restricted to deeper soils, such as cracks, which leads to very open, conditions with patchy tree cover.
9) woody species, when present, are often stunted and may easily die off in drought years.
10) vegetation composition is highly variable with a mix of boreal, prairie, arctic and eastern deciduous forest vegetation in North America and arctic-alpine, continental-Siberian, south-west Europe, south Europe, south-east Europe and circumpolar elements in Europe.

1.2 Distribution

In Europe, the majority of alvars occur in the coastal areas and islands of the Baltic Sea in Sweden (Öland and Gotland) and Estonia (Saaremaa, Hiiumaa and Muhu) (Pärtel *et al.* 1999). Alvars also occur on the mainland of Sweden in the Västergötland region (Pärtel *et al.* 1999). In Estonia, alvars only remain in a fraction of their previous range due to urbanization and cultivation (Pärtel *et al.* 1999). Sweden represents the largest area (>70%) of alvars in Europe followed by the areas in Estonia (<28%) (Eriksson and Rosén 2008). Smaller alvar areas occur in south-west Finland (Avenamaa, <1%) and north-western Russia, in the regions of Volosovo and

Gatchina, on the Izhora plateau (Pärtel *et al.* 1999; Znamenskiy *et al.* 2006; Eriksson and Rosén 2008).

In the United States, alvars occur in Michigan (Stephenson 1983), Ohio (Reschke *et al.* 1999) and in New York State (Reschke 1990). In Michigan, alvars extend from Drummond Island to Cedarville and westward to Seul Choix Point and Garden Peninsula. Smaller alvar remnants can be found on the lower peninsula of Michigan (Catling and Brownell 1995). Alvars occur in northern New York State within Jefferson County (Catling and Brownell 1995). Alvars in Ohio have been destroyed or badly degraded but previously occurred near Toledo (Catling and Brownell 1995).

The majority of alvar areas in Canada occur along the border of the Canadian Shield in Ontario and Québec (Figure 1.2) (Catling and Brownell 1995; Catling *et al.* 2014). The most studied alvars in Canada are within Ontario. These include the Bruce Peninsula (Jalava 2008), Pelee Island (Kirk 1992), Burnt Lands (Belcher 1992), Manitoulin Island (Belcher 1992) and sites near Kingston (Beschel 1965, 1969). Twenty-two alvar sites have been discovered in Québec along the Ottawa River and also near Montreal (Cayouette *et al.* 2010). Lesser studied alvars also exist in the Northwest Territories (Catling 2009a) and the Interlake region of Manitoba (Manitoba Alvar Initiative 2012). Alvars in Manitoba are the focus of this thesis and will be discussed in further detail in Chapter 2.

1.3 Formation

During the Paleozoic Era, including the Ordovician, Silurian and Devonian periods, calcareous rocks (limestone, dolomite, etc.) were formed over the Baltic region of Europe (including Sweden, Estonia, Finland and Russia) and North America, which were located under the Iapetus Ocean (Sjörs 1965; Corkery 1996; Cocks and Torsvik 2006, Cocks and Torsvik 2011). Through continental shifts and glaciation processes these deposits became exposed and today characterize the surficial bedrocks of alvars worldwide. The Pleistocene Glaciation period is the most recent geological event that contributed to the formation of alvar ecosystems. At the maximum extent of the Pleistocene Glaciation period, ice sheets extended from Ireland west to Estonia and into Russia and to the northern parts of Norway, Sweden and Finland (Cornwall 1970). In North America, the Laurentide and Cordilleran ice sheets covered most of Canada and extended into the mid-eastern region of the United States (Cornwall 1970; Dawson 1992). Glaciers and ice sheets have many effects on the land including the formation of outwash-fans, terminal moraine, kettle-holes, eskers, drumlins, ice-gouged rock-basins, erratic boulders, and exposed bedrock pavements (Cornwall 1970; Dawson 1992). However, it was weight and scouring of the heavy ice mass that had the most pronounced effect on alvars and contributed to their flat topography, thin soil cover, and exposed areas of bedrock. Glacial lakes followed the retreat of ice leading to the erosion and deposition of sediments in alvar regions (Sjörs 1965; Cornwall 1970). The global distribution of alvars corresponds to glacial lakes that formed after the Pleistocene Glaciation period in both North America (Sommers 1977; Corkery 1996) and Europe (Lundqvist 2004; Stroeven *et al.* 2015). These glacial lakes include Lake McConnell (Northwest Territories), Lake Iroquois (Ontario), Lake Algonquin (Ontario) and Lake Agassiz (Manitoba) in North America and the Baltic Ice Lake in Europe (Sommers 1977; Corkery 1996; Lundqvist 2004).

It is thought that in both North America and Europe, alvar ecosystems resulted from similar processes of erosion and scraping at the edge of the continental ice sheet that exposed flattened bedrock. This provided a recently disturbed open area with a cool climate for vegetation to colonize. The combination of flat barren limestone and thin soils leads to drought conditions (see next section) and contributes to the maintenance of alvar vegetation (Catling *et al.* 1975; Catling and Catling 1993; and Catling and Brownell 1995). Catling *et al.* (1975), Catling and Catling (1993) and Catling and Brownell (1995) describe possible origins of the alvar vegetation in Ontario, suggesting that alvar ecosystems are remnants of *Picea* parkland and tundra that developed in open cool areas as the glacier receded. They also highlighted the process of prairie range extension into Ontario during a dry interval post glaciation that affected vegetation composition (Catling et. al. 1975; Catling and Catling 1993; Catling and Brownell 1995). The mixture of native plant species, including endemics (see section on *Vegetation of Alvars*), plus the nature of the soils and underlying geology clear shows that alvar communities in North America are a relic post-glacial ecosystem and not the result of European settlement (Day 1953; Gilman 1995). It is likely that similar processes were responsible for the creation of alvars in other parts of North America and Europe.

1.4 Geology and Soil Conditions of Alvars

The surficial geology and soil conditions of alvars within North America have been best documented in Ontario. Within Ontario, alvars vary on the basis of the thickness (18m to 90m) and nature of the underlying bedrock and surficial geology (Brownell and Riley 2000). Bedrock ranges from limestone and dolomite, to shale, chert, sandstone, crystalline limestone and calcarenite (Brownell and Riley 2000). Alvars in Québec are on Ordovician Paleozoic limestones or dolomites and Precambian marble or limestone (Cayouette *et al.* 2010). Alvars in New York Sate occur on the Chaumont limestone and dolomite of the Ordovician period (Catling and Brownell 1995). Alvars in the Northwest Territories and southern alvars in Michigan are on Devonian limestone (Albert 2006; Ecosystem Classification Group 2007). The alvars in northern Michigan, including Drummond Island, are on Silurian and Ordovician limestone (Sjörs 1965; Albert 2006). The alvars of Europe also occur on Silurian and Ordovician limestone that are either Cambro-Siluric or Precambrian in origin (Eriksson and Rosén 2008).

The characteristics of limestone bedrock contribute to the soil conditions on alvars. For example, studies in Ontario showed that the soils over calcareous bedrocks are basic (an average pH of 8) with lower pH's observed in regions of deep sand (Brownell and Riley 2000). New York alvars had soil pHs ranging from 5.1 to 8.5 but were predominately alkaline (Whitehouse 1933; Gilman 1995). Limestone rock is high in calcium and magnesium but deficient in iron, manganese, aluminum, zinc and copper (Wentworth 1981). The calcium carbonate of alvar limestone in the Great Lakes (Canada and U.S.A) ranges from 59-95.5% and magnesium ranged from 1.4-12.7% (Rescke *et al.* 1999). Soils created from limestone rock are finer in texture and hold moisture closer to the surface where it is more easily lost to evaporation compared to the coarser soils created from granite that drain more readily (Wentworth 1981). Limestone associated soils are more organic than those found over granite barrens (Wentworth 1981). For Example, on New York alvars, organic content ranged from 2-6% (Whitehouse 1933; Gilman 1995). Soils on alvars range from sand, loam or clay and can be well to poorly drained (Gilman 1995).

Because of variation in the pattern of bedrock exposure, soil depth and chemistry, growing conditions can change dramatically within a short distance (sometimes < 1m) and create a patchwork of environmental conditions within a site. In addition to the variation in soil types, the substrate directly under the soil can also vary. For example, studies in Europe found that some sites had shallow soils directly over limestone pavement, but in other areas the soil layer is underlain with a thin limestone gravel layer over top of the bedrock (Partel *et al.* 1999). Changes in topography and features such as cracks, grykes, ridges and ledges lead to highly variable soil depths and moisture availability (Krahulec *et al.* 1986). Soil depth on alvars is usually less than 10cm (average of 6cm in Great Lakes region), but sometimes up to 30cm with deeper areas only occurring in cracks or depressions (Rescke *et al.* 1999). Soil depth may also alter the effects of disturbances such as frost heaving, drought and grazing (Krahulec *et al.* 1986). These are discussed further in the section on *Disturbance Ecology of Alvar Vegetation*.

1.5 Climate

Alvars are defined as having a temperate climate, although the specific climatic conditions vary significantly between regions. Due to air and water currents, alvars in the coastal Baltic region are more humid and experience a higher annual temperature than other regions at equivalent latitudes (Sjörs 1965). The coastal regions of Sweden become quite arid in the summer months because of orographic effects (mountain ranges causing air to rise) from the mainland, but experience mitigated temperatures that are not as harsh as the mainland in the winters (Sjörs 1965). For example, in January, the alvars in Sweden experiences a mean low temperature of -5°C (ClimaTemps 2015b), whereas alvars in Russia experience a mean low temperate of -11°C (ClimaTemps 2015a). The alvars in the Great Lakes region experience highly variable weather conditions within a season but the lakes moderate temperature and humidity across seasons (Gilman 1995). Summers are generally dry and increase the probability of drought on alvars in the Great Lakes region (Gilman 1995). The alvars of Manitoba and the Northwest Territories are located in a more continental position with more extreme conditions, such as extreme dry and cold. For comparison, the alvars in the Pelee Island region of southern Ontario, Canada receive 900.7mm/year in precipitation and have a mean January low temperature of -7.1°C while alvars in the Northwest Territories experience only 336.4mm/year of precipitation and a mean low temperature of -26.2°C (Environment Canada 2015a, 2015b). The effects of a continental climate as they relate to the alvars of Manitoba are discussed in further detail in Chapter 2.

1.6 Vegetation of Alvars

Within rock barrens (including alvars and limestone barrens), both habitat and microclimate niches (areas too small to quantify as habitats but differing in environmental characteristics from the surroundings) affect vegetation patterns (Winterringer and Vestal 1956; Yarranton and Beasleigh 1969; Willis 2011). Changes in topography, soil depth and moisture availability have a distinct effect on vegetation patterns across larger areas leading to a patchy network of alvar communities within the ecosystem (Catling *et al.* 1975; Belcher and Keddy 1992; Gilman 1995). Higher species richness and biomass on alvars is correlated with increased soil depth (Belcher and Keddy 1992) and vegetation patterns on alvars are frequently associated with local variation in soil depth and moisture availability (Catling *et al.* 1975).

Hydrologic studies on alvars have shown that soil moisture is correlated with variation in vegetation communities (Reschke 1995), suggesting that these patterns in topography and moisture regime lead to the formation of different communities that vary in both physiognomy and species composition. Some open alvar habitat types are graminoid dominated while others are dominated by trees and shrubs (Brownell and Riley 2000). Graminoid dominated alvars are often associated with shallow, poorly drained soils, while shrub dominated communities are found on more mesic alvars especially in cracks in the bedrock or deeper soils. Treed alvars, found in areas with deeper soil or deep cracks in limestone, are particularly variable (tree cover of 0-60%), and include savannas and more densely treed woodlands (Brownell and Riley 2000).

On a smaller scale, microhabitats also contribute to the high diversity of plants found on rock barrens because of species that specialize in certain microhabitats (Gilman 1995; Willis 2011). Microhabitats include areas that vary in any combination of moisture availability, soil depth and/or shade (Catling *et al.* 1975; Willis 2011). For example, since alvars are predominately open areas, tree and shrub cover can create microhabitats of shade where plants less tolerant of full sunlight may establish. In addition to microhabitats created by shade, microhabitats exist on floodways where water runs over rock or inside rock-crevices that have increased moisture and shade.

1.6.1 Europe

The alvars of Europe are most similar to the heath vegetation of the steppe in south-eastern Europe that includes both open grassland and shrubland areas (Rusch and van der Maarel 1992; Znamenskiy *et al.* 2006). This was first described by Witte (1906) who stated:

> *"...the 'alvar' vegetation is a steppe vegetation conditioned by edaphic factors in a more or less insular climate and which has several features in common with the southeast European steppe vegetation and also some similarities with the mountain vegetation in the far north, but no or at least a highly insignificant similarity with true heath vegetation*."
>
> (Witte 1906 translated in Sjörgen 1988).

European alvars are usually more biodiverse than steppe or heathland habitats as a result of the microhabitat complexity created by bedrock type and patchy environmental conditions that leads to a variable distribution of alvar plant communities (Eriksson and Rosén 2008). These floral elements include arctic-alpine (e.g. *Poa alpina, Cerastium alpinum*), continental-Siberian (e.g. *Artemisia rupestris, Anemone sylvestris*), south-west Europe (e.g. *Baldellia ranunculiodes, Plantago uniflora*), south Europe (e.g. *Anthericum ramosum*, *Veronica praecox*), south-east Europe (e.g. *Plantago tenuiflora, Pulsatilla pratensis*) and circumpolar species (e.g. *Dasiphora fruiticosa* and *Juniperus communis)* (Eriksson and Rosén 2008). Endemic taxa of alvars in Europe include *Allium schoenoprasum* var. *alvarense, Arenaria gothica, Artemisia oelandica, Festuca rubra* ssp. *oelandica, Galium oelandicum*, *Helianthemum oelandicum* var. *oelandicum, Helianthemum oelandicum* var. *canescens, Pulsatilla vulgaris* ssp. *gotlandica, Senecio jacobea* ssp. *gotlandicus* and *Silene uniflora* ssp. *petraea.*

As a generality, the European alvars can be separated by geographic regions and at the site level have a patchy arrangement of vegetation communities (Hemmendorff 1897; Krahulec *et al.* 1986; Partel *et al.* 1999; Znamenskiy *et al.* 2006; Eriksson and Rosén 2008). Although no quantitative comparisons have been made that relate alvars between Sweden, Estonia and

Russia, studies have suggested similarities among all of these geographic regions (Znamenskiy *et al.* 2006; Erikkson and Rosén 2008). Znamenskiy *et al.* (2006) and Eriksson *et al.* (2002) suggest that the historic trade of domestic animals using these lands as pastures could lead to the similarities between alvars across Europe through seed dispersal. However, climatic and edaphic conditions do affect which species can occur in a specific region and cause regional differences (Partel *et al.* 1999).

Overall, the studies of Swedish alvars describe an open ecosystem rich in cryptogams and dominated by graminoids and forbs with sparse shrub cover (Krahulec *et al.* 1986; Bengtsson *et al.* 1988). The high diversity and uniqueness of these alvars was recognized and described in many early visits to Öland and Gotland (Linnaeus 1745 translated by Asberg and Stearn 1973; Pärtel *et al.* 1999). During his botanical exploration of the alvars in Sweden, Linnaeus (1745) described 311 species of plants (Sjören 1988). Further study has revealed over 1100 species of plants on the Swedish alvars (Sjören 1988), with a single alvar site (Stora Alvar) having 300 species of vascular plants, 153 bryophytes and 84 lichen species (Löbel *et al.* 2006). Tree (*Betula pendula, Betula pubescens, Fraxinus excelsior, Populus tremula* and *Sorbus intermedia*) and shrub colonization (*Juniperus communis* and *Dasiphora fruiticosa*) increases where there is deep soil or grazing is less frequent or has ceased (Rosén 1988). Deciduous trees are more frequent on Öland than Gotland, however *Pinus sylvestris* was planted on various parts of the island and *Picea abies* occurs locally in some areas (Rosén 1988). Hemmendorff (1897) and Petterson (1965) demonstrated the large variety of communities on alvars sites, which ranged from dense shrubland to open areas that had a sparse cover of vegetation. Plant assemblages described by vegetation composition include 1) *Crepis- pumila- Allium alvarense* 2)

Heliathemum oelanndicum – Galium oelandicum 3) *Gypsophila fastigiata – Globularia vulgaris* and 4) *Veronica spicata- Avenula pratensis* (Krahulec *et al.* 1986). These communities have distinct vegetation composition, disturbance history and environmental characteristics (Krahulec *et al.* 1986). Albertson (1950) classified the alvars in Sweden into community types based on environmental conditions: exposed rock, weathering deposits, gravelly deposits, alvar lakes, fens and pools and wet meadows. The alvars on Öland, Sweden were described as being comprised of 54% weathering deposits, 25% gravelling deposits, 18% wet meadows and fens and only 1% bare limestone (Krahulec *et al.* 1986). Together, these studies emphasize the patchy nature of alvar vegetation communities in Sweden on a small scale within the site and between geographic locations (Öland vs Gotland).

Like the alvars in Sweden, the alvars of Estonia are often graminoid dominated with patchy shrub cover (Partel *et al.* 1999). Over the 58 sites that occur in Estonia, 236 vascular species (Partel *et al.* 1999) and 246 lichen species (Jüriado *et al.* 2015; Leppik *et al.* 2015) were discovered. Of the lichen species, 106 grow on soil, debris or moss and 140 species are epiphytic on *Juniperus communis* (Jüriado *et al.* 2015; Leppik *et al.* 2015). Floristic classification determined that the types of vegetation communities in Estonia correspond well to those in Sweden (Partel *et al.* 1999) although composition does change geographically and Öland contains more endemic species (Krahulec *et al.* 1986). Partel *et al.* (1999) found seven vegetation communities when classifying alvar vegetation of Estonia, which also existed in a patchy complex that corresponds to environmental conditions. Of these, the *Avenetum alvarense* or 'ryhk-alvars' variety is the most common. This community is characterized by *Astragalus danicus, Carex tomentosa, Briza media, Festuca ovina,* and *Selsaria caerulea.*

Characteristic species of other vegetation communities include: *Galium boreale*, *Ranunculus polyanthernos, Veronica chamaedrys, Arenaria serpylifolia, Ranunculus bulbosus, Sedum acre, SIlene nutans, Artemisia campestris, Artemisia rupestris, Satureja acinos, Carex flacca* and *Carex panacea* (Partel *et al.* 1999). Woody vegetation includes *Juniperus communis, Pinus sylvestris* and *Corylus avellana* (Partel *et al.* 1999; Kalamees *et al.* 2012). Species composition differs between alvars within Estonia and separates into northern, northwestern and western regions that differ in environmental conditions such as soil pH, soil type and parent materials (Partel *et al.* 1999). For example, alvars in northern Estonia are characterized by *Carex spicata, Lathyrus pratensis* and *Trifolium repens,* infrequent species on alvars in western Estonia (Partel *et al.* 1999).

Research on alvars in Russia is limited, but they appear to be most similar to those in Estonia and share some similarity to alvars in Sweden (Botch *et al.* 1992; Partel *et al.* 1999; Znamenskiy *et al.* 2006; Eriksson and Rosén 2008). In a quantitative vegetation study of Russian alvars by Znamenskiy *et al.* (2006) 105 vascular plant species were recorded, with 52-63 per site. Znamenskiy *et al.* (2006) found that the vegetation composition of Russian alvars did not differ significantly from those in Estonia and vegetation communities fit most closely with the *Avenetum alvarense* vegetation communities of northern Estonia (described above). The *Avenetum alvarense* community also occurs in Sweden although composition is different from the *Avenetum alvarense* community in Estonia and Russia due to more endemics on the Swedish alvars (Krahulec *et al.* 1986). Dominant species of Russian alvars, including *Briza media, Taraxacum officinale, Alchemilla vulgaris* and *Dactylis glomerata,* are also dominant on Estonian alvars (Znamenskiy *et al.* 2006). Russian alvars are geographically isolated from those in Sweden and Estonia, leading to compositional differences (Znamenskiy *et al.* 2006). Species characteristic of alvars in Estonia, such as *Avenula patensis* and *Filipendula vulgaris*, were absent from Russian alvars. Other characteristic species such as *Ranunculus bulbosus* and *Carex caryophyllea* were rare (Znamenskiy *et al.* 2006).

Alvars in Finland represent a small portion of European alvars (<1%) (Eriksson and Rosén 2008). These habitats have been poorly studied but limited research suggests that they are distinct from the majority of alvars in Sweden and all of the alvars in Estonia and Russia (Erikkson and Rosén 2008). The bedrock on alvars in Finland is Precambian limestone, whereas the majority of alvars in Europe have limestone of Cambrosiluric origin (Eriksson and Rosén 2008). Characteristic species of Finland alvars are *Androsace septentrionalis, Arenaria serpyllifolia, Artemisia campestris, Asperula tinctoria, Botrychium lunaria, Gentianella amarella, Geranium columbinum, Linum catharticum, Melica ciliata, Origanum vulgare, Potentilla tabernaemontani, Satureja acinos, Veronica spicata* and *Schistidum apocarpum* (Eriksson and Rosén 2008). Conversely, characteristic species of the alvars in Estonia, Russia and the majority of Sweden include *Allium schoenoprasum* var. *alvarense*, *Anthericum ramosum*, *Apera interrupta*, *Arenaria gothica, Artemisia rupestris, Cerastium pumilum, Crepis tectorum* ssp. *pumila, Dasiphora fruiticosa, Festuca rubra* ssp. *oelandica, Fumana procumbens, Globularia vulgaris, Inula ensifolia, Linum catharticum, Poa alpina, Silene uniflora* ssp. *petraea, Teesdalia nudicaulis* and *Thymus serpyllum*.

1.6.2 North America

As in Europe, the alvars of North America are a mix of species with various phytogeographical origins including Arctic, Beringian/Cordilleran, boreal, prairie and eastern mixedwood deciduous forest plant assemblages as well as endemics (Catling and Brownell 1995; Catling *et al.* 2014). Species such as *Pinus banksiana*, *Abies balsamea, Populus tremuloides*, *Arctostaphylos uva-ursi*, *Dasiphora fruticosa*, *Juniperus communis, Agrostis scabra*, *Carex aurea, Comandra umbellata*, *Danthonia spicata*, *Packera paupercula* and *Sisyrinchium montanum* show a boreal affinity (Cayouette *et al.* 2010). *Quercus rubra, Tilia Americana, Thuja occidentalis, Erigeron strigosus, Lonicera dioica, Polygala seneca*, *Prunella vulgaris*, *Sanicula marilandica, Solidago nemoralis, Symphyotricum lanceolatum* and *Symphoricarpos albus* have an affinity with the eastern deciduous forests of the Appalachians and the Great Lakes (Cayouette *et al.* 2010). A prairie influence is evident by the presence of species such as *Andropogon gerardii*, *Sporobolus heterolepis*, *Geum triflorum, Lathyrus ochroleucus* and *Oligoneuron album* (Catling and Brownell 1995; Cayouette *et al.* 2010). The endemic element of alvars in North America varies geographically (Brownell and Riley 2000; Catling 2009a; Cayouette *et al.* 2010; Manitoba Alvar Initiative 2012) but is highest in the Great Lakes. Floristic composition and vegetation communities vary geographically and within sites (Catling and Brownell 1995; Reschke *et al.* 1999; Brownell and Riley 2000), primarily on the basis of disturbance and environmental conditions including soil depth and moisture (Gilman 1995; Reschke *et al.* 1999). Within North American, disturbance dynamics separates two different types of alvars. The majority of alvars in North America are plateau alvars, occurring inland and experiencing prolonged summer droughts that maintain their openness (Brownell and Riley

2000). Shoreline alvars are smaller, open areas occurring on the shorelines of large rivers and lakes (predominately the Great Lakes) (Brownell and Riley 2000). Shoreline alvars are kept open by frequent flooding of the shoreline as well as erosion from wind and water (Brownell and Riley 2000). The communities within shoreline and plateau alvars are diverse (see Appendix 2 for an example), but shoreline alvars are generally dominated by species more tolerant of flooding (Brownell and Riley 2000).

In Canada, alvars were first recognized in Ontario by Beschel (1965) near Camden East (south of Kingston) who noted that:

> "*Vegetation types dominated by forbs and grass-like plants are highly diverse. They cover most of the shallow limestone plains which are partly flooded in spring and very dry during most of the summer and correspond to the Swedish alvars*." (Beschel 1965)

Since Beschel's (1965) initial research, Ontario alvars have been the focus of numerous studies (Catling *et al.* 1975; Belcher *et al.* 1991; Catling and Brownell 1995; Schaefer and Larson 1997; Brownell and Riley 2000). These, and other works, describe plateau alvar habitats with exposed limestone and shallow soils that are dominanted by forbs and graminoids such as *Carex crawei*, *Danthonia spicata*, *Packera paupercula*, *Oligoneuron album, Deschampsia cespitosa, Panicum philadelphicum, Sporobolus vaginiflorus* and *Sporobolus heterolepis* (Belcher 1992; Brownell and Riley 2000). Common shrubs are *Juniperus horizontalis, Dasiphora fruiticosa, Juniperus communis, Viburnum rafinesqueanum* and *Cornus racemosa* (Brownell and Riley 2000). *Dasiphora fruiticosa* and *Juniperus communis* are common shrubs on alvars in Europe and contribute to the similarities that Beschel (1965) saw between Ontario and Sweden. Alvar savannas contain coniferous (*Pinus banksiana, Pinus resinosa, Thuja occidentalis, Juniperus virginiana* and *Picea glauca*) and deciduous tree species (*Quercus macrocarpa, Quercus alba, Quercus rubra, Quercus muehlenbergii, Carya ovata* and *Populus tremuloides*) that can form mixed savannas (Brownell and Riley 2000). Shoreline alvars in Ontario occur on shorelines of the Great Lakes and of smaller lakes. Communities are dominated by graminoids including *Panicum* spp., *Schizachyrium scoparium*, and *Scirpus* spp. (Brownell and Riley 2000).

Species diversity is relatively high with approximately 350 species of vascular plants known from Ontario alvars (Catling and Brownell 1995). At the Bruce Peninsula alvar in Ontario 370 lichen and related fungi were discovered by Brodo *et al.* (2013). In addition to their high species diversity, Ontario alvars are characterized by a number of rare and endemic species. In the study by Brownell and Riley (2000), ten species were globally significant (G1-G3, see NatureServe 2015c for more information on the criteria used for conservation ranking) and fourteen were ranked as nationally endangered or threatened by COSEWIC (Committee on the Status of Endangered Wildlife in Canada). These fourteen species were: *Agalinis gattingeri, Gentiana flavida, Cirsium pitcheri, Morus rubra*, *Carex juniperorum, Hymenoxys herbacea, Cystopseris laurentiana, Valerianella umbilicata, Cyprededium arietinum, Cirsium hillii, Iris lacustris, Astragalus neglectus, Solidago houghtonii* and *Erigeron philadelphicus* ssp. *provancheri* (Brownell and Riley 2000). Brownell and Riley (2000) also documented 80 species with provincial ranks of S1 (critically imperiled) to S3 (vulnerable) plus six additional that were also considered uncommon (S4) (NatureServe 2015c). Of these species, *Hymenoxys herbacea* and *Iris lacustris* are endemic to alvars and largely confined to the shorelines of the Great Lakes (Catling and Brownell 1995). Other species, such as *Carex juniperorum, Cirsium hillii, Erigeron* *philadelphicus* ssp. *provancheri* and *Solidago houghtonii,* are restricted to the Great Lakes region but do not occur solely on alvars (Catling and Brownell 1995).

Ontario alvars are characterized by a variety of boreal, prairie and eastern mixedwood forest plant species although the relative proportions of these species varies widely in the province (Catling and Brownell 1995). For example, the Pelee Island alvar (southern region) is comprised of approximately 75% species with deciduous mixedwood forest affinity, including Chinquapin oak savannas, with few boreal taxa (<25% of species) (Catling and Brownell 1995). On the other hand, Manitoulin alvars (northern region) have a stronger boreal element with over 25% of species having a boreal affinity and are dominated by open pavements with *Juniperus communis, Juniperus horizontalis* and boreal conifer savannas (Catling and Brownell 1995; Brownell and Riley 2000). Less than half of the species on Manitoulin alvars have a mixedwood forest affinity (Catling and Brownell 1995). The alvars within the eastern-central region of Ontario (Kawartha Lakes and Almonte regions) are a mix of mixedwood forest, boreal and prairie influences although the majority of influence comes from the mixedwood forest region to the south (Catling and Brownell 1995).

Alvars in Québec are most similar to the alvars in the eastern-central region of Ontario (Cayouette *et al.* 2010). Approximately 55% of all species have eastern mixedwood forest affinities, with only 30% and 15% having a boreal and prairie affinity, respectively (Cayouette *et al.* 2010). The study by Cayouette *et al.* (2010) identified 599 species occurring on Québec alvars with between 95-259 species found at each site. As in Ontario, two main alvar types are recognized in Québec: plateau and shoreline types. Shoreline alvars are dominated by graminoids and flooded in the spring with pockets of wetland areas (Cayouette *et al.* 2010). Plateau alvars have more diverse vegetation community types and a variable vegetation composition. Woody vegetation on plateau alvars includes *Thuja occidentalis, Pinus banksiana, Juniperus virginiana* var. *virginiana, Juniperus communis* var. *depressa, Rhus aromatica* var. *aromatica, Symphoricarpos albus, Fraxinus pennsylvanica, Quercus macrocarpa*, *Thuja occidentalis, Viburnum rafinesquianum* and *Physocarpus opulifolius.* Graminoids such as *Andropogon gerardii*, *Poa pratensis*, *P*. *compressa, Festuca rubra,* Schizachyrium *scoparium*, *Sorghastrum nutans*, *Sporobolus heterolepis* and *Danthonia spicata* are dominant. Forbs species are variable between alvar communities and sites (Cayouette *et al.* 2010). The alvars in Québec have a large number (66) of threatened or vulnerable species (Cayouette *et al.* 2010). There are 70 threatened or vulnerable species on Québec alvars including *Carex sartwellii, Cyprededium arietinum, Lathyrus ochroleucus, Minuartia michauxii, Panicum philadelphicum*, *Selaginella eclipes*, *Oligoneuron album*, *Sporobolus vaginiflorus* var. v*aginiflorus,* and *Ulmus thomasii* (Cayouette *et al.* 2010). *Hypericum kalmianum* is a Great Lakes endemic that grows on the Québec alvars and *Lycopus americanus* var. *laurentianus* is an endemic to northeastern North America. *Asclepias tuberosa* ssp. *interior*, *Bromus kalmii* and *Sporobolus heterolepis* are restricted to alvars in Québec but are found in a variety of habitats outside of the province (Cayouette *et al.* 2010).

In the Northwest Territories, studies by Catling (2009a) recorded 87 species of vascular plants over five plateau alvar sites (NWT lacks shoreline alvars) and 48 species on two limestone cliff tops. In descending order, the most dominant species were: *Juniperus horizontalis, Juniperus communis* var. *depressa, Geum triflorum* var. *triflorum, Carex* *richardsonii, Populus tremuloides, Elymus trachycaulus* ssp. *trachycaulus, Koeleria macrantha, Saxifraga tricuspidata, Artemisia campestris* ssp. *borealis, Senicio lugens, Arctostaphylos uva-ursi* and *Galium boreale* (Catling 2009a). *Populus tremuloides* and *Pinus banksiana* were the only trees common in open areas (Catling 2009a). The alvars in the Northwest Territories have a distinct floral composition due to a strong boreal, Arctic, Beringian and Cordilleran element with fewer prairie and eastern mixedwood forest species in comparison to alvars in Ontario and Quebec (Catling and Brownell 1995; Catling 2009a; Cayouette *et al.* 2010). Despite their more northern affinities, species such as *Geum triflorum,* a prairie relict that predates the western extension of the boreal forest into the Northwest Territories, is found here (Catling 2009a). Twelve percent of the species present on alvars in the Northwest Territories are rare and at the northern limit of their range including both prairie (*Avenula hookeri*) and boreal (*Danthonia spicata* and *Prunus virginiana*) species (McJannet *et al.* 1995). The Northwest Territories alvars lack endemics, but *Plantago canescens* is endemic to the Beringia area. Although alvars in the Northwest Territories are less biodiverse than those found to the east, this ecosystem still has high species diversity for its latitude (Catling 2009a).

In Manitoba, the alvars are all plateau alvars, characterized by a mixture of boreal and prairie plants (Manitoba Alvar Initiative study 2012). These are discussed in more detail in Chapter 2.

Alvars in the U.S.A. are found in close proximity to the Great Lakes and are comparable to their adjacent regions in Canada. For example, Catling and Brownell (1995) determined that alvars in New York State, U.S.A. are most similar to the alvars in south central Ontario with a mix of boreal and eastern deciduous forest influences. Both shoreline and plateau alvars occur in the U.S.A. (Reschke *et al.* 1999) and composition of these is similar to those described for Ontario above. Gilman (1995) identified 303 native species and 71 introduced species on New York alvars. Individual alvar communities had between 89-234 plant species. Vegetation communities included pavement barrens, meadows, cedar savannah and limestone woodlands that correspond with the communities described in Ontario (Belcher 1991; Catling and Brownell 1995; Gilman 1995) (Appendix 2). Currently the Marblehead Peninsula in northern Ohio on Lake Erie only has remnants of alvar vegetation that colonized quarries in the region (Catling and Brownell 1995). The southern alvars in Michigan are most similar in vegetation composition to the southern alvars in Ontario (Pelee Island region) and alvars of Ohio (before disturbance) (Catling and Brownell 1995). The alvars in northern Michigan are most similar to the alvars in the Lake Huron region of Ontario and are characterized by a mixture of boreal and prairie species (Catling and Brownell 1995). *Pinus strobus*, *Abies balsamea, Thuja occidentalis, Populus tremuloides* and *Picea glauca,* occur as the sparse tree cover (Albert 2006). Michigan also has shoreline alvars along the Escabana River and the Great Lakes that contain a number of fen species including *Carex buxbaumii, Solidago ohioensis, Hypericum kalmia* and *Dasiphora fruiticosa* (Chapman and Brewer 2008). The same rare and/or endemic species found on alvars in Ontario are found in the U.S.A. (Reschke *et al.* 1999; Brownell and Riley 2000).

1.7 Disturbance Ecology of Alvar Vegetation

Disturbances such as drought, flooding, disease, herbivory and fire limit tree cover and help to maintain the openness of alvars over the long-term (Whitehouse 1933; Burbanck 1980;

Phillips 1981; Catling 2014). These disturbances can occur on an annual basis, like the extremes of flooding and drought, or sporadically as is the case with fires (Catling 2014).

1.7.1 Drought and Flooding

Thin soils and flat topography on alvars limit water retention and drainage leading to seasonal extremes of drought and flooding (Jones and Reschke 2005). Flooding is primarily a result of precipitation and snowmelt that pools on rather impermeable rock (Reschke *et al.* 1999). Severe drought and poor drainage, leading to flooding, can cause drastic changes in plant populations on alvars due to die off of woody vegetation (Pärtel *et al.* 1999). A study by Reschke *et al.* (1999) found that summer surface temperatures on alvars in the Great Lakes region are between 43°C and 53°C. These temperatures can lead to intense drought conditions in areas with thin soils but had less influence on areas with thicker soils. A study by Reschke (1995) on the Chaumont Barrens in New York indicated that spring flooding and summer droughts create a variety of alvar types. For example, the tufted hairgrass wet alvar grassland community in Ontario (Appendix 2) occurs in low depressions and experiences flooding conditions due to snowmelt in the spring and retention of rain water in warmer months (Reschke *et al.* 1999; Brownell and Riley 2000). In contrast, pavement and shrubland alvars are more frequently associated with thin soils that experience seasonal drought (Reschke 1995). Drought has been shown to cause 10-100% mortality of woody species and helps maintain high biodiversity of herbaceous plants (Catling 2014; Stephenson and Herendeen 1986). This variation can be attributed to inconsistency in soil depth and topography that determines moisture availability (Catling 2014). Habitats that are xeric in nature have a prevailing cover of herbaceous plants (Nelson and Ladd 1981) and these harsh conditions favour specific plant communities that are adapted to these conditions (Cayouette *et al.* 2010). For example, in the Great Lakes region over half of alvar communities are dominated by mosses, forbs, and graminoids (13403 acres with less than 25% shrub cover) and these open alvars are more prevalent than shrubland (11283 acres with an average of 46% shrub cover) and savanna (2293 acres of Great Lake Region with 10-25% tree cover) alvar communities (see Appendix 2) (Reschke *et al.* 1999). Droughts on Öland, Sweden resulted in a decrease in graminoids and an increase in annual forbs (Krahulec *et al.* 1986).

1.7.2 Grazing

Studies in Öland have found that anthropogenic grazing (by livestock and sheep) causes fragmentation/dislodging of mosses and lichens, reduced flowering and/or fruiting in vascular plants, death or restricted growth in shrubs, an increase in ruderal species typical of fields and pastures, and an increase in erosion and nutrient loading (Rosén 1982). Areas with thinner soils or bare rock are more susceptible to damage from grazing since fragmentation combined with wind causes significant erosion of an already thin soil layer. Grazing can also be selective and damage certain species more heavily while providing a competitive advantage for ruderal/introduced species (Rosén 1982). Heavy grazing negatively affects both moss and lichen presence although tolerance does vary by species (Rosén 1982). For example, fruticose lichens (such as *Cladonia* spp.) and cushion forming mosses (such as *Tortella* spp.) can become fragmented because of grazing and take a long period of time to recover (Rosén 1982). Conversely, vascular species such as *Cirsium arvense, Trifolium pratense* and *Poa pratensis* increase with grazing (Rosén 1982). These species may do well under disturbed conditions due to traits such as rapid growth or increased seed set (MacDougall and Turkington 2005).

Grazing can also have a positive influence on alvar habitats if managed to avoid some of the negative effects (discussed above) as it can increase and maintain the biodiversity (Dzwonko and Loster 1998) and openness by reducing shrub cover (Pärtel *et al.* 1999). For example, Rosén and van der Maarell (2000) and Pärtel *et al.* 1998 described the 'main threat' to alvars in Sweden and Estonia as shrub encroachment by *Juniperus communis* and *Dasiphora fruiticosa* that followed the abandonment of grazing activities. It is suspected that alvars in Estonia exist as alvar grasslands (rather than 'wooded' alvar communities) due to the clearing of woody vegetation and grazing of domestic animals (Znamenskiy *et al.* 2006). After grazing of alvar grasslands in Estonia ceased, shrub encroachment resulted in a decline of species diversity (Pärtel *et al.* 1998). Research on Scandinavian alvars has found that removal of litter encourages re-establishment of grassland species (Bakker *et al.* 2012) and that the biodiversity of overgrown grasslands quickly increases after removal of woody vegetation through disturbances such as grazing (Pärtel *et al.* 1998). Even when overgrown, many species remain in the seed bank and are able to re-establish when open conditions are restablished (Pärtel *et al.* 1998). The positive and negative influence of grazing on alvar vegetation suggests that this activity must be monitored continuously to have the maximum positive effect on alvar plant diversity (Rosén 1982).

In contrast to research conducted on European alvars, grazing studies are lacking for North America. Based on preliminary observations, Reschke *et al.* (1990) suggested that browsing by rabbits and voles has minimal effects on alvars but high numbers of white-tailed deer or livestock could alter plant communities. Determining the effects of grazing on Canadian alvars is critical to their conservation and management. However, grazing is a complex process that varies geographically (Hejcman et. al. 2013). Therefore, we cannot assume that the results of grazing studies in Europe can be applied to alvars in North America. Grazing will be discussed further in Chapter 4.

1.7.3 Fire

As with grazing, moderate intensity fires can increase plant diversity through maintaining vegetation dynamics (Catling 2009b). If unrestricted, large fires can restore alvar savanna or woodland to open alvar (Catling and Brownell 1998; Reschke *et al.* 1999), although fires large enough to 'create' alvars are rare events in recent history due to fire suppression (Reschke *et al.* 1999). Jones and Rescke (2005) state that fire is not a main factor in maintaining openness of alvars but small fires can occur unnoticed due to the remote and patchy nature of some sites and can contribute to the maintenance of open alvar habitats (Jones and Reschke 2005). Some alvar communities are more strongly associated with fires than others. For example, in the Great Lakes region, 71% of all bur oak savanna, white cedar-jack pine savanna, creeping juniper- shrubby cinquefoil shrubland, and non-vascular pavement showed evidence of burning (Rescke *et al.* 1999). Catling and Brownell (1998) showed that burnt sections of the Burnt Lands Alvar, Ontario had higher species diversity and more rare species after burning. In contrast, Schaefer and Larson (1997) found little difference between burned and unburned alvars indicating that fire may only be necessary in maintaining the vegetation in some alvar types, such as oak savanna, white cedar-jack pine savanna, creeping juniper- shrubby cinquefoil shrubland and non-vascular pavement. Due to the varying reliance of alvar communities on fire, Jones and Reschke (2005) recommended that controlled burning not be used as a management for all alvars but natural fires should be allowed to continue when possible.

1.7.4 Anthropogenic Threats

Despite the global significance of alvars, they are subjected to many threats (Figure 1.3) including development, road construction, quarrying, off-road vehicle use, logging of adjacent woodlands, overgrazing, invasive species, climate change, garbage dumping, vandalism, and the removal of plants and rocks for home gardening (Catling and Brownell 1995; Reschke *et al.* 1999; Jalava 2008). As discussed previously, fire suppression can cause encroachment of woody vegetation and a decrease in biodiversity on alvars (Catling 2009b). Similarly, alvars can be directly impacted by grazing as well as indirect effects related to increased number of invasive species, nutrient supplementation, and increased off-road vehicle use (Rosen 1982; Reschke *et al.* 1999). Off-road vehicle use disturbs or removes the thin soils, increases presence of invasive species and affects drainage by creating ruts where water collects (Reschke *et al.* 1999). Colonization by exotic shrubs, such as *Lonicera tatarica, Syringa vulgaris* and *Rhamnus cathartica*, can reduce the presence of native alvar flora (Catling and Brownell 1995). In Québec, between 6-37% of species at each site were introduced with 26 introduced species being found at over half the alvar sites (Cayouette *et al.* 2010). One hundred and nine introduced species were observed on alvars in the Great Lakes region with their presence varying by community (Reschke *et al.* 1999). For example, in the Great Lakes region, *Rhamnus cathartica* is only found in three alvar communities (juniper shrubland, alvar nonvascular pavement and annual alvar pavement/grassland, (see Appendix 2) whereas *Poa compressa* is more widespread across alvar communities (Reschke *et al.* 1999). Reschke *et al.* (1999) suggest that this is more dependent on certain communities (such as those with *Rhamnus cathartica*) being more heavily disturbed rather than the introduced species preferentially growing in them.

The full effect of climate change on alvars is unknown, however, literature predicts that effects on similar types of habitats including limestone barrens (see below) could be severe from altering the ecological processes (such as frost, drought and flooding) (Limestone Barrens Species at Risk Recovery Team 2014). These processes maintain openness and restrict what flora can survive on alvars. Studies on the mustard species *Braya longii* and *Braya fernaldii*, which are endemic to the limestone barrens of Newfoundland (see section on *Similar Habitats*), found that flowering time was significantly affected by the date of snowmelt and mean ground temperature (Donato 2005) suggesting that species on rock barren ecosystems may be susceptible to the effects of climate change. The lack of public knowledge of the ecological significance of alvars increases the above risks and reduces the possibility of recovery and management (Jalava 2008).

1.8 Vegetation Dynamics on Alvars

Succession in rock barren habitats, including alvars, is dependent on soil characteristics and moisture regimes (Whitehouse 1933). As a generality, succession begins with exfoliation of rock surfaces and the establishment of crustose lichens followed by foliose lichens and mosses (Gilman 1995). The next stage is dominated by graminoid and herbaceous plants (Gilman 1995). This is followed by increased abundance of woody plants in regions with more soil deposition and a higher moisture regime, such as cracks or depressions in the rock (Whitehouse 1933; Belcher 1992; Gilman 1995). Studies of similar habitats called cedar glades (see *Similar Habitats* section) have shown that vegetation development occurs in a similar manner with woody vegetation restricted to cracks in the rock (Gilman 1995; Quarterman 1950b). The variable environmental conditions within alvar ecosystems also lead to a mosaic of 'successional stages' for vegetation since succession might proceed faster in some areas (due to increased soil depth or moisture regime) than others (Gilman 1995).

Succession on rock barren habitats lacks long-term stability due to frequent natural disturbances (Burbank and Platt 1964). Despite these re-occurring 'setbacks' from disturbance, succession can still progress on alvars and limestone cliff faces since the patchy nature of vegetation within them can cause disturbances such as fire to miss certain regions. The oldest trees Eastern North America (stems up to 1032 years) are found on limestone cliffs associated with the alvars of the Bruce Peninsula, Ontario (Larson and Kelly 1991). Many of the trees on alvars in Québec are over 200 years old (Cayouette *et al.* 2010) and trees up to 500 years old have also been found on alvars in the Great Lakes region (Jones and Reschke 2005).

Many factors affect plants ability to colonize and survive the harsh conditions of alvars (Wentworth 1981). Soil depth, bedrock type, drought and flooding can all restrict succession of alvars to 'treed' ecosystems by limiting where species can establish. In a comparison of limestone and granite barrens, Wentworth (1981) found that calcareous rock, such as limestone and dolomite, may act as barriers against colonization since only high pH tolerant species, which are less common, can occur there. Competition is reduced on barren landscapes leading to many endemic species that occupy harsher niches (Kruckeberg 1954). Rock barren restricted species have stress-tolerant adaptations and characteristics including low potential growth rate, late and low seed production and low competitive ability. Weedy species may grow faster when moisture and nutrients are available but stress tolerant species are favored when these are low (Kruckeberg 1954; Keener 1983). These characteristics lead alvars to be relatively biodiverse with restricted migration and succession.

1.9 Similar Rock Barren Ecosystems

It is important to recognize that there are a variety of rock barren ecosystems with similar ecological processes to alvars including; granite outcrops, cedar glades, Garry oak savanna, limestone pavement, chert barrens, shale barrens and sandstone barrens (Jeffries 1985; Znamensiy *et al.* 2006). The differences between these ecosystem types are not always clear and some are difficult to distinguish from alvars.

Cedar glades occur in the eastern United States and are characterized as areas of thin soil over limestone or dolomite dominated by grass cover with scattered cedars (*Juniperus virginiana* and *Juniperus ashi*) or shrubs and intermittent areas of exposed rock (Kucera and Martin 1957). The common species of cedar glades include *Schizachyrium scoparium, Hedyotis nigricans, Sporobolus neglectus, Rudbeckia missouriensis, Panicum virgatum*, *Sorgastrum nutans* and *Carex* spp. (Baskin and Baskin 2000). Although cedar glades formed as a result of glacial processes, they differ from alvars in that they were not glaciated during the most recent ice age (Pleistocene era) and they have a topography that varies from sloping to flat (Harper 1926; Steyermark 1959; Nelson and Ladd 1981). The sparse vegetation cover on cedar glades is maintained by processes such as drought and fire (Harper 1926; Quarterman 1950b). Cedar glades occur in Kentucky (Baskin and Baskin 1985), Missouri (Erickson *et al.* 1942), Tennessee

(Quarterman 1950a; Quarterman 1950b) and the Midwest region including Illinois, Indiana, Ohio and Wisconsin (Baskin and Baskin 2000). In the Great Lakes Region, there are Red Cedar (*Juniperus virginiana*) woodlands (30-70% tree cover) and some alvars may include cedar savannas, although these have a different topography and vegetation composition from the cedar glades in the southern United States (Reschke *et al.* 1999; Brownell and Riley 2000) and these were glaciated during the Pleistocene.

Limestone rock barrens occur in Europe and North America. In Europe, limestone barrens occur in Ireland (Beltman *et al.* 2003) and Great Britain (Margules *et al.* 2003; Limestone Pavement Conservation 2013). In Canada, they are found in the arctic, western Canada and Newfoundland (Belcher 1992). Like alvars, limestone rock barrens are characterized by thin soil over limestone or marble rock with sparse cover of woody vegetation (Willis 2011). However, unlike alvars, these habitats are distinguished by frequent clints (sections separated by fissures) and grikes (larger vertical cracks) formed by erosion (Willis 2011). These features create a unique microclimate (Willis 2011) and facilitate drainage from the surrounding region. Willis (2011) found that the majority of vegetation on limestone barrens in Europe is located in grikes and the composition of communities varies based on width and depth of these features. Another contrasting feature between alvars and limestone barrens is that limestone barrens vary from having hills and cliffs to flat areas (Claudia Hanel, Pers. Comm.). These characteristics contrast with alvars, which are flat, have restricted drainage and are frequently flooded. In Europe, limestone barrens contain endemics such as *Carex digitata, Dyras octopetala* and *Salix myrsinites* (Willis 2011). As in alvars, communities on limestone barrens can vary between ‘wooded’ and open communities (Willis 2011).

In Canada, the limestone rock barrens of Newfoundland are the most comparable ecosystem to alvars that have been well studied. Like alvars, limestone rock barrens in Newfoundland are a mixture of limestone and dolomite rock. These limestone barrens are primarily on the north-west part of Newfoundland and include areas in Table Point Ecological Reserve, Port-au-Choix National Historic Park, Sandy Cove Ecological Reserve, Watt's Point Ecological Reserve and Burnt Cape Ecological Reserve (Limestone Barren Species at Risk Recovery Team 2014). Due to a wealth of interesting wildlife, these barrens have been the focus of research for more than a hundred years (Limestone Barrens Habitat Stewardship Program 2011). Early botanical surveys documented differences between plants present in the limestone regions and other areas in Newfoundland (Fernald 1911). More recently, research has focused on the rare flora of the barrens and species and ecosystem management strategies (Limestone Barrens Habitat Stewardship Program 2011). Many rare plants occur in these barrens including *Salix jejuna, Braya fernaldii, Astragalus robbinsii* var. *fernaldii*, *Arnica griscomii* ssp. *griscomii*, *Braya longii*, *Braya humilis*, *Hedysarum boreale* ssp. *mackenzii* and *Arnica angustifolia* ssp. *tomentosa* (Department of Environment and Conservation 2016). These areas of Newfoundland have variable topography and a moister climate than alvars in other parts of Canada. It is suspected that the limestone barrens in Newfoundland are treeless due to a combination of the thin soils and a somewhat alpine/arctic climate that makes them more comparable to tundra on the Hudson Bay coast than alvar (Claudia Hanel, Pers. Comm. 2016).

Sandstone, chert and shale barrens are open rocky ecosystems in North America that are similar to alvars but with differing underlying bedrocks. Like alvars, these are rocky, open ecosystems with shallow soils over calcareous bedrocks. However, shale is a finer textured sedimentary rock and chert shatters with heat (Heiken *et al.* 1994), differing from limestone, which forms complete bedrocks and restricts drainage. In addition, soils on the chert and shale barrens may be acidic and well drained, and the topography is sloping (Heiken *et al.* 1994). In contrast, alvars have a flat topography and poorly drained, basic soils. In the absence of fire, chert and shale barrens succeed to deciduous forest (Heiken *et al.* 1994) whereas alvars always remain open regardless of the presence or absence of fire (Jones and Reschke 2005). Like alvars and cedar glades, these ecosystems can occur as savannas, glades or more open areas. In addition, they are species diverse and contain taxa that must tolerate harsh conditions such as heat and drought (Missouri Department of Conservation 2016). Chert and shale barrens frequently contain prairie species (Heiken *et al.* 1994). *Quercus stellata* and *Schizachyrium scoparium* are dominant in chert and shale barrens with *Ulmus alata, Vaccinium arboretum, Helianthus divicatus* and *Danthonia spicata* being frequent associates (Heiken *et al.* 1994).

Granite barrens occur throughout North America, including the Canadian Shield region in Canada (Catling and Brownell 1999a). Granite barrens are open areas with acidic soils (pH of 4-5) and granitic bedrocks (Philips 1981). These ecosystems experience harsh environmental conditions due to their thin soils and highly variable temperatures (Philips 1981; Catling and Brownell 1999a). Topography is variable with some areas being flat and experiencing flooding while others are well drained and xeric (Catling and Brownell 1999a). Soil depths also vary (0-50cm) with soil and organic debris collecting in cracks (Philips 1981). Environmental variation results in highly variable and patchy plant communities with woody vegetation occurring in regions of deeper soil while lichen and moss communities dominate the bare rock surfaces. Compared to alvars where the actual exposed pavement can occupy less than 1% of the total alvar area (Krahulec *et al.* 1986), the amount of bare rock on granite barrens can be very extensive and can occupy the majority of the ecosystem (Philips 1981). A study of the granite barrens in southern Ontario found 70 characteristic vascular plants including *Danthonia spicata, Deschampsia flexuosa, Carex pensylvanica, Rhus typhina* and *Vaccinium angustifolium* (Catling and Brownell 1999a). Species richness per site in southern Ontario ranged from 30-100 species (Catling and Brownell 199a). A study of granite outcrops in Georgia, U.S.A (Burbank and Platt 1964) found 76 species of vascular plants, bryophytes and lichens indicating that these areas are not as diverse as alvars. Endemic species found on granite barrens include *Cyperus granitophilus*, *Viguiera porteri*, *Oenothera fruiticosa* var. *sublobosa*, *Portulaca smallii*, *Isoetes melanospora,* and *Amphianthis pusillus* (Burbank and Platt 1964).

Calcareous prairies exist as elevated openings (0.2- 10 hectares) within complexes of short leaf pine-oak-hickory forests in North America (Bekele *et al.* 2006). They are naturally open, treeless areas found on various calcareous substrates (Department of Wildlife and Fisheries 2005). These prairies have developed over marly clays from the Tertiary period and occur in a higher position than the surrounding forested regions. Like alvars, soils are calcareous with a pH of 7.5-8 (Department of Wildlife and Fisheries 2005) but they do not have a consistently flat topography (Bekele *et al.* 2006). There are no restrictions on soil depth for defining calcareous prairies and in general soils are deep (>20cm) (NatureServe 2015b). Vegetation is dominated by graminoids (Department of Wildlife and Fisheries 2005), including *Carex cherokeensis, Carex microdonta, Muhlenbergia expansa, Schizachyrium tenerum, Schizachyrium scoparium, Andropogon gerardii, Sporobolus asperm, Sporobolus silveanus, Andropogon glomeratus, Panicum* spp. and *Sorghastrum nutans*. Woody species become more frequent in forested transition zones and include *Crataegus* spp., *Diospyros virginiana, Berchemia scandens, Juniperus virginiana* and *Quercus* spp. (Department of Wildlife and Fisheries 2005; Bekele *et al.* 2006; NatureServe 2015b). Although alvars contain prairie elements, the mix of other affinities (e.g., boreal species) and the unique combination of edaphic conditions/ ecological processes (openness, restricted drainage, thin soil and flat topography) makes them distinct from calcareous prairie ecosystems (Catling and Brownell 1995).

The Eurasian Steppe is a large vegetation region that extends from Europe to Asia (Coupland 1993). The Eurasian Steppe is a natural temperate grassland ecosystem with an open appearance that is dominated by graminoids but can also include more wooded forest-steppe communities (Coupland 1993). The general appearance of alvars and North American prairies is similar to steppe vegetation, in terms of being open and graminoid dominated, but the vegetation composition is distinct between all three ecosystems (Witte 1906; Coupland 1993; Bai *et al.* 2007). Like alvars, this region also formed after the Pleistocene glaciation (Velichko and Zelikson 2005). Meadow steppes in the U.S.S.R. can be characterized into three association types: 1) *Bromus riparius, Bromus inermis, Koeleria gracilis, Stipa joannis, Medicago falcata, Galium verum*; 2) *Festuca pseudovina, Poa angustifolia, Vicia cracca, Medicago falcate*; and 3) *Festuca pseudovina, Agropyron repens, Artemisia pontica* (Coupland 1993). Meadow steppes are on Chernozem soil that is slightly saline (Coupland 1993). The variable rolling topography (including rolling hills), deeper soil depth and soil acidity (pH between 4.5- 6.5) contrasts with the characteristics of alvar ecosystems (Cremene *et al.* 2005; Bai *et al.* 2007).

Garry oak ecosystems are found on the west coast of North America (from British Columbia Canada to California) with a dominant tree cover of *Quercus garryana* (Garry Oak Ecosystem Recovery Team 2003; Capitol Regional District 2016). Communities range from woodlands with closed-canopies to open meadows (Garry Oak Ecosystem Recovery Team 2003; Capitol Regional District 2016). Like alvars, the Garry oak ecosystem is highly diverse (Nature Conservancy of Canada 2016). The understory vegetation of Garry oak communities can either be dominated by forbs and grasses or a thick shrub layer comprised of species such as *Symphoricarpos albus* (Garry Oak Ecosystem Recovery Team 2003). In contrast to alvars, this ecosystem occurs on conglomerate bedrock formed from the compression of pebbles (Irvin Banman, Pers. Comm. 2016). This ecosystem ranges from having a flat to highly sloping topography (P. Catling, Pers. Obs. 2016) and unlike alvars, soils can be deep (>20cm) (Irvin Banman, Pers. Comm. 2016). It is uncertain if all Garry oak communities are naturally open (Irvin Banman, Pers. Comm. 2016) since historically these were maintained by Indigenous peoples. Today fire and grazing are used to manage these habitats (Irvin Banman, Pers. Comm. 2016).

1.10 Significance of Alvars

Alvars are highly diverse ecosystems that contain rare and endemic floral elements that represent relics of historic ranges and as such are of global significance and worthy of protection (Catling and Catling 1995; Catling *et al.* 2014). The alvar on Öland was designated as an UNESCO world heritage site in 2000 due to its unique nature and historic value (Eriksson and Rosén 2008). In Great Britain and Ireland, limestone barrens are protected by Limestone

Pavement Orders and Areas or Sites of Special Scientific Interest in order to conserve wildlife and geology (Limestone Pavement Conservation 2013). The Nature Conservancy of Canada has listed alvars as globally imperiled ecosystems and with the Nature Conservancy of the United States they initiated an international project to locate and preserve alvar habitats (Schaefer 1996). NatureServe (2013) also ranks alvars as an endangered habitat. The Canadian Botanical Association has listed alvar as an "Area of Special Conservation Concern for Plants" (Catling *et al.* 2014). The alvars in Ontario are now internationally recognized for their rare species (Jalava 2008). After their recognition as unique ecosystems, by the International Alvar Conservation Initiative, approximately 50 government and non-government organizations have focused on understanding and conserving this ecosystem (Reschke 1999). Finally, in 2015, Manitoba became the first province in Canada to list alvar ecosystems as endangered and protect them under the *Endangered Species and Ecosystems Act* (Manitoba Conservation 2015).

In addition to their importance for biodiversity, alvars also have economic importance for agriculture, the restoration of damaged habitats and ecotourism. The rugged beauty and wide variety of flowering plants on alvars has made them valuable ecotourism sites in Ontario and provides economic benefits to the nearby communities (Kirk 1992; Catling and Brownell 1995; Reschle *et al.* 1999). Alvars in Europe have been grazed for approximately 6000 years (Eriksson and Rosén 2008) and currently the majority of alvar areas within Manitoba are used as pasture (Manitoba Alvar Initiative 2012). These include regions of crown land being leased and public pastures that benefit communities (Manitoba Alvar Initiative 2012). The proper management (that prevents negative effects of overgrazing) of these alvar pasture lands can benefit the local community by maintaining lease agreements that provide land for pasture and have positive effects on the biodiversity of alvars through reducing shrub encroachment (Rosén 1982; Partel *et al.* 1998; Partel *et al.* 1999). Alvars are also a source of genetic material of drought and flood adapted plants including crop relatives (Catling and Catling 1995). With increases in anthropogenic disturbances, the restoration of disturbed areas is a growing concern (Shannon *et al.* 2008).

The quarrying of rock (aggregate extraction) is one example of increasingly demanding human activities that destroys many ecosystems (Larson *et al.* 2004). As harsh ecosystems, alvars are a refuge for vegetation tolerant to the harsh conditions present in recently mined areas. Alvar-like vegetation might grow on human disturbed sites such as previously mined areas allowing for restoration of these areas (Gilman 1995). For example, a study by Shannon *et al.* (2008) surveyed thirteen abandoned limestone quarries in Ontario revealing that twelve percent of the re-established vegetation was characteristic of alvars and 79 species (vascular and non-vascular) occurred in both alvars and quarries. Therefore, gaining an understanding of alvar ecology will improve our ability to restore these disturbed areas (Shannon *et al.* 2008). Although introducing alvar flora into disturbed sites can allow for the re-establishment of vegetation in otherwise barren landscapes, this does not “create” an alvar, which is a long-lasting naturally open area (Catling 2013).

1.11 Summary

Alvars are unique ecosystems defined by topography (flat), climate (temperate), environmental conditions (thin soil over limestone bedrock with poor drainage) and vegetation (open areas with sparse trees and a drought adapted flora that is highly biodiverse). The vegetation of alvars is a mix of multiple floral elements that add to their diversity (Brownell and Riley 1995; Eriksson and Rosén 2008). In North America this includes arctic, boreal, prairie and eastern mixedwood deciduous forest plant species, while in Europe it includes a mixture of arctic, heath and grassland species (Catling and Brownell 1995; Eriksson and Rosén 2008; Catling 2009a). Localized endemics are also frequent, especially on the Great Lakes alvars of North America. On a local scale, alvar communities can be highly variable as result of subtle changes in edaphic conditions, creating a patchwork of vegetation types (Catling and Brownell 1995). Disturbances such as drought, flooding, grazing and fire can contribute to the openness and patchiness of alvars, however these effects vary by geographic location, environmental conditions and the initial vegetation community. Alvars experience similar ecological processes as other rock barren ecosystems. However, they have unique edaphic features and post glacial history that contributes to their distinctiveness (Witte 1906; Catling and Brownell 1995). Despite the extensive knowledge of alvars in Europe, the alvars in Canada, especially Manitoba, remain understudied.

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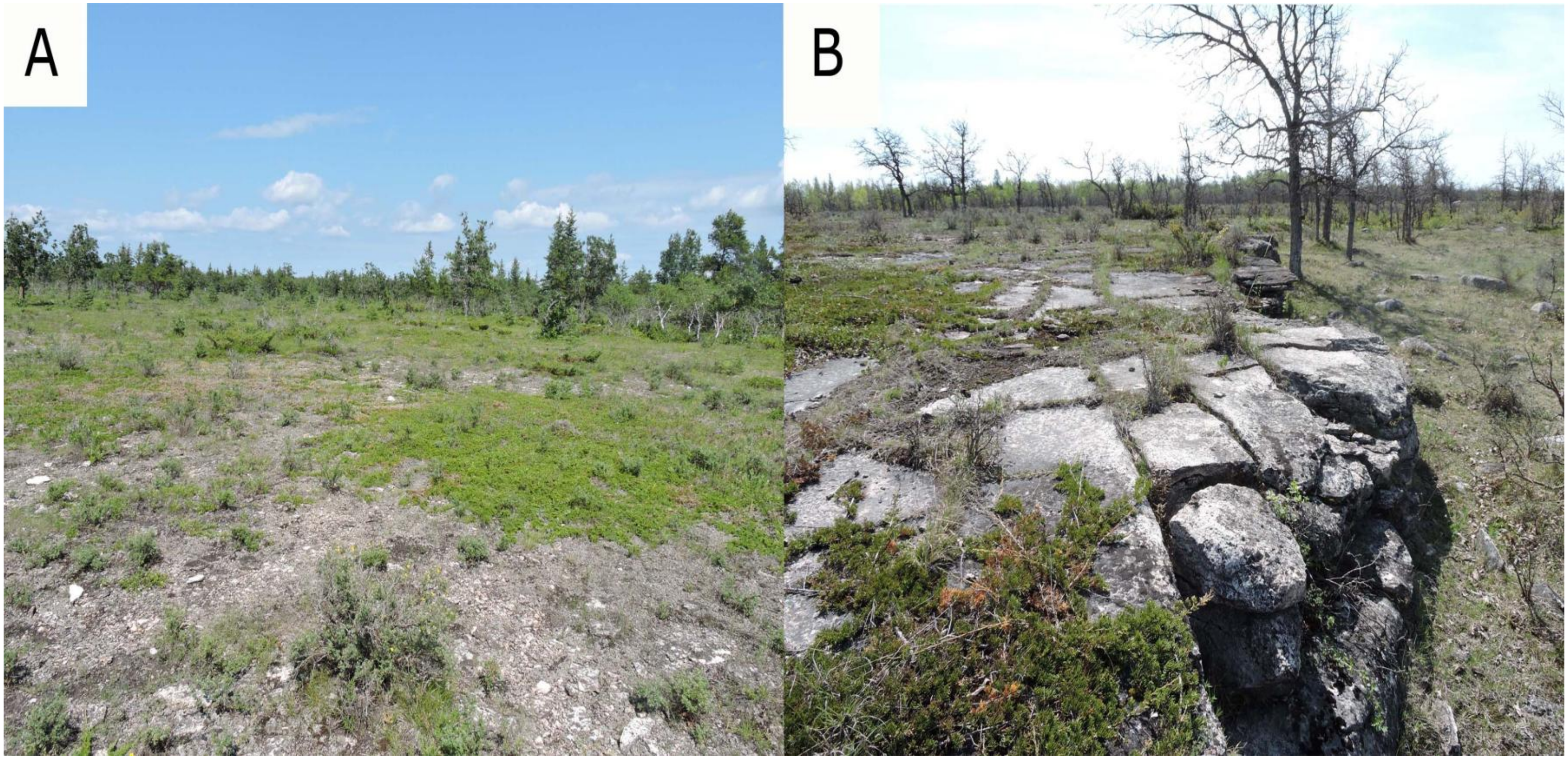

Figure 1.1: Alvars are characteristically flat, open (<60% tree cover) areas with thin soil over limestone bedrocks. Communities range from open areas (A) to savannas and may include limestone ridges (B).

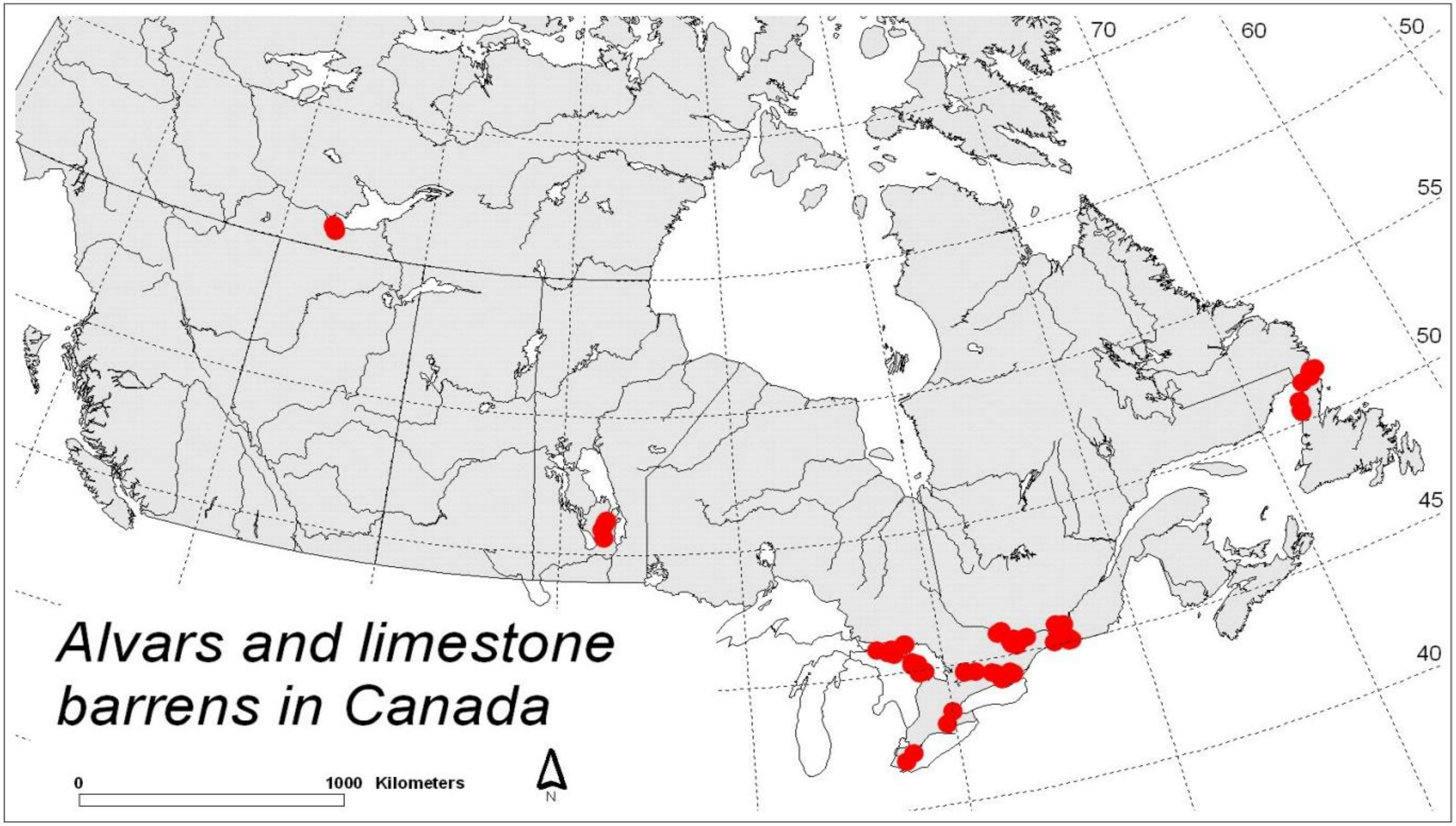

Figure 1.2: Distribution of alvars and limestone barrens in Canada (Catling *et al.* 2014)

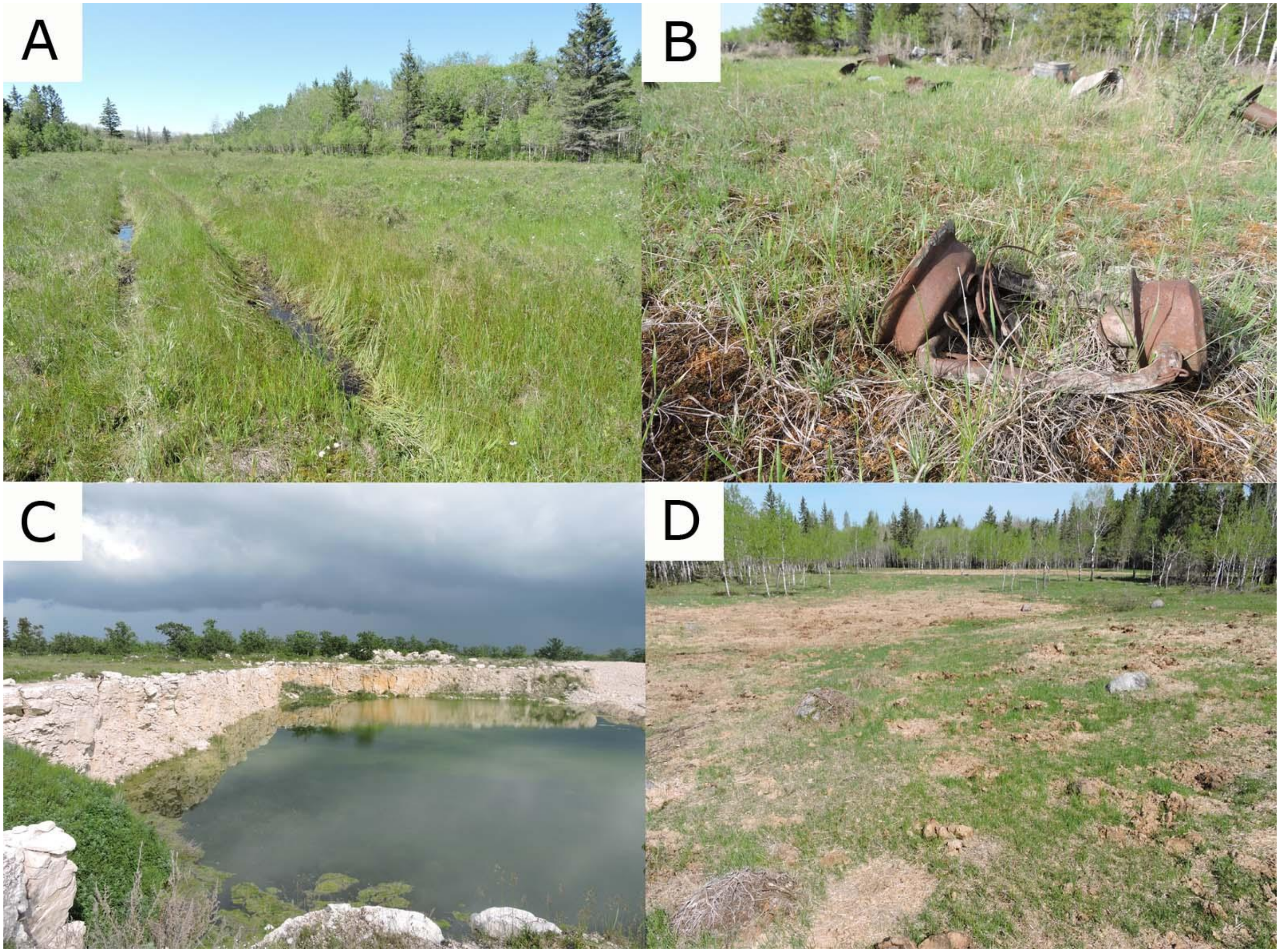

Figure 1.3: Threats to alvars include A) off road vehicle use, B) garbage dumping, C) quarrying and D) overgrazing and the associated effects such as supplemental hay feeding.

Chapter 2: Study Site and Objectives

2.1 Alvars in Manitoba

Alvar ecosystems have only recently been recognized as occurring in Manitoba (Hamel and Foster 2004), and it was only in 2010 that the Nature Conservancy and Manitoba Conservation began to develop a broad conservation plan for Interlake Region alvars (Manitoba Alvar Initiative 2012). The Manitoba Alvar Initiative (2012) mapped out potential alvar areas in the southern Interlake region and confirmed alvar locations occurring in the municipalities of Fisher, Armstrong and Bifrost; between Peguis and Inwood (Figure 2.1). The members of the Manitoba Alvar Initiative (2012) have called attention to the uniqueness of Manitoba alvars, their contribution to the overall biodiversity of the province, and their importance globally. These two agencies have also highlighted the need to obtain more information on Manitoba alvars, including quantitative data on biodiversity, variation, extent, and ecological health.

2.2 Geology and Glaciation History

During the Paleozoic Era (including the Silurian and Ordovician time periods), Manitoba was under a shallow sea in a tropical climate (Corkery 1996). Across North America, the calcareous sediments that formed limestone and dolomite rocks were deposited on a southward-sloping continental shelf edge under the Iapetus Ocean (Plummer *et al.* 2007). Evidence of this is shown by fossils of marine organisms that can be found in these rocks today (Corkery 1996). The southern Interlake region of Manitoba occurs on the eastern edge of this formation with 40% of the province covered by Paleozoic sedimentary rock (Manitoba Geology 2015). Continental shifts placed Manitoba where it is today, although it is the combined effects of uplifting, glaciation, volcanoes, orogeny (which formed the granitic rocks of the Canadian Shield) and glaciation that produced the current topography (Corkery 1996), including the flat topography of the Interlake region where alvars exist.

The Pleistocene glaciation period and its recession are the most recent geological events that contributed to the formation of alvar ecosystems. During the Pleistocene, Manitoba was covered by the Laurentide Ice Sheet. This massive glacier occupied most of Canada (Teller and Leverington 2006) and reached a thickness of 1.5km (Welsted *et al.* 1996). The Laurentide Ice Sheet started to recede from Manitoba 11,500 years ago. The receding glacier scraped off surface layers and exposed outcrops of Ordovician and Silurian rocks (limestone and dolostone deposited in the Paleozoic Era) (Corkery 1996). Eroded rocks were picked up by the glacier and contributed to the scouring of the earth that exposed these bedrocks but were later deposited as till (Corkery 1996). This till can currently be seen as frequent granite erratics over these limestone areas. This erosion, deposition and sedimentation contributed greatly to Manitoba's current landscape (Corkery 1996) and the formation of alvars. Deglaciated areas were subsequently inundated by Lake Agassiz, which developed along the glaciers margin and over time receded into Hudson Bay (Manitoba Historical Society 2015; Corkery 1996). At its maximum (9200 ybp), Lake Agassiz was larger than all the Great Lakes combined, with Lakes Winnipeg and Manitoba being remnants of this vast glacial lake. All alvars in Manitoba are found between these two extant lakes and in areas that up until 7700 ybp were covered by Lake Agassiz (Manitoba Historical Society 2015; Corkery 1996).

The southern Interlake region is dominated by surficial deposits; however, exposed bedrock pavement, sinks, crevices and caves are common and include the world famous Narcisse snake dens (McRitchie and Monson, 2000). Figure 2.2 shows limestone cliffs and limestone tabletop features (flat fragments of limestone rock approximately 1 m high and a few meters wide that sit on top of the bedrock) on Manitoba's alvars. The exposed bedrock that characterizes Manitoba's alvars is similar to that found on other alvars in North America and Europe, which have limestone from the Ordovician, Silurian or Devonian periods (Regnell 1948; Brownell and Riley 2000). The soils of the southern Interlake region is Brunisolic (imperfectly-drained mineral soils) including; Dark Chernozem and Dark Grey Chernozem (Weir 1983). These soils are black- grey in colour and are formed from the accumulation of lime carbonate, leached clay and organic matter (Mills 1984). Soils on the Manitoba alvars include loam, sandy loam and silty loam (Manitoba Alvar Initiative 2012).

2.3 Climate

Climate plays an important role in determining vegetation composition and dynamics and is particularly important on alvars due to thin soils (Krahulec *et al.* 1986). While all alvars occur in a temperate climate zone, the alvars in Manitoba experience some of the harshest conditions because of their more northerly latitude and continental position (Blair 1996). The highly variable and potentially harsh climatic conditions in the province (Blair 1996) can affect alvar vegetation through disturbances such as drought, flooding, frost heaving and wind erosion. In contrast, the alvars in eastern North America are further south and close to the Great Lakes. This region experiences a more moderated climate with less extremes and longer growing seasons. Despite being at about the same latitude as Manitoba, the alvars in Europe have a warmer and drier climate due to their proximity to the Baltic Sea and orographic effects (mountain ranges causing air to rise) from the mainland (Sjörs 1965). It is only the alvars in the Northwest Territories that experience similar temperature extremes as Manitoba.

Figure 2.3 shows a summary of the climatic normals of Fisher Branch, which is centrally located in the study area. The Interlake region receives an average of 515.2mm of precipitation per year with from 14.5mm-87.9mm monthly (Environment Canada 2015a). On average, 25% of the yearly precipitation is snow (Environment Canada 2015b). The mean daily temperature ranges from -14.4 to 18.9 °C. The coldest minimum daily temperatures occur in January with an average of -22.7°C. The warmest daily maximum temperatures occur in July and August varying between means of 24.8-25.5 °C (Environment Canada 2015a). Based on a period from 1929-1988, the frost free period (number of days between last spring frost and first fall frost) in the Interlake region ranged from 75-115 days/year. Growing degree days >5°C (a measure of useful heat for the growth of plants; GDD=minimum development temperature/daily mean temperature) ranged from 1400-1600 (Manitoba Agriculture 2015): conditions that characterize this area as a sub-humid low-boreal ecoclimate (Scott 1996).

In comparison to other alvar regions, Manitoba (Environment Canada 2015a) receives less annual precipitation than alvars in Europe and eastern Canada (Table 2.1). The Northwest Territories experiences drier conditions than the alvars in the rest of Canada and less precipitation in the winter months (Environment Canada 2015g). The mean daily high temperatures in summer on alvars in Europe are a few degrees cooler than those in Manitoba but the mean low winter temperatures are 11-18°C higher in Europe (Table 2.1). Compared to Manitoba, the Great Lakes alvar region experiences relatively equivalent or somewhat warmer summer temperatures with warmer winters by 5-15°C (Table 2.1). The Northwest Territories experiences cooler summer temperatures and colder winters; however there is only a slight difference in average temperatures (Environment Canada 2015g). Along with different edaphic factors, these climatic trends could contribute to the observed differences in vegetation composition between alvars by geographic location (as discussed in Chapter 1).

2.4 Alvar Vegetation in Manitoba

The study area in the southern Interlake is located in the aspen parkland and boreal plains ecozone in the Interlake plain ecoregion (Smith *et al.* 1998). The boreal zone extends north and east of the study area. Aspen parkland, marshlands and prairie vegetation zones extend south and west (Scott 1996). The plant species found in North American alvars are often associated with prairie and boreal ecosystems, but the specific species assemblages (i.e. plant communities) that characterise alvar habitats are geographically and floristically distinct because they include a combination of these floristic elements. The floristic assemblage of alvars in Manitoba's Interlake Region contains a number of provincially, nationally and globally rare species. Although Manitoba lacks the endemic species found on the Great Lakes alvars, this region has its own unique complement of rare species including the ferns *Pellaea gastonyi* and *Pellaea glabella* subsp. *occidentalis* and the moss *Grimmia teretinervis* (Manitoba Alvar Initiative 2012). In Manitoba, these species are restricted to regions with limestone features, including limestone cliffs and tabletops (Friesen and Murray 2015), and do not fit into either boreal or prairie plant assemblages.

The Manitoba Alvar Initiative undertook a preliminary classification of alvar vegetation in 2012 (Manitoba Alvar Initiative 2012). In their report, 61 potential alvar sites (= locations) were surveyed, with plant communities characteristic of alvars confirmed at 28 of these locations. Communities were characterized as savanna, shrubland or grassland based on their physiognomy. These broad groups were then further divided into 10 vegetation types (Grassland, Prairie Shrubland, Boreal Shrubland, Prairie/Boreal Intermediate Shrubland, Boulder/Exposed Ridge Shrubland, Bur Oak Savannah, White Spruce Savannah, Jack Pine Savannah, Wetland, Inland Cliff) based on a qualitative assessment of species-habitat relationships (Table 2.2). For example, savannas were defined as treed areas having between 10-25% tree cover whereas grasslands had less than 10% tree cover but frequently lacked any tree cover. Further subdivisions were made on the basis of the mixture of boreal and prairie species, physiognomic composition and soil depth. However, the Manitoba Alvar Initiative (2012) study represents only a “*first approximation of alvar types*", and their report recommends that a “*quantitative data-based classification scheme be developed to refine the conservation status of alvar types, establish site-condition metrics, recommend compatible land-management activities, and advance conservation activities*”.

2.5 Human Settlement and Disturbance History

Manitoba was initially settled by hunters and gatherers from the south and west following the recession of the Laurentide Ice Sheet (Nicholson 1996). Prior to European settlement, Manitoba was occupied by the Assiniboine, Cree and Ojibway, with Sioux, Mandan, Gros Ventre, and Iroquois present on occasion (Nicholson 1996). The Interlake area was frequently used as a “natural highway” due to its proximity to water (Mills 1984; Nicholson 1996). These cultures were largely dependent on bison but plant resources were also important (Nicholson 1996). However, little is known about the effect these cultures had on the vegetation of the area.

European colonization began in 1812 in the Red River Valley and was initially dominated by fur traders. Through large land claims, the fur trade initially restricted the development of land in Manitoba (Kaye 1996). When Manitoba became part of Canada in 1870, immigration increased (Nicholson 1996) and impact from agricultural settlement increased respectively (Kaye 1996). This development was focused along the Red and Assiniboine Rivers with strip farms and domestic animals (Kaye 1996). After this period, settlements radiated away from the Red River Valley. Towns in the Interlake region remain small to this date and the area is predominantly used for agriculture and mining (Manitoba Alvar Initiative 2012).

The rocky nature and poor soil quality of the Interlake region made this area undesirable for crops. However, the more recent mechanization, diversification and intensification of agriculture in Manitoba has led to increased habitat loss and additional strain on the natural environment (Everitt 1996) including demand on these poor quality areas. Table 2.3 summarizes the 1971 and 1976 Statistics Canada censuses on farm uses in the study area (Fisher, Bifrost and Armstrong municipalities) (Weir 1983). These surveys showed that livestock farming is more prevalent than crop agriculture within the study area, likely due to poor soil conditions and a rocky landscape. Although crop farms are infrequent (Weir 1983), a wide variety of crops are grown in the study region, including canola and alfalfa (P. Catling, Pers. Obs. 2014) with smaller amounts of wheat, barley oats and rye (Carlyle 1996). Beef cattle farms are often located on the poorest quality farmlands (Carlyle 1996) such as areas that were too rocky to produce crops, as is the case with alvars.

The majority of alvar areas (76%) within the Interlake Region of Manitoba are currently grazed or have been grazed previously (Manitoba Alvar Initiative 2012). Currently, alvars in Manitoba are under public and private ownership with two-thirds of the alvars occurring on crown lands that are leased for grazing or remain vacant. The crown land leases on alvar study sites ranged from zero to 37 years (Allen Kokolski, Pers. Comm. 2016). All of these leased locations are currently grazed and it is assumed that they have been grazed for the duration of the lease (P.K. Catling, Pers. Obs. 2014). Some sites are heavily grazed with the primary grazers being cattle, but horses, bison and deer are also present (Manitoba Alvar Initiative 2012). Stocking rates for the alvars on leased land are not monitored or recorded and intensity of grazing is unknown. An exception to this is three alvars sites located on the Sylvan Community Pasture that was established in 1967 (Barry Ross, Pers. Comm. 2016). Traditionally, the entire Sylvan Community Pasture has been stocked with approximately 600 cattle occupying each 751 hectare field, a total of 5793 cattle (AAFC 2012). Suplementary feeding is common practice on the alvars in Mantioba, suggesting that stocking rates are not based on the productivity of the ecosystem and are likely higher than the ecosystems capacity.

The Silurian and Ordovician rocks found in the southern Interlake contribute to Manitoba's mineral industry with silica sand, dolomitic limestone for building, dolomite and high calcium limestone for cement (Corkery 1996). It is assumed that the mining of the Interlake region started before 1989 since two cement companies (Inland Cement Ltd. and Canada Cement Lafarge Ltd.) operated near Winnipeg and used limestone at that time (Young 1996). High-calcium lime, high-magnesium lime (Young 1996), aggregate resources (sand, gravel and crushed rock), magnesium metals and building stone are also produced in Manitoba from limestone and dolostone rock (Young 1992). These materials may have historically been mined from the study area. Twenty-six percent (1026 Hectares) of Manitoba's known alvar sites are currently under mining claim or quarry lease and recent limestone and dolostone extraction has taken place adjacent or within a few of the alvar sites (Manitoba Alvar Initiative 2012). Given such anthropogenic threats to these rare and unique plant communities, a landscape management plan that includes a system of protected alvar habitats in Manitoba is long overdue.

2.6 Aims and Objectives

Alvar habitats have only recently been recognized in the Manitoba by the Nature Conservancy of Canada and Manitoba Conservation, with both organizations emphasizing the need to acquire further knowledge on the extent, ecological health, and biological attributes of these ecosystems in the face of threats posed by overgrazing, quarrying, and mining (Manitoba Alvar Initiative 2012). The preservation of natural resources is an important goal of many conservation focused organizations. Focus is generally on species level conservation; however, habitats that support rare species (or unique species assemblages) are gaining increased attention. In 2015, Manitoba became the first province in Canada to list alvar ecosystems as endangered. This ecosystem is now protected under the *Endangered Species and Ecosystems Act* (Manitoba Conservation 2015). With continually growing anthropogenic pressures, there is an increasing demand to understanding the diversity, ecology and geographic extent of these natural communities in order to prioritize areas for conservation and to make informed management decisions. As a contribution to this goal, this study provides the first comprehensive botanical survey and classification of alvar plant communities in Manitoba based on a quantitative assessment of plant species abundance and diversity. This study also determines the edaphic conditions that regulate vegetation community composition within this ecosystem. Based on this information, organizations such as Manitoba Conservation and the Nature Conservancy of Canada will be able to identify areas of conservation concern and develop appropriate land management strategies. An additional goal is to set permanently marked plots for future long-term studies on Manitoba alvars. Overall, my research will provide information that is critical to the protection and management of Manitoba Interlake alvars, as part of a larger nation-wide system of protected alvar sites (Reschke *et al.* 1999, Brownell and Riley 2000, Cayouette *et al.* 2010; Manitoba Alvar Initiative 2012).

Chapter 3 provides the classification of alvar vegetation, using quantitative multivariate methods. Vegetation communities are described using numerical methods (classification and ordination) based on life form abundance (trees, shrubs, graminoids, forbs, etc), species abundance, vegetation affinity (boreal, prairie or generalist) and the proportion of introduced species. In addition, numerical methods will determine what environmental conditions of alvars in Manitoba differ between vegetation communities (as described by the quantitative classification system). Chapter 4 demonstrates the impact of how grazing influences vegetation in terms of vegetation cover, species diversity, species composition and the presence of introduced versus native species. Within this chapter all various activities associated with grazing (off-road vehicle use, supplemental hay feeding, etc.) that are expected to increase the presence of invasive species and cause damage the alvar are discussed. Chapter 5 provides a summary of Manitoba’s alvar vegetation and places Manitoba alvars into a global context.

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Table 2.1: Estimated climatic normals for alvars using the closest weather station with complete data. Extreme maximum and extreme minimum temperatures are the highest and lowest temperatures recorded at that weather station between 1981 to 2010.

Continent	Alvar Location	Weather Station	Precipitation (mm/year)	Mean Daily High Temp (°C) July	Mean Daily Low Temp (°C) January	Extreme Max Temp (°C)	Extreme Min Temp (°C)
Europe*	Russia	St. Petersburg, Russia	572	22.0	-11.0	--	--
	Sweden	Stockholm, Sweden	538	21.9	-5.0	--	--
	Estonia	Helsinki, Finland**	693	22.0	-9.0	--	--
	Finland	Turku, Finland	661	22.0	-9.0	--	--
North America †	Bruce Peninsula, Ontario	Owen Sound	1114.5	24.8	-9.0	35.0	-34.0
	Montreal, Quebec	Pierre Elliot Trudeau Airport	1000.4	26.3	-14.0	37.6	-37.8
	Ottawa, Ontario	MacDonald Cartier Airport	943.6	26.5	-14.8	37.8	-36.1
	Pelee Island, Ontario	Kingsville	900.7	26.8	-7.1	37.5	-29.0
	Manitoba	Fisher Branch	515.2	25.5	-22.7	39.0	-45.0
	Northwest Territories	Hay River	336.4	21.1	-26.2	36.7	-48.3

*European climate data from ClimaTemps (2015a-d)

** Helsinki, Finland was used to estimate temperatures in the adjacent Estonian alvars due to incomplete climatic data for this region

† North American data from Environment Canada (2015 a-g) showing 1981 to 2010 Canadian Climate Normals

Table 2.2: Alvar communities in Manitoba recognized by the Manitoba Alvar Initiative (2012).

Alvar Types	Subtypes	Characteristics	Dominant Species
Alvar Wetland	N/A	dominant cover by sedges, rushes and spike rushes, ~5 cm of soil	*Carex* spp., *Juncus* spp., *Eleocharis* spp. and *Deschampsia ccaespitosa*
Alvar Grassland	N/A	dominant graminoid cover, trees absent, soil depth 5-10 cm	*Danthonia spicata, Bromus porteri, Elymus trachycaulus, Koeleria macrantha* and *Poa* spp.
Alvar Shrubland	Prairie	dominant shrub cover, soil <5 cm to absent	*Juniperus horizontalis, Arctostaphylos uva-ursi, Corylus cornuta, Festuca hallii, Andropogon gerardii* and *Danthonia spicata*
	Boreal	dominant shrub cover, soil <5 cm to absent	*Juniperus communis, Viburnum rafinquesianum, Juniperus horizontalis, Arctostaphylos uva-ursi* and *Danthonia spicata*
	Boreal/Prairie	dominant shrub cover, soil <5 cm to absent	mix of boreal and prairie species, but more boreal
	Boulder/ Exposed Ridge	dominant shrub cover, limestone boulders or outcrops	mix of boreal or prairie species with species unique to limestone features (*Pellaea gastonyi, Pellaea glabella* and *Grimmia* moss)
Alvar Savanna	Jack Pine	treed but <60% cover, soil thin except in cracks	*Pinus banksiana* and dominant boreal shrubland species
	Bur Oak	treed but <60% cover, soil thin but deeper than other types	*Quercus macrocarpa* and dominant prairie shrubland species
	White Spruce	treed but <60% cover, soil thin except in cracks	*Picea glauca, Populus tremuloides* and dominant prairie shrubland species

Table 2.3: Summary of the 1971 and 1976 Statistics Canada censuses on farm uses in Interlake region of Manitoba (Fisher and Armstrong municipalities) (Weir 1983).

	Township		
	Fisher	**Armstrong**	**Bifrost**
Cattle per square km	10 – 25	20 – 25	10 – 25
Cattle per farm	41 – 60	61 – 80	21 – 60
Land in crops (%)	35 – 44	> 20	35 – 64
Cattle farms as % of all farms	26 – 35	66 – 85	16 – 25
Dairy farms as % of all farms	> 2 – 5	11 – 20	2 – 15
Small grains farms as % of all farms	26 – 35	> 7	7 – 35
Wheat farms as % of all farms	2 – 10	> 2	2 – 10

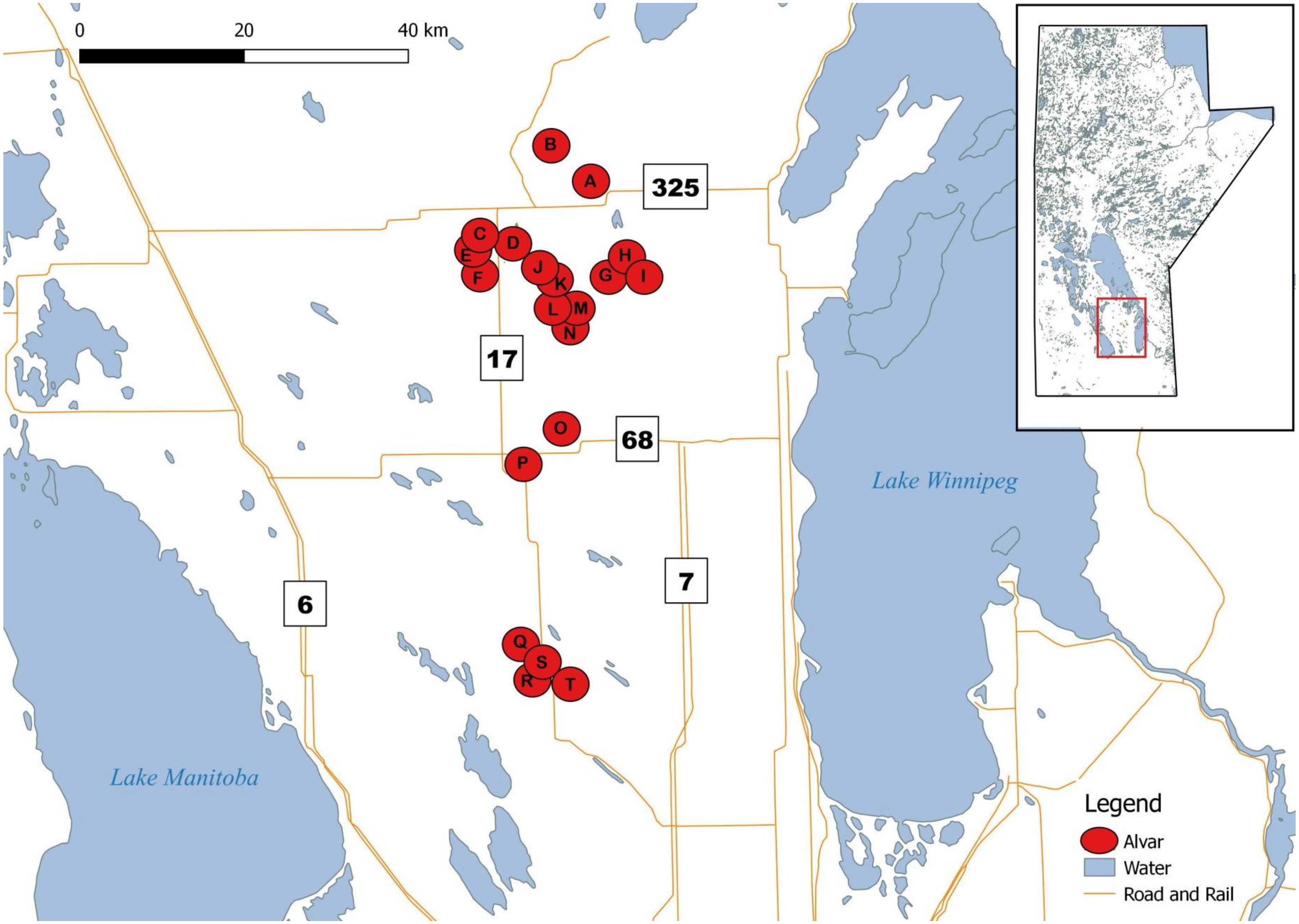

Figure 2.1: Location of twenty known alvar sites (letters A-T) on crown land in Manitoba as recognized by the Manitoba Alvar Initiative (2012). Exact site and plot locations are on file with the Nature Conservancy of Canada and Manitoba Conservation.

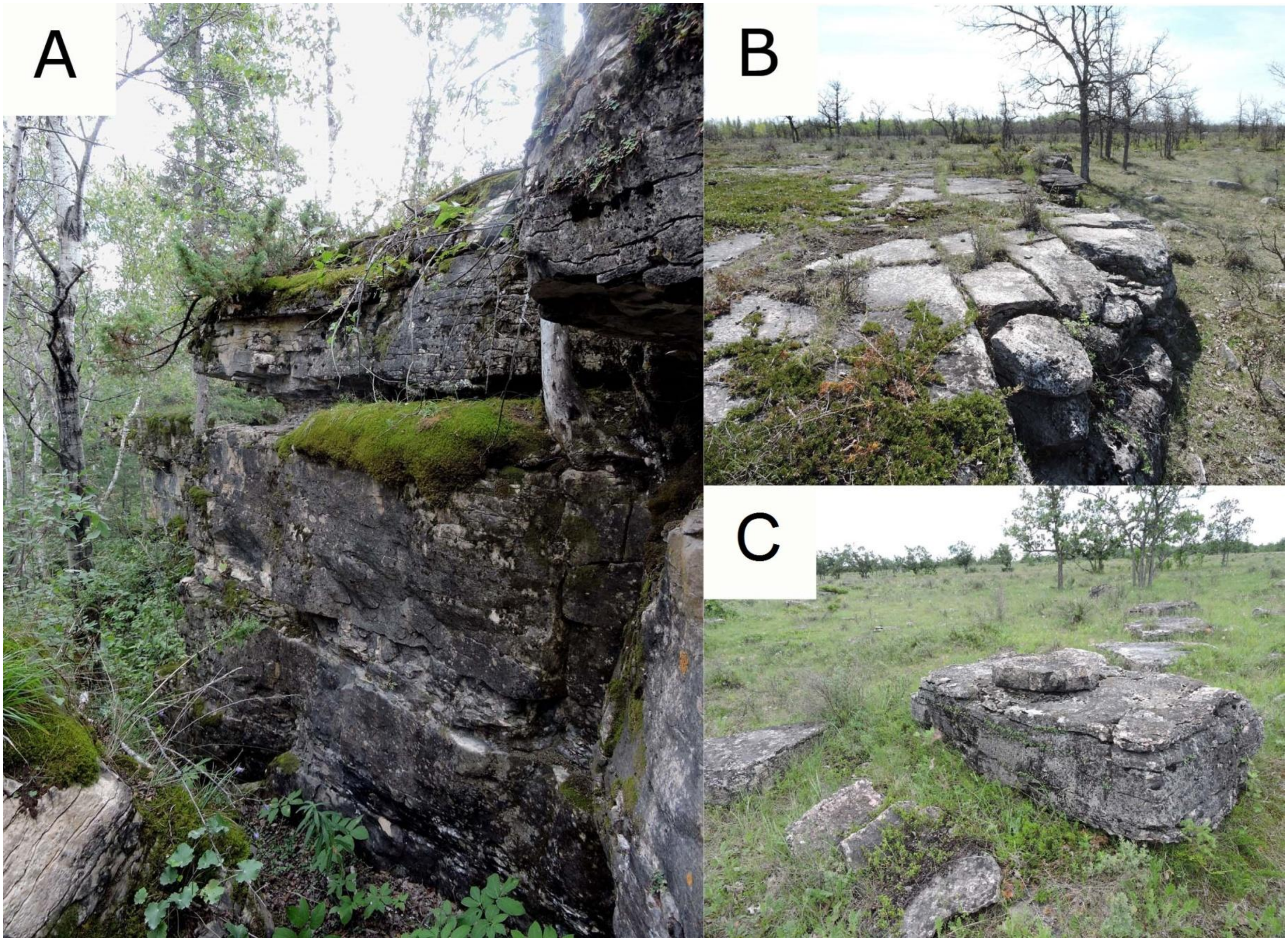

Figure 2.2: Alvar features include A) limestone cliffs, B) limestone ridges and C) limestone formations that look like tabletops.

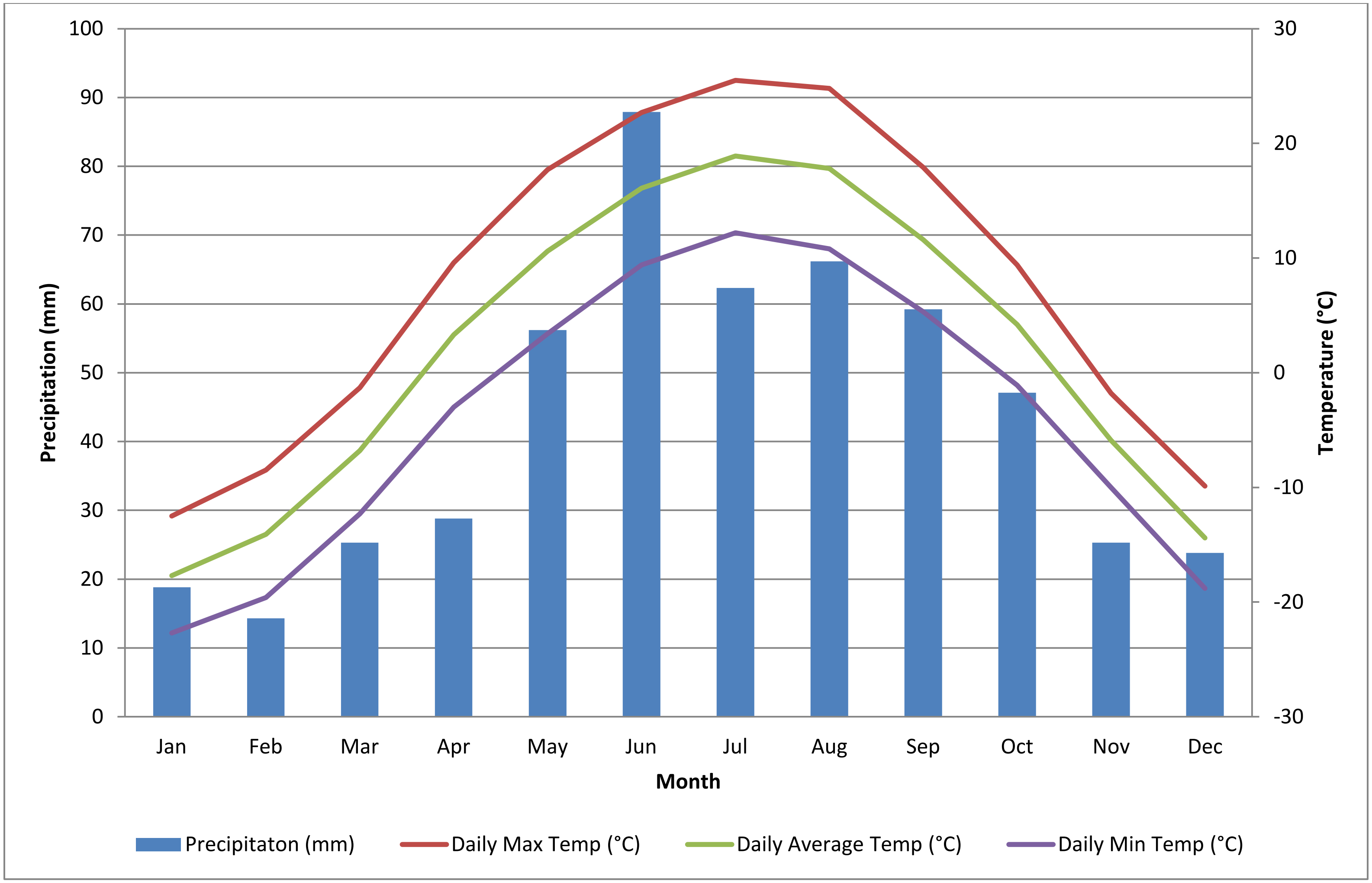

Figure 2.3: Monthly climatic normals for Fisher Branch in the southern Interlake region of Manitoba from 1981 to 2010 (Environment Canada 2015a).

Chapter 3: Alvar Vegetation in Manitoba: Types and Environmental Gradients

3.1 Vegetation Classification and Plant Ecology

3.1.1 History of Vegetation Classification

> "*For the human race, classification is a natural and inherent, intuitive process; to create some semblance of order from an otherwise disorderly matrix by the pigeon holing and categorization of the matrix entities.*" Shimwell (1971)

The aim of vegetation classification is to group similar communities such that vegetation patterns can be described simply. Despite the inherent nature of humanity to classify what they see in nature, the methods of vegetation classification are very diverse. Initially, communities were defined by their dominant species by adding the suffix '-etum' after the generic name (Shimwell 1971). The use of physiognomic (structural) classification into broader descriptions, such as forest, woodland, scrub, savanna, grassland, marsh, bog, desert, and tundra was initiated by Curtis (1959) and Fosberg (1967). Curtis (1959) defined plant communities by saying:

> "*The local assemblages of plants are called plant communities. They may differ from one another in the kinds of species they contain, in the relative amounts of the same species, or in both ways*." Curtis (1959)

The work of Curtis (1950), which established geographical limits, species compositions and environmental relationships for vegetation communities of Wisconsin, was a vital contribution to the discipline of plant ecology and formed the foundation for studies in this field. The common approaches to vegetation classification are: 1) physiognomic or structural, 2) environmental, 3) many factor or landscape, 4) biotic areas, 5) segments of community gradients, 6) dominant species 7) vegetation dynamics, 8) life form divisions, 9) strata combinations, 10) forest undergrowth types, 11) numerical comparisons and 12) floristic units of the Braun-Blanquet system (Whittaker 1978). After 1960, the use of numerical classification systems (based on cluster analysis and ordination) to classify plant communities, became increasingly common (Mucina 1997).

This study aims to consider environmental conditions, physiognomy (life form, e.g., shrub, tree, etc.), dominant species, indicator species, plant associations and species affinities to vegetation zones, in order to provide a comprehensive classification of the alvars in Manitoba. These aspects of vegetation will be analysed using numerical methods (classification and ordination) (Goodall 1978).

3.1.2 Classification of Alvar Vegetation

Like forests, wetlands and other ecosystems, alvars can be classified into vegetation communities or types. Alvars and the vegetation communities within them have been classified using a wide variety of techniques, including physiognomic structure (Gilman 1995; Manitoba Alvar Initiative 2012), environmental features (Albertson 1950; Krahulec *et al.* 1986), dominant species (Catling 2009a; Manitoba Alvar Initiative 2012) and numerical methods based on vegetation cover (Gilman 1995; Reschke *et al.* 1999). Many studies use a combination of these approaches to describe community types (Gilman 1995; Brownell and Riley 2000; Manitoba Alvar Initiative 2012). On the island of Öland, Sweden, studies using multivariate numerical methods delineated eight vegetation assemblages (Krahulec *et al.* 1986; Bengtsson *et al.* 1988). The first study that used a numerical approach to classifying Canadian alvars using cluster analysis and ordination was Belcher (1992). The author compared vegetation at four sites in Ontario, Canada, and found that alvar vegetation differs by geographic location. Similarly, Catling and Brownell (1999) grouped 57 alvar sites in Ontario using cluster and principal components analysis. They found that these alvars separated into three major groups based on their location in Ontario (Catling and Brownell 1999). Alvar sites in North America have also been classified based on the geographic affinity of the vegetation present (Catling and Brownell 1995; Cayouette *et al.* 2010). These studies found that the alvars in North America have distinct boreal and prairie affinities that differ in proportion based on geographic location (Catling and Brownell 1995; Cayouette *et al.* 2010). Gilman (1995) also used cluster analysis and ordination to quantitatively describe four structural communities (alvar woodland, pavement, meadow and savanna) of alvar vegetation in New York State, U.S.A. finding that within the physiognomic communities, floristic composition differs between mesic and xeric areas. However, Gilman (1995) used different methods for vegetation data collection between the qualitatively recognized physiognomic types (alvar woodland, alvar savannas, alvar meadows and alvar pavement), making data incomparable to each other by quantitative methods. The most comprehensive studies of the Great Lakes Alvars (Ontario, Michigan and New York State) are by Brownell and Riley (2000) and Reschke *et al.* (1999). Reschke *et al.* (1999) used a combination of observation points, sample plots (10 X 10m) and species lists by site. In order to delineate and describe vegetation groups, Reschke *et al.* (1999) used cluster analysis and ordination, resulting in thirteen vegetation communities. See Appendix 2 for an example of floristic community descriptions from the Great Lakes region.

3.1.3 Classification of Vegetation and the Environment

In order to understand the complex nature of vegetation- environmental relationships, studies in plant ecology attempt to include many aspects of vegetation and environment. Life form characteristics, competitive strategies, reproductive strategies and many other features combine with soil characteristics, moisture availability, disturbance, and so forth, to influence a plants ability to colonize an area (Spalding 1909; Gleason 1910; Clements 1916; Bray and Curtis 1957; Curtis 1959; Wallace 1858; Whittaker 1967; Pickett and White 1985). The idea of environment contributing to vegetation patterns within ecosystems was well described by Spalding (1909); "*The establishment of a plant in the place where it occupies is conditioned quite as much by the influence of other plants as by that of physical environment*". This stresses the importance of both competition (plant-plant interactions) and plant-environment interactions. The great influence of environment on plant communities was further supported by many additional studies (Gleason 1910; Clements 1916; Bray and Curtis 1957; Whittaker 1967). Given the strong relationship between vegetation and environment, it is vital in community classification to use a system that is descriptive of both characteristic environmental conditions and vegetation assemblages, and their interaction.

3.1.4 Disturbance and Vegetation Composition

Disturbance also plays an important role in determining vegetation composition and patterns (Clements 1916; Pickett and White 1985), but the impact of disturbance varies greatly and may be difficult to quantify. The effect of a disturbance varies based on type, size, frequency, intensity (Johnson and Miyanishi 2007), and on interactions with other disturbance or environmental factors (Hartnett *et al.* 1996). For example, the type of grazer will affect the impact of grazing on floristic composition and spatial heterogeneity, due to selective grazing and differential species preferences (Hartnett *et al.* 1996). Plant responses to grazing also vary with fire regime (Hartnett *et al.* 1996). Intensity of disturbance also influences its effects and studies on alvars in Europe have shown that intensity determines the effects of grazing. A moderate grazing intensity can reduce shrub encroachment and have a positive effect on species richness (Partel *et al.* 1998; Rosén and Bakker 2005) but overgrazing may result in the introduction of exotic species, fragmentation of cryptogamic species, reduction of flowering and fruiting in vascular species, soil erosion, and selective removal of certain species (Rosén 1982). The challenge is to determine how these various factors (environment and disturbance) affect vegetation composition patterns, since the effects can interact and vary significantly through a suite of factors (intensity, type, interaction with other disturbances, and so forth). Multi- factor classification systems are more complex, requiring a great deal of information and analyses, but are more comprehensive than studies that rely solely on floristic composition (Grossman *et al.* 1998).

3.1.5 Significance and Objectives

Rocky barren environments, such as alvars, are of particular ecological interest since they are considered harsh environments for the establishment of plants. As such, they can provide insights into the effects of disturbance and competition in structuring vegetation assemblages (Gilman 1995). Plants growing on alvars experience spatial and temporal variability in environmental conditions, making them ideal candidates for studying how these conditions affect floristic composition (Belcher 1992; Gilman 1995). Manitoba became the first province in Canada to list alvar ecosystems as endangered and to protect them under the *Endangered Species and Ecosystems Act* (Manitoba Conservation 2015). The Manitoba Alvar Initiative (2012) has stressed the importance of the need for a complete botanical survey and quantitative classification system. The objective of this chapter is to produce a comprehensive quantitative classification system for the vegetation communities within alvars in Manitoba based on floristic composition, and to describe these communities in terms of species composition, plant physiognomy, characteristic indicator species, diversity, boreal/prairie affinity, edaphics and disturbance (grazing). This chapter will determine the edaphic conditions that regulate vegetation composition on alvars and establish various vegetation community types.

3.2 Methods

3.2.1 Field Sampling/Data Collection

Context

The Manitoba Alvar Initiative (2012) used qualitative surveys to define ten alvar community types at 28 locations (Table 2.2) in the Interlake Region of Manitoba based on physiognomic structure and dominant species. Using the broad framework established by the Manitoba Alvar Initiative (2012) as a first approximation, the robustness of the current qualitative classification of Manitoba alvars was evaluated using quantitative methods. In 2014 and 2015, quantitative vegetation and environmental data were collected from 103 plots established at 20 alvar sites. Eight other alvar locations were not surveyed because they are privately owned. Note that for conservation reasons, site and plot coordinates are not included here but are on file at the Nature Conservancy of Canada and Manitoba Conservation.

Vegetation Sampling

Stratified random sampling (Cochran 1977) was used to divide sites into sections (strata) based on the qualitative descriptions of alvar communities from the Manitoba Alvar Initiative (2012). In order to examine small-scale variation necessary for classifying alvar vegetation assemblages, plots were placed at random within these strata. The number of plots per strata (1-3) followed proportional sampling (Cochran 1977) where the number of plots within each strata is proportional to the size of the strata. All plots were precisely located with GPS, permanently marked with metal tags, and photographed. A plot size of 10 X 10 m was selected to ensure that vegetation composition of grassland, shrubland and savanna could be accurately captured, and the size was kept consistent for analysis purposes (Reschke *et al.* 1999). This plot size is consistent with studies of alvar vegetation in the Great Lake region and was used so future research to compare these regions. Each plot was divided into four 5 X 5 m subplots (A-D) and cover was estimated separately in each of the four subplots (Figure 3.1).

Within each subplot, all vascular plant species were recorded and their abundance estimated using a ten-point cover scale: 1=trace, 2= 0.1–<1%, 3= 1–<2%, 4= 2–<5%, 5= 5–<10%, 6= 10–<25%, 7= 25–<50%, 8= 50–<75%, 9= 75–<95%, 10= >95% (Grossman *et al.* 1998; Manitoba Alvar Initiative 2012). The median of each cover class was used to average data over the entire 10 X 10 m plot for analysis. Eleven easily identified and common non-vascular plant genera (*Abietinum, Barbula, Brachythecium, Bryum, Ceratodon, Dicranum, Ditrichum, Hedwigia,* *Grimmia, Tortella* and *Tortula*) were also included since it was possible to accurately quantify these in the field. Three lichen forms (crustose, foliose and fruitose) and the terrestrial algae, *Nostoc,* were also included as cover classes in the analyses. Rank scales for vegetation cover have frequently been used to survey alvar and limestone barren vegetation (Reschke *et al.* 1999; Brownell and Riley 2000; Willis 2011). Vascular plants were identified using *Flora of Manitoba* (Scoggan 1957), *Field Manual of Michigan Flora* (Voss and Reznicek 2012), *Shrubs of Ontario* (Soper 1990) and *Flora of North Americ*a (Flora of North America 1993). Moss and liverwort identifications are based on *Moss Flora of the Maritime Provinces* (Ireland 1987) and *Mosses of the Great Lakes Forest* (Crum 1983). Specimens collected as part of this study have been deposited in the University of Manitoba Vascular Plant Herbarium (WIN) and the University of Manitoba Cryptogamic Herbarium (WIN-C).

Due to time constraints, each plot could only be visited once during the 2014 season. As a result, the full complement of plant species that may be present at a particular location was not fully documented. Revisiting these plots in the reverse order in 2015 produced a more complete list of flora for each plot. A reverse order strategy was appropriate since plots surveyed during mid season (early-mid July) would have had a full complement of early and late flowering species. Cover values of previously recorded species were not changed but new species were added. Voucher specimens were collected and identified in order to document the floristic diversity of alvars in Manitoba.

The status (introduced or native) and growth form (perennial or annual; forb, graminoid, shrub or tree) of each species was determined using the USDA PLANTS Database (USDA 2016).

Floristic affinities (boreal, prairie, generalist or introduced) were determined using Löve (1959) and Looman *et al.* (1979). The proportion of the species represented by a generalist category included species with specialized habitat preferences that can be widespread through both boreal and prairie zones, such as wetland species. Also included were species with very restricted habitat preferences, such as *Pellaea gastonyi,* which requires limestone cliffs as habitats and therefore could not be associated with a boreal or prairie affinity due to this specialization. This information allowed for data to be partitioned according to status, form and affinity, providing additional ways to describe alvar communities.

Environmental and Disturbance Variables

The same ten-point cover scale adopted for vegetation studies was used to characterize the abundance of bare rock, leaf litter and bare soil in each plot. The use of percent cover (on the same ranking scale described above) of cow patties and deer pellets provided an estimate of grazing and browsing intensity (Cingolani *et al.* 2003). Plots were also ranked on a ten-point moisture index scale (1 - very xeric to 10 – mesic) based on topography. Lower areas where water accumulates were ranked as wetter than higher regions that could not accumulate water.

The thinness of alvar soils over bedrock allowed for only one zone of soil sampling. Soil depth was measured at the centre of each 5 X 5 m subplot and averaged for the plot. Soil samples were taken at opposite corners (B and D; Figure 3.1) of the plot and combined in the field to approximately fill an 18X 15cm bag (roughly 500-1000g). Soils were analysed by Farmers Edge Laboratories, Winnipeg, Manitoba for Nitrate-Nitrogen (NO3-N mg/kg), Bicarbonate-Extractable Phosphate-Phosphorus (PO4-P mg/kg), Exchangeable Potassium (K mg/kg), pH and electrical conductivity (EC mS/cm). Nitrate-Nitrogen was extracted with 30ml 0.01M CaCl2 added to 15g of soil in a vessel. A reciprocating shaker was used to agitate for 30 minutes and then the solution was filtered through filter paper. Automated colorimetry was used to measure Nitrate-Nitrogen after reduction by hydrazine and complexing with n-(1-naphthyl) ethyenediamine dihydrochloride (Carter 1993). Bicarbonate-Extractable Phosphate-Phosphorus used 2.5 grams of soil to which 50ml of 0.5M sodium bicarbonate was added. This solution was agitated for 30 minutes and filtered through a paper filter. Phosphate-Phosphorus was measured with automated colorimetry after a reaction with ascorbic acid and complexation with ammonium molybdate (Carter and Gregorich 2008). Exchangeable potassium used 5g of soil with 50ml of 1.0M ammonium acetate which was agitated for 30 minutes and filtered through filter paper. Potassium was measured by ICP-OES (inductively-coupled plasma optical emission spectrometry) (Warncke and Brown 1998). Analyses for N, P and exchangeable K are reported in mg/kg. For pH and electrical conductivity 25 g of soil was weighed and extracted by 50ml of deionized water. After 30 minutes of agitation, electrochemical methods were used to measure pH (in pH units) and electrical conductivity (in deciSiemens per meter or dS/m) (Carter and Gregorich 2008). Four plots were selected for duplicate samples (roughly 500-1000g) that were sent to Farmers Edge Laboratories to ensure quality control. Results from these duplicate samples were consistent with samples from their corresponding plot.

3.2.2 Data Analysis

R Packages and Data Transformations

Multivariate statistical analyses were used to classify alvar vegetation in order to examine floristic trends and to summarize vegetation-environmental relationships of alvar habitats (Legendre and Legendre 2012). All statistical analyses were run in R (R Core Team 2013) using the following packages: vegan (Oksanen et. al. 2013); ade4 (Thioulouse *et al.* 1997); gclus (Kaufman and Rousseeuw 1990); and labdsv (Roberts 2015). Vegetation cover data (mean cover in plots) was log-transformed ($y'=\log_2(y)+1$ except if $y=0$, then $y'=0$) in R to account for the high number of zeros in the data (Anderson *et al.* 2006). The environmental variables soil depth, pH and soil moisture were not log transformed. The nine other variables including: soil conditions (Nitrate-Nitrogen (NO3-N); Bicarbonate-Extractable Phosphate-Phosphorus (PO4-P); Exchangeable Potassium (K) and electrical conductivity), disturbance intensity (grazing and browsing) and environmental conditions (percent cover of bare rock, bare soil and litter), were log transformed ($y'=\log_{10}(y)$) before importing into R. Since exploratory analyses showed little variation in pH between plots, it was not included as a variable as it did not have an evident influence on vegetation trends.

Community classification

This study used a combination of ordination and classification to provide maximal information (after Anderson 1965). A sum of squares agglomerative cluster analysis (Ward 1963) using a chord distance matrix (Orlóci 1967) was used to classify plots into vegetation assemblages (after Kenkel 1987). The cut-off level in cluster analysis is subjective; however, with the consideration of needing a manageable number of vegetation types and from a familiarity with the ecosystem, the eight-group level was considered most logical. This number of vegetation types was supported by various distance matrixes (chord, Euclidean and Jaccard) revealing consistent results showing that the classification is robust at this level.

Indicator species analysis was used on the eight cluster groups in order to reveal diagnostic species for the eight alvar vegetation types, and to quantify how characteristic these species are for each type. This analysis calculates indicator values based on fidelity (relative frequency) and relative abundance (mean abundance in that group relative to mean abundance in all groups) so that a species that is only found in one community and at a high abundance is highly indicative for that community (Dufrene and Legendre 1997). Indicator values ranged from 0-1, with higher values indicating that a species is strongly associated with that community and therefore diagnostic of that type. This methodology was used to determine diagnostic species so that vegetation community types can be described based on dominant species (shown in raw data) as well as diagnostic species that may be unique to a type but not the dominant cover.

Communities were also compared based on affinity and diversity. The proportion of species richness and species abundance (% cover) was determined for life form and affinity (boreal, prairie, generalist and introduced) groups within each vegetation community. Species richness (S), Shannon diversity index (H) and effective richness (e^H) were calculated per plot (10 X 10 m) and averaged for each vegetation type (Legendre and Legendre 2012). Species richness is the total number of species per plot. Shannon diversity index is a measure of entropy that incorporates both richness and proportional abundance to evaluate variance in the distribution of species frequencies (Rényi 1961). Compared to other diversity indices, rare species are given relatively high importance in the Shannon diversity index (Rényi 1961). Shannon diversity index (H) is calculated by the equation $H = -\sum_{i=1}^{S} p_i \ln p_i$, where p_i is the proportional abundance a species. Effective species richness (e^H) is a non-linear transformation of the Shannon diversity index with values ranging from 1 to S (Hill 1973b). These methods provided a comparison of diversity between communities.

Ordination

Ordination is used to delineate and summarize trends in vegetation composition (Kenkel 2006). Principal component analysis (PCA; Orlóci 1978) with a covariance matrix was used to obtain a summary of both plots and species in order to summarize floristic trends. This method simplifies a complex data matrix by revealing dominant linear trends in the data that are visualised within Euclidean space on two ordination axes (Kenkel 2006). This methodology allows for a comparison to the group structure from the cluster analysis by how plots ordinate in relation to other vegetation types and within the vegetation types.

Vegetation-Environmental Relationships

A redundancy analysis (RDA: Wolllenberg 1977; Legendre and Legendre 2012) was used to examine the relationships between vegetation (floristic composition) and environmental/disturbance variables including soil conditions (depth, moisture regime, electrical conductivity, pH and the concentration of N, P and K), disturbance intensity (grazing and browsing) and substrate conditions (percent cover of bare rock, bare soil and litter), on vegetation compositions, for the 103 plots. Redundancy analysis is the appropriate model when environmental factors are used to predict floristic composition (Kenkel 2006). RDA was used to determine what proportion of the variation in floristic composition can be explained by environmental variables. The RDA also reveals the relative strength of impact on vegetation composition of each variable in determining vegetation composition. A Monte Carlo permutation test (Legendre and Legendre 2012) was used to determine whether floristic composition was significantly different between plots due to the environmental variables assessed in this study.

Vegetation Model: Life Forms

Correspondence analysis uses a chi-squared matrix to examine the relationships between row and column categories in a contingency table (Hill 1973). In order to examine the relationship between alvar community groups and the physiognomic characteristics of plots, the mean cover of life form groups (lichen, moss, introduced graminoid, introduced perennial, native graminoid, native perennial, shrub and tree) for the eight groups were used to obtain a contingency table that was then used in a correspondence analysis (Hill 1973). This was used to determine if vegetation types had associations with specific life forms. Exploratory analyses indicated very different group relationships between *Juniperus* spp., *Arctostaphylos uva-ursi* and other shrubs. Consequently, these shrubs were separated from a general shrub category that includes all other species. Together, these multivariate analyses provided an objective, statistically based quantitative summary of the plant communities and environment of alvar habitats in the Interlake Region of Manitoba that is consistent across a variety of statistical analyses.

3.3 Results

A total of 231 vascular plant species were encountered in the 103 plots over 20 sites. Of these, 61% were forbs (9% annuals, 52% perennials), 25% graminoids, 13% woody species and 1% ferns. Table 3.1 shows the number of introduced versus native species (according to USDA 2016) for each vegetation form. The number of species per plot ranged from 13 to 69 with a mean of 54. All vascular plant species, including rare/infrequent species, found in plots were included in the analyses. A complete species vascular plant species list, with floristic affinities (Löve 1959; Looman *et al.* 1979) is given in Appendix 3.

3.3.1 Community Classification

Cluster Analysis

The cluster analysis dendrogram for 103 plots is shown in Figure 3.2. Eight vegetation types are recognized. The first dichotomy of the dendrogram separates graminoid dominated alvars (Types I-III) from wooded alvars (dominated by trees or shrubs, Types IV-VIII). Finer-scale groupings within the graminoid dominated cluster are based on a moisture gradient separating vegetation types in wet, moist and dry areas. The graminoid dominated vegetation types are wet graminoid meadow (Type I); moist graminoid meadow (Type II, with one highly graminoid and one increasingly shrubby sub-type) and dry grassland (Type III, with one *Poa pratensis*-*Geum triflorum* dominated sub-type and one *Festuca* spp. sub-type). The second dichotomy within the wooded alvars divides types occupying rocky areas with thin soil (Types IV and V) from wooded types occurring in deeper soil (Types VI-VIII). The vegetation types on thin soil were rocky dwarf shrubland (Type IV) and boreal- bur oak- jack pine- low shrub (Type V, *Arctostaphylos uva-ursi-* coniferous tree and *Juniperus* spp. – *Quercus macrocarpa* sub-types). Wooded vegetation types occurring on deeper soils were bur oak- tall shrub (Type VI); prairie- jack pine- low shrub (Type VII); and spruce savanna- bluestem grassland (Type VIII, with spruce savanna and bluestem grassland sub-types).

Floristics

Table 3.2 summarizes the eight vegetation types in terms of physiognomic composition and diversity with mean values (with standard deviations) for richness per plot, mean Shannon diversity index and mean cover of life form groups (moss, lichen, graminoid, annual, perennial, shrub and tree) per plot. Mean species richness (per plot) by type ranged from 20 to 60 species per vegetation type (Table 3.2). Mean Shannon diversity index (per plot) ranged from 1.55 to 2.55 per vegetation type while effective richness ranged from 4.9 to 13.1 (Table 3.2). Wooded alvars (Types IV-VIII) had higher diversity values than graminoid dominated alvars (Table 3.2). In all vegetation types, native perennials had the highest richness followed by native graminoids (Figure 3.3). The proportion of richness due to woody species (8-17% of species) and introduced perennial forbs (4-11% of species) varied by type (Figure 3.3). Herbaceous annuals were not very diverse or dominant in any type (Figure 3.3) and had low cover in all types (Table 3.2).

Mean herbaceous perennial cover for the eight vegetation types ranged from 6.05% to 33.96% (Table 3.2) showing that this life form group is extensive (Table 3.2) but not the dominant cover in any type. Tree cover ranged from 0% to 13.23% and shrub cover ranged from

2.09 to 57.32% (Table 3.2). Graminoid cover ranged from 14.15% to 82.60% mean cover (Table 3.2). Types I-III have the highest proportion of cover of native graminoids (28-87% proportion of vegetation cover) and the lowest cover of woody species (2-19% proportion of vegetation cover), separating these graminoid alvars from ‘wooded’ alvars (Types IV-VII) (Figure 3.4). Introduced species cover ranged from 4.30% to 21.31% (Figure 3.4). In all types introduced graminoids were more frequent than introduced forbs and these have the highest cover in Types II, III, VI and VII (Figure 3.4). Proportion of cover by introduced species was negligible in Type VIII (Figures 3.4).

The proportions of species with boreal, prairie, generalist or introduced affinities are shown in Figure 3.5. All of the vegetation types had their highest influence from the prairies (Figure 3.5). The proportion of species with boreal, generalist and introduced affinities varies somewhat by vegetation type although the differences are not large (Figure 3.5). For example, Types II-VII all have 20-25% of species with a boreal affinity and between 15-20% of species with a generalist affinity (Figure 3.5). Despite the lack of large differences between vegetation types in proportion of species from various affinities, Figure 3.6 shows that the vegetation types do differ in their proportion of cover by these affinities. The most drastic differences between proportion of richness (Figure 3.5) and cover (Figure 3.6) are evident in Types IV, V and VIII where cover of boreal species dominates the vegetation type but represents a smaller portion of the richness than prairie species.

The graminoid types (I-III) all have high proportion (45-71%) of vegetation cover due to prairie species (Figure 3.6). Within the wooded alvars (Types IV-VIII), Types IV, V and VIII had high proportion of cover by boreal species whereas Types VI and VII had high proportions of prairie species. Introduced species were most abundant (% cover) in Types VI, II and I (Figure 3.6).

Environment and Disturbance

Table 3.3 summarizes the soil conditions (depth, moisture regime, nutrients, pH and electrical conductivity), disturbance intensity (grazing and browsing) and environmental conditions (percent cover of bare rock, bare soil and litter) of the eight vegetation types. All vegetation types had shallow soils and mean soil depth by type ranged from 1.9 to 8.1 cm (Table 3.3). Soil nitrogen content ranged from 19.37 to 152.26 mg/kg while phosphorus content ranged from 8.15 to 29.00 mg/kg. All vegetation types had near neutral pH. Bare rock cover ranged from 0.3% to 14.08% (Table 3.3). Types IV and V had the highest bare rock cover (Table 3.3). Intensity of cattle grazing was highest in Types VI, III and I (Table 3.3). Types VIII, VII and IV experienced the least intense cattle grazing. Browsing intensity was highest in Type VIII with all other groups having low browsing intensity (Table 3.3).

Indicator Species

Indicator species values for characteristic plant species (highest fifteen indicator values for that vegetation type) are shown in Table 3.4. The indicator species of Type I had very high values (close to 1) showing that these species (*Rumex aquaticus, Deschampsia cespitosa, Carex tenera*, etc.) have a high affinity for occurring in that community and are thus very indicative. Conversely, the highest indicator species values for Type V are lower showing that these species (*Juniperus communis, Symphoricarpos albus*, crustose lichens, etc.) are not as restricted to this community and therefore less indicative for distinguishing between types. Types IV to VIII share species with high indicator values (including *Arctostaphylos uva-ursi*, *Anemone cylindrica, Cerastium arvense, Symphoricarpos albus, Heuchera richardsonii* and *Quercus marcocarpa*) showing that in wooded alvars the species with highest indicator values may be indicative of multiple vegetation types. Most of these are shared indicator species are with Type V. For example, the moss genus *Tortella* is within the top five highest indicator species for both Types IV and V but is not indicative for other wooded types (Table 3.4). *Quercus macrocarpa* also occurs as an indicator of multiple types being within the top five highest indicator species of Type VI and within the top fifteen for Type V but has low indicator values for the other wooded types (Table 3.4).

Descriptions of Vegetation Community Types

The following provides a summary of the vegetation and environmental conditions of the eight vegetation types and incorporates information from the cluster analysis (Figure 3.2), indicator species analyses (Table 3.4) and means of raw data (Tables 3.3 ad 3.4) to describe vegetation assemblages. More detail is given in Appendix 4.

(I) Wet graminoid meadow (n=5)

Wet graminoid meadow (Figure 3.7) occurs in relatively small patches within lower sections of the alvar topography and is the wettest alvar vegetation type. Nutrient concentration (N, P) is the highest of all vegetation types and also reflected as a high electrical conductivity value (Table 3.3). Cover of bare rock and bare soil is low compared to other vegetation types (Table 3.3). Although soil depth is moderate (4.9 cm) there is a thick bryophyte layer (1-5 cm deep, 23.97% mean cover), consisting mainly of *Campylium stellatum, Drepanocladus sordidus, Drepanocladus polygamus* and *Ptychostomum pseudotriquetrum*, occurring over the soil. This moss layer assists in retaining moisture for longer periods of time. This is a very open community with no trees and very low shrub cover (2% mean cover, freq = 60% for most common species). When present, shrubs are predominately *Salix bebbiana, Salix pediolaris*, *Spiraea alba* and *Dasiphora fruiticosa*. Herbaceous forbs are uncommon (6.05% mean cover), but hydrophilic species such as *Mentha arvense*, *Rumex aquaticus* and *Symphyotrichum lanceolatum* occur here but are absent or uncommon in other types. This vegetation type is dominated by graminoids (Table 3.2), which had a mean cover of 82.60%. The most abundant species include *Deschampsia cespitosa* (31% mean cover, freq=100%), *Eleocharis compressa* (14.68% mean cover, freq =60%)*, Carex pellita* (10.34% cover, freq= 100%)*, Carex praegracilis* (9.16 % cover, freq = 60%)*, Carex tenera* (1.39% cover, freq = 80%) and *Juncus balticus* (ranged from 0-26.25% cover in plots with a mean of 8.65% cover, freq = 80%). Indicator species analysis (Table 3.4) revealed that these dominant graminoid species are also indicator species for this type. This vegetation type has a highly prairie and generalist affinity in terms of both proportion of richness (Figure 3.5) and proportion of cover (Figure 3.6). This type has a low proportion of cover by both introduced and rare species. Species richness and diversity values are the lowest of all types (Table 3.2). Grazing intensity was relatively high (third highest) in this vegetation type while there was no evidence (pellets) of browsing (Table 3.3).

(II) Moist graminoid meadow (n=13)

The moist graminoid meadow vegetation type (Figure 3.8) occurred in lower patches on the alvar topography or as transitional zones between dry and wet areas. This was not a dominant community at any site. Moist graminoid meadows had the highest cover of bare earth (4.81% mean cover), moderate rock cover and moderate soil depths (Table 3.3). This is an open (no tree cover), graminoid dominated (50.23% mean cover) vegetation type. This vegetation type had the highest proportion of introduced species (Table 3.2), which were predominately graminoids (Figure 3.4), including *Poa pratensis* (9.90% cover, freq= 77%) and *Poa compressa* (7.23% cover, freq=85%). Dominant native graminoids include *Eleocharis compressa* (11.91% cover, freq= 85%), *Deschampsia cespitosa* (8.53% cover, freq= 77%) and *Koeleria macrantha* (3.23% cover, freq = 92%). *Dasiphora fruiticosa* is the dominant shrub (12.62% cover) and occurred in all plots. Dominant forbs are *Geum triflorum* (3.52% cover, freq=85%)*, Potentilla gracilis* (2.67% cover, freq=54%)*, Antennaria howellii* ssp. *neodioica* (1.37% cover, freq= 92%) and *Galium boreale* (1.21% cover, freq=92%). *Ditrichum flexicaule* (46.25% cover, freq=69%), *Bryum* spp. (11.03% cover, freq=62%) and *Syntrichia ruralis* (14.65% cover, freq =54%) are the dominant bryophytes. Lichen cover is low (3.76%) with the dominant lichen genera being *Cladonia*, *Xanthoparmelia* and *Peltigera*. Indicator species analysis revealed *Poa pratensis, Poa compressa, Allium stellatum, Prunella vulgaris* and *Potentilla gracilis* as indicators of this type (Table 3.4). Species richness and diversity values are the second lowest compared to other types (Table 3.2). Grazing intensity was moderate in this type and there was no evidence of browsing (Table 3.3).

Further separation of the cluster analysis divides this vegetation type based on amount of shrub cover. *Dasiphora fruiticosa* (12.62% mean cover, freq=100%) has a mean cover of 1.47% in sub-type 1 but a cover of 19.59% in sub-type 2. *Poa pratensis* and *Poa compressa* are more common in sub-type 1 (23.65 and 14.62% cover respectively) than in sub-type 2 (1.27 and 2.29% cover respectively). Conversely, sub-type 2 has higher native graminoid cover by *Deschampsia cespitosa* and *Sporobolus heterolepis.*

(III) Dry grassland (n=22)

Dry alvar grassland (Figure 3.9) occurs in open areas (very little tree cover, mean=0.02%) higher on the topography. This is a prevailing vegetation type in Manitoba and it is often associated with patches of moist graminoid meadow alvar or alvar shrubland that occur within its larger expanse. This grassland type has moderate soil depths (5.6 cm, but is deepest of graminoid groups), rock cover (third highest, 5.64% cover), bare soil cover (2.53%) and soil moisture (Table 3.3). Dry alvar grassland has the highest cover by native perennials (33.33% cover) and woody plants (19% cover) but the lowest graminoid cover (38.07%) of any graminoid alvar type (Types I-III) in Manitoba (Table 3.2). Graminoid cover was still higher than Types IV-VIII. Within this vegetation type, *Arctostaphylos uva-ursi* (8.28% mean cover but up to 62% in a single plot, freq=36%) often has a patchy distribution with high cover in certain areas, while *Dasiphora fruiticosa* (3.27% cover, freq=82%) has lower cover more frequently. Dominant cover is by *Poa pratensis* (9.72% cover, freq=100%)*, Geum triflorum* (16.35% cover, freq= 95%), *Danthonia spicata* (9.12% cover, freq=95%), *Antennaria howellii* ssp. *neodioica* (2.70% cover, freq= 86%), *Achillea millefolium* (1.50% cover, freq=95%) and *Koeleria macrantha* (1.20% cover, freq=95%). Lichen (8.02%) and bryophyte (4.24%) cover is moderate in this type. *Ditrichum flexicaule* (9.83% cover, freq=45%), *Abietinella abietina* (6.21% cover, freq=55%) and *Syntrichia ruralis* (17.25% cover, freq =45%) are the dominant bryophytes. Crustose, foliose and fruticose lichen forms are all common. Affinity of this type is predominately prairie with approximately even proportions of boreal, generalist and introduced species (Figure 3.5). Indicator species analysis showed that *Agrostis scabra, Elymus trachycaulus subsp. subsecundus, Festuca saximontana, Geum triflorum, Achillea millefolium, Arenaria serpyllifolia* and *Trifolium pretense* are characteristic for this vegetation type (Table 3.4). This type had moderate richness and diversity compared to other types (Table 3.2). This vegetation type experienced the highest grazing intensity of all types but had a very low browsing intensity (Table 3.3).

Further branching within the cluster analysis (Figure 3.2) showed two sub-types that do not differ in physiognomy but have different species compositions. Sub-type 1 is more a diverse *Festuca* grassland with both *Festuca hallii* and *Festuca saximontana* being characteristic. Sub-type 2 is a predominately *Poa- Geum triflorum* grassland that only occurs at the alvar on Sylvan Community Pasture and might be a result of heavier grazing activities.

(IV) Rocky dwarf shrubland (n=9)

Rocky dwarf shrubland (Figure 3.10) occurs in patches or strips of higher topography and/or rocky areas with thinner soils. This type is the driest with the shallowest soils (mean=2.0 cm) and highest cover of bare rock (mean=14.08%). Rocky dwarf shrubland had high amounts of nutrients in the soils compared to other groups (Table 3.3). Affinity of the vascular vegetation cover in Type IV is predominantly boreal (>50%) with a strong prairie influence (35%) but little generalist or introduced species (Figure 3.6). Despite having no tree cover this type has the highest cover of woody perennials. Dominant ground cover is shrubs growing in the soil filled cracks and mosses over the thin soil or rock. Dominant shrub cover is *Juniperus horizontalis* (33.54% cover, freq = 78%) and *Dasiphora fruiticosa* (18.73% cover, freq= 100). Forb cover is low (8.91%) but diverse with no one species becoming noticeably more common than others. This vegetation type is rich in composites including *Oligoneuron album* (1.30% cover) and *Solidago nemoralis* (1.08% cover), which occur in every plot. Graminoid cover is the lowest of all types (14.15%) with low lying grasses and sedges such as *Danthonia spicata* (4.68% cover, freq=100%) and small *Carex* spp. being the dominant graminoids. Moss cover in this type is high (9.07%) and comprised of *Syntrichia ruralis, Tortella tortuosa, Tortella fragilis, Thuidium abietinum, Ditrichum flexicaule* and *Grimmea* spp. Lichen cover is high (22.04%) with crustose lichens that were unidentified being dominant on the exposed rock. Macro-lichen cover included species in the genera *Cladonia* (in form of squamules), *Umbilicaria, Xanthoparmelia* and *Peltigera*. Indicator species for this vegetation type include: *Elymus trachycaulus subsp. trachycaulus, Carex scirpoidea, Artemisia campestris ssp. caudate, Solidago simplex ssp. simplex, Minuartia dawsonensis, Solidago nemoralis* and *Juniperus horizontalis* (Table 3.4). Due to limited food resources, this area has low browsing and grazing intensity (Table 3.3). There was a high proportion of richness due to introduced species (Figure 3.5) but these were not abundant in cover (Figure 3.6). This type had moderate diversity and richness values (Table 3.2). This vegetation type experienced lower grazing (second lowest) and browsing (third lowest) intensity compared to most types (Table 3.3).

(V) Boreal -Bur oak-Jack pine-Low shrub (n=21)

The boreal -bur oak- jack pine- low shrub vegetation type (Figure 3.11) occurs along exposed limestone ridges or rocky pavement with cracks large enough for tree development and includes unique features such as limestone tabletops and exposed ridges (C and D, Figure 2.2). This type is moderately dry with thinner soils (mean= 3.6 cm) and the second highest bare rock cover (mean = 8.85%) compared to other types (Table 3.3). Soil nutrient levels (NO3-N = 94.17 mg/kg, PO4-P = 10.44mg/kg) are moderate (Table 3.3). Vegetation cover is predominantly boreal (>50%) with prairie vegetation occupying over a quarter and generalist and introduced species cover being minimal (Figure 3.6). Type V is dominated by woody vegetation (Figure 3.4) and has the second highest tree cover (mean= 11.83% cover, range of 0-32%) and the most diverse combination of tree species including *Quercus macrocarpa* (6.52% cover freq =71%) and *Pinus banksiana* (3.63% cover, freq = 29%) with the occasional *Picea glauca* and *Populus tremuloides*. Shrub cover (mean= 48.15% cover) is dominated by *Arctostaphyos uva-ursi* (17.87% cover, freq =100%), *Juniperus horizontalis* (13.84% cover, freq =100%), *Dasiphora fruiticosa* (8.14% cover, freq =90%) and *Juniperus communis* (3.77% cover, freq= 95%). Forb cover (12.73% cover) is moderate but diverse with many species occurring in each plot at low cover. Dominant forb species in descending order include: *Geum triflorum, Antennaria howellii* ssp. *neodioica, Oligoneuron album, Erigeron glabellus*, *Symphyotrichum laeve, Solidago nemoralis* and *Monarda fistulosa* being of the highest cover, although these were all under 6%. Graminoid cover is variable from <5%- 50% (mean is second lowest of all types, 21.97% cover) and dominant graminoids are *Danthonia spicata* (6.91% cover, freq=95%), *Carex richardsonii* (occurs in patches up to 20% cover but mean cover is only 2.36%, freq=29%), *Festuca hallii* (1.24% cover, freq= 52%) and *Carex crawei* (1.34% cover, freq=38%). The moderately high moss cover (mean = 6.59% cover) is dominated by *Thiudium abietinum* and *Tortella* spp. (including *T. tortuosa* and *T. fragilis*). Since this vegetation type contains a wide variety of substrates for attachment (bare rock, soil, wood), lichen diversity is high (second highest, mean =17.75% cover) with all three forms (crustose, foliose and fruticose) represented. Dominant lichen taxa included *Cladonia* and *Cladina* spp*. Flavopunctelia, Parmelia, Physia* and *Candelaria* lichens were frequently found growing on oak bark. This type experiences moderate levels of cattle grazing (Table 3.3), has few introduced species (Figure 3.6) and a rich diversity of rare species including *Pellaea glabella* ssp. *occidentalis* (cover< 0.01%, freq= 5%) and *Pellaea gastonyii* (0.03% cover, freq = 10%). Indicator species analysis (Table 3.4) revealed species such as *Carex richardsonii, Heuchera richardsonii, Juniperus communis, Symphoricarpos albus, Arctostaphylos uva-ursi* and *Quercus macrocarpa* as characteristic for this vegetation type. Type V experienced the fourth highest level of grazing intensity and the second highest browsing intensity (Table 3.3).

Finer-scale groupings in the cluster analysis (Figure 3.2) are associated with two distinct sub-types that vary in the amount and type of tree cover. Sub-type 1 has a mean tree cover of 16% while sub-type 2 has a mean tree cover of 8%. *Pinus banksiana* is present in 75% of sub-type 1 (mean cover = 9.52%) but completely absent in sub-type 2. *Arctostaphylos uva-ursi* is more common in sub-type 1 (mean of 29% compared to 11%) while *Juniperus horizontalis* is more abundant in sub-type 2 (mean of 17% compared to 9%). *Carex richardsonii* in sub-type 1 is replaced by *Carex crawei* and *Carex inops* as dominant graminoids in sub-type 2.

(VI) Bur oak- Tall shrub (n=10)

Type VI (Figure 3.12) occurs in patches within the alvar or as an edge habitat. The bur oak-tall shrub vegetation type has relatively deep soils (second deepest, mean=7.5 cm), moderate rock cover (4th highest of all groups) and moderately moist soils (Table 3.3). Very little bare soil (lowest of all groups, 0.5%) is present in this type. This type has very nutrient poor soils (Table 3.3). Type VI has roughly similar amounts of cover by prairie, boreal, generalist and introduced species although prairie influence does become slightly higher in this type (Figure 3.6). Vegetation cover is dominated by woody vegetation (Figure 3.4). Tree cover (0-25% with mean cover of 14.23%) is almost completely by *Quercus macrocarpa* (13.00% cover, freq= 80%) with infrequent *Picea glauca* and *Populus tremuloides*. Shrub cover (20-70%) is very high with dominant species being *Arctostaphylos uva-ursi* (12.86% cover, freq=90%)*, Dasiphora fruiticosa* (7.80% cover, freq=80%), *Corylus cornuta* (3.50% cover, freq=50%)*, Amelanchier alnifolia* (4.30% cover, freq=100%) and *Prunus virginiana* (7.80% cover, freq=90%). The moderate cover of herbaceous perennials 24.62%) includes: *Monarda fistulosa* (1.70% cover, freq=100)*, Galium boreale* (1.10% cover, freq=100)*, Symphyotrichum ciliolatum* (1.58% cover, freq=90), *Erigeron glabellus* (1.30% cover, freq=80)*, Geum triflorum* (3.00% cover, freq=80)*, Oligoneuron rigidum* (2.24% cover, freq=70) and *Sanicula marilandica* (0.12% cover, freq=70). Graminoid cover is relatively high (between 5-40%, mean=34.75%) and dominated by *Poa pratensis* (15.30% cover, freq=100) and *Danthonia spicata* (11.17% cover, freq=80). Moss (<1%) and lichen (2%) cover is low in this group. Indicator species include *Schizachne purpurascens, Poa pratensis, Lysimachia ciliata, Sanicula marilandica, Hieracium umbellatum, Symphyotrichum ciliolatum, Artemisia ludoviciana, Monarda fistulosa, Thalictrum venulosum, Prunus virginiana, Amelanchier alnifolia,* *Corylus cornuta* and *Quercus marcocarpa.* The richness and diversity values of this type are the highest of all types. Shannon H (per plot) is 2.55. Effective Richness per plot is 13.1 and mean species richness per plot is 60 species. This type experienced high level of cattle grazing intensity (second highest of all groups) and medium levels of browsing by deer (fourth highest). Type VI has a high proportion of introduced species (18.57% cover) that is mostly graminoid (15.88% cover) dominated by *Poa pratensis* (mean cover 15.3%, 100% frequency), and a mixture of introduced forbs (2.63% cover) that occur frequently at lower cover. The rare species, *Achnatherum richardsonii* (0.75% cover, freq =10%), although infrequent was only found in this one vegetation type. Type VI had the second highest grazing intensity and the fourth highest browsing intensity (Table 3.3).

(VII) Prairie – Jack Pine- Low shrub (n=14)

Type VII (Figure 3.13) has the deepest soils of all vegetation types (mean=8.1 cm) with low cover of bare soil and bare rock (Table 3.3). There are a low amount of nutrients in the soils of this group and pH is neutral (Table 3.3). Vegetation cover in this type is dominated by prairie species (~50%) with boreal having less influence (~30%) than Types IV and V (Figure 3.6). There is little cover by introduced or generalist species (Figure 3.6). Woody vegetation is dominant with approximately equal amounts of native graminoid and native perennial cover (Figure 3.4). Tree cover (0-25% with a mean of 3.09%) is dominated by *Pinus banksiana* (2.86% cover, freq=14%). Shrub cover is dominated by *Arctostaphylos uva-ursi* (27.12% cover, freq=86%) and *Dasiphora fruiticosa* (15.50% cover, freq=93%). The variable graminoid cover (2-75%, mean=36.01%) is dominated by *Koeleria macrantha* (0.38% cover, freq=100%), *Poa* *pratensis* (5.67% cover, freq=86)*, Elymus trachycaulus subsp. subsecundus* (0.40% cover, freq=93%) and *Festuca saximontana* (0.41% cover, freq=86%). Forb species (highest cover, 33.96%) are diverse and dominant species are: *Geum triflorum* (6.38% cover, freq=100%)*, Symphyotrichym laeve* (5.40% cover, freq=100%)*, Oligoneuron album* (2.59% cover, freq=79%)*, Oligoneuron rigidum* (4.99% cover, freq=100%)*, Erigeron glabellus* (1.52% cover, freq=86%) and *Antennaria howellii* ssp*. neodioica* (1.29% cover, freq=93%). Lichen and moss cover is low (Table 3.2). Richness and diversity values are moderate compared to other groups (Table 3.2). Indicator species for Type VII include *Rosa acicularis, Arctostaphylos uva-ursi, Dasiphora fruticosa* ssp*. floribunda, Bromus porteri, Hesperostipa spartea, Oligoneuron rigidum, Agoseris glauca, Symphyotrichum laeve, Gaillardia aristata* and *Potentilla arguta.* Type VII experiences low levels of cattle grazing (second lowest of all groups) and includes some sites that were completed ungrazed (A and B). Moderate levels of browsing by deer (third highest) were observed (Table 3.3).

(VIII) Bluestem grassland- Spruce savanna (n=9)

The bluestem grassland- spruce savanna vegetation tyoe (Figure 3.14) is located at the most southern reaches of alvars in the Manitoban Interlake region and occurs as patches intermixed with shrublands or as edge habitat. This vegetation type has moderate soil depths (mean= 4.86 cm), bare rock cover (mean= 4.65%) and soil nutrient content compared to other types (Table 3.3). The proportion of cover by boreal (52%) and prairie (45%) vegetation is almost equally dominant with extremely low cover by generalist or introduced species (Figure 3.6). Cover is dominated by woody vegetation including *Arcostaphylos uva-ursi* (16.72% cover, freq=100%), *Juniperus horizontalis* (14.74% mean cover, freq=89%), *Dasiphora fruiticosa* (6.13%

mean cover, freq=100%) and *Picea glauca* (7.36% mean cover, freq=44%). Within the 'wooded' alvar communities (types V-VII), native perennial cover is the lowest and graminoid cover is the highest (Figure 3.4). Type VIII had the most obvious prairie elements due to the presence of typical tallgrass prairie graminoids. *Andropogon gerardii* (28.78% cover, freq=100%) is the dominant graminoid. Perennial herbs are diverse in this group and many species occur frequently at low cover: *Symphyotrichum laeve* (0.80% cover, freq=100%), *Comandra umbellata* (0.58% cover, freq=100%), *Oligoneuron rigidum* (0.55% cover, freq=100%), *Solidago hispida* (0.39% cover, freq=100%), *Oligoneuron album* (0.39% cover, freq=100%) and *Monarda fistulosa* (0.35% cover, freq=100%). Indicator species analysis showed that *Andropogon gerardii, Dalea purpurea*, *Pediomelum esculentum, Dalea candida, Lilium philadelphicum, Solidago hispida, Picea glauca* and *Betula glandulosa* are characteristic of this vegetation type. Richness and diversity values are moderate compared to the other types (Table 3.2). Type VIII is completely ungrazed and experienced the highest browsing intensity (Table 3.3).

Further branching in the cluster analysis (Figure 3.2) revealed two distinct sub types. Sub-type 1 is a spruce savanna/shrubland. The spruce savanna/shrubland sub-type had <25% graminoid cover, >25% shrub cover and 1-26% tree cover (mean=12%). *Solidago nemoralis, Antennaria howellii* ssp. *neodioica, Oligoneuron rigidum*, and *Dalea purpurea* are common in this habitat but less so in bluestem grasslands. The bluestem alvar grassland sub-type has >85% graminoid cover, low shrub cover (<20%) and almost no tree cover (>1%) supporting its distinction from spruce savanna alvars. Forb cover is lower than in spruce savanna/shrubland alvars with common species being *Dalea candida, Oxytropis splendens, Cyprepedium parviflorum, Cirsium drummondii, Symphyotrichum laeve* and *Pediomelum esculentum*.

Cyprepedium parviflorum was observed in this sub-type but not found in spruce savanna/shrubland alvars. *Cirsium drummondii* was also common in bluestem grasslands but not as frequent in spruce savanna/shrubland alvars.

3.3.2 Ordination

The PCA (Figure 3.15) result for plots supports the vegetation type structure in the cluster analysis, which has been superimposed upon the scattergram of plots (Figure 3.16). The ordination of plots also revealed that there is a stronger association between the compositions of vegetation types than composition of plots by their geographic location, as shown by the the lack of association among plots at the same site (Figure 3.15). For example, plots from site C are associated with a variety of vegetation types and ordinate closer to plots of the same vegetation type rather than plots from the same site. The scattergram of species is shown separately (Figure 3.17). The first two axes account for 15.5% and 9.2% (24.7% total) of the variation in the vegetation composition, respectively.

Trends of the Primary Axis

As in the cluster analysis, there is a distinct separation along the first axis between plots in the graminoid types (Types I-III) and wooded types (Types IV-VIII) (Figure 3.16). The PCA biplot analysis of species (Figure 3.17) indicates a separation of woody and graminoid species along the first axis. In particular, *Arctostaphylos uva-ursi* is very heavily weighted on the positive side of the first axis along with *Monarda fistulosa, Prunus virginiana, Comandra umbellata, Juniperus horiontalis, Juniperus communis* and *Oligoneuron rigidum* (Figure 3.17). *Arctostaphylos uva-ursi* and trees have a high relative cover-abundance in plots with positive

PCA scores along the first axis but are relatively absent in plots with negative scores (Figure 3.18). The relative cover-abundance of woody vegetation (Figure 3.18) shows that *Juniperus* spp. are most closely associated with Type IV, whereas *Arctostaphylos uva-ursi* and trees are much more abundant in Types V-VIII. Other shrubs (excluding *Arctostaphylos* and *Juniperus*) are abundant in all 'wooded' alvar Types (IV-VIII) and somewhat in the graminoid Type III. Conversely, relative cover-abundance of graminoids is highest in plots with negative scores, belonging to Types I-III (Figure 3.19). *Deschampsia cespitosa, Eleocharis compressa* and *Juncus dudleyi* are most heavily weighted on the negative side of the first axis (Figure 3.17). The presence of these species corresponds to the higher moisture availability in plots with negative scores (Figure 3.20). The relative cover-abundance of introduced species is also highest in plots with negative scores, in Types I-III (Figure 3.19). This is reflected by the negatives scores along PCA1 for the introduced graminoids *Poa alpina, Poa compressa* and *Poa pratensis* (Figure 3.17).

Species richness, Shannon diversity and effective species richness are all higher in plots with positive scores along PCA1 (Figure 3.21), which includes all wooded vegetation types (Types IV-VIII). Browsing intensity is also highest in plots belonging to the wooded types (IV-VIII), which have positive scores along PCA1 (Figure 3.22).

Trends of the Secondary Axis

Species associated with deeper soils within the wooded types (Types VI-VIII) included *Oligoneuron rigidum, Fragaria virginianum and Hieracium umbellatum,* having negative scores along PCA2 (Figure 3.17). Conversely, *Juniperus horizontalis, Tortella spp., Syntrichia ruralis, Ditrichum flexicaule* and foliose lichens are ordinated positively along PCA2 (Figure 3.17) corresponding to the low soil depths (Figure 3.20). *Juniperus* species were most common in plots with shallow soils and positive scores on PCA2 (Figure 3.18). Hydrophilic species, such as *Deschampsia cespitosa*, are most characteristic of Type I (Figure 3.16) and occur in close proximity on the ordination with negative scores on both PCA1 and PCA2 (Figure 3.17). Species that prefer moderate moisture and soil depths (Figure 3.20) are most associated with Type II (Figure 3.16) and include *Juncus dudleyi* and *Potentilla gracilis* (Figure 3.17), which have negative scores on PCA1 and PCA2 scores close to zero*. Poa compressa* and *Poa alpina* have positive scores along PCA2 but negative scores on PCA1 (Figure 3.17) and are most associated with graminoid dominated plots with thin soils (Type III). Introduced species are most associated with graminoid alvars (negatively scored on PCA1) but along PCA2 they show increased abundance in plots with deeper soils (Figure 3.19).

Within the graminoid plots (negatively scored on PCA1) species richness, Shannon diversity index and effective richness are higher in plots with shallow soils rather than deeper soils and higher moisture content (Figure 3.19 and 3.21). Within the wooded plots (positively scored on PCA1) species richness, Shannon diversity index and effective richness do not appear to change with soil depth along PCA2.

The secondary axis separates vegetation types along an environmental gradient. Plots with highly positive scores along PCA2 have higher nitrogen content (Figure 3.22), higher rock cover, lower moisture content and lower soil depths (Figure 3.20). The graminoid types (Types I-III) are distinguished from each other along an environmental gradient, with plots in Type I having the deepest soils (Figure 3.20) and negative scores along the PCA2 (Figure 3.16), whereas Type III having shallower soils and positive scores along PCA2. The highest soil depths and soil moisture values were found in plots of Type I, which are negatively scored on the secondary axis of the PCA (Figure 3.20).

3.3.3 Vegetation-Environmental Relationships

The organization of groups and plot trends on the redundancy analysis (Figures 3.23 and 3.24) are highly consistent with the organization of groups on the PCA. Consistent with the cluster analysis and PCA, there is a distinct separation of graminoid types (Types I-III) from wooded types (Types IV-VIII) along the primary axis (Figure 3.24). Further separation of types within these broader groups (graminoid and wooded) is based on environmental gradients as was demonstrated by imposing soil depth, rock cover and soil moisture of plots onto the PCA (Figure 3.20). The redundancy analysis (Figures 3.23 and 3.24) confirmed that moisture, soil depth and rock cover have the strongest effect on vegetation composition in Manitoba alvars.

The eleven environmental variables explained 26.28% of the floristic variation in the data (i.e. variation in species composition). A Monte Carlo permutation test indicated that the ability of these environmental variables to explain vegetation composition is statistically significant ($F_{1,91}$=2.92, $P < 0.005$, n=199 permutations). The first RDA constrained axis is statistically significant (8.55% of variation, $F_{1,91}$=10.55, $p < 0.005$, n=199 permutations) and was most strongly associated with a gradient of disturbance (grazing and browsing) and moisture availability (Figure 3.24). Grazing is highest in graminoid dominated alvar communities (Types I-III), while browsing was more associated with higher cover of woody species (Types V-VIII), which separate along the primary RDA axis, confirming the trends observed in the PCA. Along the primary axis, *Arctostaphylos uva-ursi, Juniperis horizontalis and Andropogon gerardii* have positive RDA scores and are most strongly associated with disturbance of browsing along the primary constrained RDA axis (Figure 3.25). Conversely, P*oa pratensis, Deschampsia cespitosa, Eleocharis compressa, Carex praegracilis, Juncus dudleyi* and *Poa compressa* have negative RDA scores along the first axis (Figure 3.25) and are most strongly associated with graminoid dominated plots that are grazed (Types I-III).

The second RDA constrained axis is also statistically significant (6.85% of variation, $F_{1,91}$=8.46,P < 0.005, n=199 permutations) and was strongly associated with a gradient of soil depth and rock cover. Moisture and soil depth are somewhat positively correlated and negatively correlated with bare rock cover (Figure 3.24). As was observed in the PCA, the composition of wooded types varies along an environmental gradient that distinguishes the types within this broader group. *Oligoneuron rigidum, Hieracium umbellatum* and *Symphiotrichum laeve* are characteristic of deeper soils in the wooded alvar types (Types VI-VIII) and have negative scores along RDA2 (Figure 3.25). *Juniperus horizontalis, Tortella spp., Syntrichia ruralis, Ditrichum flexicaule* and foliose lichens are most associated with plots having shallower soils and increased bare rock cover and ordinate positively on RDA2 (Figure 3.25), such as those belonging to Types IV and V (Figure 3.24). Types IV and VI are the driest of all vegetation vegetation community types and have the highest amount of bare rock (Figure 3.24). Within the graminoid types, the RDA scattergram showing species data (Figure 3.25) showed that species such as *Poa pratensis, Deschampsia cespitosa* and *Carex praegracilis* are most strongly associated with wetter plots and deep soil shown by their negative scores on RDA2 (Type I). *Eleocharis compressa, Juncus dudeyi* and *Potentilla gracilis* have scores close to zero and ordinate closest to Type II (Figure 3.24), which has moderate soil depths and moisture availability (Figure 3.25). *Poa compressa* has a positive score on RDA2 and is more associated to drier plots with thin soil and high rock cover (Type III).

3.3.4 Vegetation Model: Life Forms

The first two axes of the correspondence analysis (CA; Figure 3.26) explained 42.30% and 31.89% (74.19% total) of the contingency chi-square, respectively. As in the PCA and RDA, the CA discriminated groups based on more graminoid (Types I-III) or woody (Types IV-VIII) cover. Separation within the 'wooded' alvar groups is also apparent and due to the presence of *Juniperus* spp. or *Arctostaphylos uva-ursi* as shrub cover. Vegetation types associated with *Juniperus* spp. shrub cover (Types IV and VIII) also had high lichen and moss cover. Types VI and VII, which were associated with deep soils in the RDA, were separated by their high cover of trees and *Arctostaphylos uva-ursi* in the CA*.* Type V associates closely to these groups in the CA due to its high tree cover, contrasting its higher association to Type IV in the cluster analysis, PCA and RDA. This is consistent with the PCA results (Figure 3.17) that oriented these species close to these vegetation types. Introduced herbaceous perennials had the least influence on vegetation type structure (Figure 3.26), likely due to their low cover (>5%) in all vegetation types (Figure 3.4). On the contrary, introduced graminoids did affect vegetation types (Figure 3.26). The CA shows that introduced graminoids are more associated with graminoid types (I-III) than wooded types (IV-VIII). Within the graminoid types (I-III), Type I is less associated with introduced graminoids than Types II and III, which is supported by the higher proportion of cover by introduced graminoids in these groups (Figure 3.4).

3.4 Discussion

3.4.1 Environment and the Alvar 'Mosaic'

As in classifications of alvars in the Great Lakes region (Gilman 1995; Reschke *et al.* 1999; Brownell and Riley 2000), the alvar communities defined in Manitoba have distinct soil depths and moisture regimes as shown by the raw data for vegetation types (Table 3.3) and the RDA results (Figure 3.24). These factors in turn determine the physiognomic and species composition of vegetation on alvars in Manitoba and the creation of a mosaic of communities within this ecosystem. This is consistent with alvar studies in Ontario that found biomass and plant composition to be highly correlated with soil depth (Belcher *et al.* 1991) and studies in New York that showed the most vital environmental influence on alvars was soil depth (Gilman 1995). Deeper soils have reduced moisture stress through an increased water retention capacity (Gilman 1995). Within graminoid alvars, the vegetation types separate into three groups based on moisture regime (wet, moist and dry, as determined by topography) and soil depth. The moist and dry graminoid groups are less distinct than the wet group likely because of transition zones and patches of varying environmental conditions that lead to a mixture of these assemblages. Observations in Ontario alvars, which showed that graminoids dominate areas of deeper soil while small forbs dominate areas with shallower soils (Belcher *et al.* 1991), were not consistent with this study. These differences may be due to the effects of grazing that could have more impact on certain herbaceous forb species (Rosén 1982).

Manitoba alvars form a patchy 'mosaic' of vegetation communities on the landscape, which is a reflection of variable environmental conditions. Consistent with alvars in other parts of the globe, the alvars of Manitoba have a highly variable cover of shrubs and trees.

Shrublands (>25% shrub cover, <10% tree cover) were quite dominant on the terrain, whereas savannas (variable shrub cover, 10-25% tree cover) occurred mostly as an extensive edge habitat or in patches on the alvar. Differences in the vegetation composition among these wooded communities were determined by soil depth. Gilman (1995) also suggested that increased soil depths created a higher nutrient status, increasing plant growth. Results of this study show an opposite trend with nitrogen increasing with a decrease in soil depth. This is potentially due to the thin soils being highly organic or from nutrient loading by cattle dung (Dai 2000).

3.4.2 Comparison of Alvar Classifications

Broad Physiognomic Groups

Previous quantitative floristic classification of the alvars in the Great Lakes region (Canada and U.S.A.) separated alvar communities into four broad types that corresponded with physiognomic structure (Reschke *et al.* 1999). These types are open grassland/ pavement (<25% shrub cover, <10% tree cover), shrubland (>25% shrub cover, <10% tree cover), savanna (10-25% tree cover) and woodland (25-60% tree cover) (Reschke *et al.* 1999; Brownell and Riley 2000). The qualitative community descriptions from the Manitoba Alvar Initiative (2012) also separated alvar communities into similar physiognomic groups (Table 2.2) but with alvar wetland as its own distinct broad group rather than being grouped in with the open grassland/pavement communities. The distinction between open graminoid dominated areas and 'wooded' alvars, which are shrub or tree dominated, was clear in all analyses of this study, supporting the distinction of the open grassland/pavement alvar type used in the quantitative and qualitative methods from alvar studies in North America (Gilman 1995; Reschke *et al.* 1999; Brownell and Riley 2000; Manitoba Alvar Initiative 2012).

In contrast to previous studies that separated shrubland and savanna groups based on physiognomy (shrubland= >25% shrub cover, <10% tree cover; savanna= variable shrub cover, 10-25% tree cover) (Gilman 1995; Reschke *et al.* 1999; Brownell and Riley 2000; Manitoba Alvar Initiative 2012), in Manitoba quantitative methods showed that these physiognomic vegetation types are not distinct from one another. Both shrubland and savanna physiognomic vegetation types may fit into the same quantitatively described alvar type. For example, in Type V, the sub-types did separate into what would qualify as a savanna and shrubland sub-types, but in contrast to the previous alvar work this division was due to subsequent branching rather than a main characteristic of type as a whole since tree cover was highly variable (0-31% cover) within Type V. The current study found that the vegetation compositions of these physiognomic groups (shrubland and savanna) in Manitoba are not distinctive and they are often associated with each other as part of the patchy alvar mosaic of communities. Alvar savannas in Manitoba often occur on the edges of other alvar types or in patches where there are increased amounts of cracks in the landscape rather than forming a dominant alvar community as they do in the Great Lakes Region (P.K. Catling, Pers. Obs. 2014). Savannas have similar vegetation composition to the associated shrublands potentially due to the edge effects (P.K. Catling, Pers. Obs. 2014). Seed dispersal is fundamental in determining structure and dynamics of communities (Nathan and Muller-Landau 2000) and alvars in Manitoba are often surrounded by aspen parkland rather than alvar woodland habitats comprised of tree species that occur on the alvars (as is the case in the Great Lakes region), thus limiting seed dispersal of tree species onto the alvar. This may contribute to the lack of widespread savanna communities on alvars in Manitoba.

Composition of Vegetation Types

The most similar alvar communities described by previous alvar vegetation studies are shown in Table 3.5. The vegetation types described in the current study are relatively consistent with communities of previous classification with the following exceptions or differences. Type II was not defined as a distinct vegetation type by the Manitoba Alvar Initiative (2012) but is a mixture of the compositon of dry grassland and alvar wetland communities. The sub-types in Type II are most similar to the Canada bluegrass grassland (Brownell and Riley 2000) and tufted hairgrass wet alvar grassland (Reschke *et al.* 1999; Appendix 2). Type III is most similar to the grassland community described by the Manitoba Alvar Initiative (2012) and the Canada bluegrass (Brownell and Riley 2000) or poverty grass dry grassland community (Reschke *et al.* 1999) communities in the Great Lakes region.

Type IV is most similar to prairie shrubland from Manitoba Alvar Initiative (2012) since the dominant cover is *Juniperus horiontalis*. However, this vegetation type does not fully fit the prairie shrubland from the Manitoba Alvar Initiative (2012) since it lacks species such as *Corylus cornuta* and *Andropogon gerardii* (Table 2.2). When compared to the alvar communities in the Great Lakes region, the sub-types in Type V are similar to the bur oak/ common juniper or jack pine/ bearberry and jack pine/common juniper communities described by Brownell and Riley (2000). In the Great Lakes region, *Quercus macrocarpa* and *Pinus banksiana* can occur together although not as co-dominants (Brownell and Riley 2000). The presence of *Acrostaphylos uva-*

ursi and *Juniperus horizontalis* in Type VII is somewhat similar to the scrub conifer/ dwarf lake iris alvar shrubland described by Reschke *et al.* (1999); however, in Manitoba this vegetation type lacks species such as *Iris lacustris, Picea glauca* and *Thuja occidentalis* (Appendix 2). Type VIII contains white spruce savanna and bluestem grassland sub-types and is most similar to white spruce savanna and prairie shrubland communities from the Manitoba Alvar Initiative (2012). The white spruce savanna sub-type within Type VIII is most similar to the scrub conifer/dwarf lake iris alvar shrubland (Reschke *et al.* 1999) from the presence of *Picea glauca*; however, this type in Manitoba lacks *Iris lacustris* and *Thuja occidentalis,* as well as containing more prairie elements (such as *Andropogon gerardii*) that aren't prevalent in the scrub conifer/dwarf lake iris alvar shrubland community.

Species Affinity

The results of this study show that vegetation communities in Manitoba alvars contain a mixture of boreal and prairie species. Unlike Ontario alvars (Catling and Brownell 1995), the Manitoba alvars have no species with floristic affinities from the eastern deciduous mixedwood forest vegetation zone. The Manitoba Alvar Initiative (2012) used boreal and prairie affinities to distinguish shrubland types. This separation is supported by the current study. Types IV, V and VIII were dominated by boreal species while the other types had a stronger prairie affinity (Figure 3.6). Type VIII was separated into two sub-types, a spruce savanna that had a higher percent cover by boreal species due to the tree cover and a bluestem grassland that was dominated by *Andropogon gerardii*. This trend is not apparent when looking at the proportion of species with these affinities (Figure 3.5), suggesting that the proportion of species does not accurately represent the visual appearance of the vegetation community. For example, despite having relatively equal proportions of richness of boreal and prairie species, prairie species may be more dominant in terms of cover. From this perspective, presence/absence species lists would not be good at describing alvar communities in Manitoba. This demonstrates the importance of quantitative data (abundance) in describing alvar vegetation communities.

In the most heavily grazed plots (Table 3.2), which include Types III, VI and I, proportion of cover of species with prairie affinities are the highest (Figure 3.6). Conversely in vegetation community types that experience less grazing, such as Type VIII, V and IV, boreal species have the highest percent cover. This suggests that grazing may reduce boreal flora and increase the presence of prairie flora or that grazers preferentially select communities with a prairie affinity.

Richness and Diversity

The alvars in Manitoba are floristically less diverse than those in eastern North America since this study found 231 vascular species in a sample area of 10,300 m^2, whereas 374 species were found on the alvars in New York State over a sample area of 2,544 m^2 (Gilman 1995). The lower species richness is likely due to climatic differences affecting what species may establish. This supports the theory of a biodiversity-latitudinal gradient where biodiversity decreases with latitude (Wallace 1878; Stevens 1989; Gaston 2000; Hillebrand 2004). The alvars in the Northwest Territories have a much lower richness (87 vascular species) than Manitoba but are still considered a rich ecosystem for that latitude (Catling 2009b). Conversely, surveys of the alvars in Ontario listed 347 species (Catling and Brownell 1995). As in eastern North America (Gilman 1995), the alvars in Manitoba are dominated by perennials with a few annual species.

There are a wide variety of species, including many of the dominant trees in the Great Lakes region that do not occur in Manitoba.

Introduced Species

The vascular flora of alvar communities in Manitoba is mostly native although the proportion of cover and richness due to introduced species does vary among communities (Figures 3.3 and 3.4). Grazing and associated activities increases the presence of introduced species in terms of both richness and cover (see Chapter 4).

The proportion of mean species richness due to introduced species varied from 5% to 24%, having a mean of 13.5% of species across the eight communities (Figure 3.5). A similar proportion (19%) of introduced species was seen on New York State alvars (Gilman 1995). Although the only ungrazed alvar community (Type VIII) did not have the highest species richness (Table 3.2), it did have the lowest proportion of introduced species (Figure 3.5), supporting that grazing leads to increased abdundance of introduced species (Rosén 1982). Types with the highest proportions of introduced species (Figure 3.5; Types I, II and IV) also had low effective richness (Table 3.2). It is uncertain if this is caused by competitive interactions with introduced species or the direct effect of grazing, which can decrease richness (Rosén 1982; Clarke *et al.* 1995; MacDougall and Turkington 2005).

Percent cover by introduced species was highest in Types I, II and III, ranging from 20-26% of vegetation cover being introduced species (Figure 3.6). These graminoid dominated vegetation types were associated with heavier grazing (Figure 3.24). Types VII and VIII were the least grazed and had the lowest proportion of vegetation cover due to introduced species (Figure 3.6). Introduced cover in all types is predominantly introduced graminoids except in Type IV where introduced graminoids and perennial forbs have equal cover values (Figure 3.4). This is likely due to the high rock cover and thin soil of Type IV. Alvar communities with high rock cover are typically dominated by non-vascular plants and annuals, and have little graminoid cover (Gilman 1995).

Grazing on alvars in Manitoba appears to affect presence of introduced species in terms of both abundance (cover) and species richness. This is consistent with a meta-analysis of 63 field studies completed over a range of ecosystems and with variety of herbivores that found exotic herbivores facilitate introduced species in terms of both increased cover and richness (Parker *et al.* 2006). It is unknown if this indicates that introduced plant species have a negative effect on alvar diversity by outcompeting native plant species after being introduced by grazing processes or if these communities are disturbed and the introduced species are a side effect of this disturbance. Although the methods of invasion on alvars has not been studied, in Garry oak ecosystems invasive species were considered passengers to the long-term disturbance and not present as a result of an increased competitive ability (MacDougall and Turkington 2005).

Ecological theory also suggests that less diverse communities may be more easily invaded (Elton 1958; Tilman 1982, 1997; Pimm 1991; Stohlgren *et al.* 1999; MacDougall *et al.* 2009). It is suggested that communities with high diversity have complex inter-species interactions and use the available resources more completely (Tilman 1982, 1997; Pimm 1991; MacDougall *et al.* 2009), whereas communities with low diversity are more easily invaded because they have simple inter-species interactions and use resources less completely (Pimm 1984). Therefore, if grazing decreases the diversity of a community it may also decrease its resistance to invasion.

3.4.3 Disturbance and Vegetation Dynamics

Grazing

The methodology used for estimating grazing intensity compensated for a lack of data on stocking rates for leased crown land. Even if these stocking rates had been known, it cannot be assumed that sites are grazed evenly across all vegetation communities (Olofsson *et al.* 2001). The current study does suggest that grazing plays a role in determining vegetation composition and is more often associated with graminoid dominated areas. This was shown in the RDA and the higher grazing intensity within vegetation Types I-III (Table 3.3). This may be due to preference of cattle to feed in these communities, or the more intensely grazed areas become more graminoid dominated due to grazing effects (Olofsson *et al.* 2001).

Previous studies have demonstrated that grazing decreases shrub cover (Olofsson *et al.* 2001; Clarke *et al.* 1995) and that this transition to grassland furthers grazing pressure since these graminoid areas are more appealing to herbivores (Olofsson *et al.* 2001). Despite having high amounts of grazing, Type VI had the highest cover by tall shrubs, such as *Prunus virginiana, Amelanchier alnifolia, Corylus cornuta* and *Symphoricarpos albus.* This observation might suggest that these tall shrubs do not experience the same negative effects of grazing as dwarf shrubs, which could be more susceptible to trampling. Studies by Clarke *et al.* (1995) showed that grazing reduced cover of dwarf ericoid shrubs in heather moorland but the study did not mention the effect on other types of shrubs. The alvars of Manitoba are bordered by aspen parkland at all sites, and boreal coniferous forest (mainly *Picea glauca* but also *Pinus banksiana*) is adjacent to some sites. *Populus tremuloides* saplings were found on many sites although they are increasingly common in ungrazed areas (P.K. Catling, Pers. Obs. 2014) indicating that seedlings are negatively affected by grazing. Studies have found that cattle grazing can reduce growth of *Populus tremuloides* through trampling and foraging, however the majority of impact is due to soil compaction, reduced root oxygen and the severing of lateral roots (Dockrill *et al.* 2004).

Grazing intensity has also been shown to influence the available Nitrogen in soils (Shariff *et al.* 1994) and the Nitrogen levels in cattle dung are twice as high as in soil (Dai 2000). This study did not show a distinct relationship between these variables. Further research is necessary to determine if grazing is changing environmental conditions on alvars in Manitoba, including soil nutrients.

Drought and Flooding

The 2014 and 2015 seasons did not represent extreme drought conditions, although xeric conditions were observed on the alvars in late summer. A drought year in Europe reduced biodiversity, increased juniper mortality and increased the proportion of annuals showing that disturbance by drought changes vegetation composition (Rosén 1995). Grazing has a more severe effect on vegetation in drought years (Rosén 1995). Extreme droughts periodically cause significant (average 50%, range of 10-100%) die off of woody vegetation on alvars and naturally prevent shrub encroachment (Catling 2014). This study can not compare vegetation composition between years of drought and years with normal conditions, and long-term monitoring is required to document these differences.

Large amounts of snowfall in 2014 led to extensive spring flooding at most sites; however this study did not provide a basis for a comparison between flooding and non-flooding events. The effects of extreme flooding have not yet been studied on alvars. Studies in Europe (Rosén 1995), Canada (Belcher *et al.* 1992) and U.S.A. (Gilman 1995) support the idea that drought/flood conditions combined with micro topographic drainage features lead to differences in vegetation composition on the landscape. This is consistent with the Manitoba alvars where moisture regime has a large effect on vegetation composition, as shown by the RDA results (Figure 3.24). The graminoid communities in particular showed a distinct moisture gradient both on the landscape and in the statistical analyses. Communities occurring lower in the topography where water collects, or in areas of deeper soil may be less affected by drought than dry areas with thin soil (Reschke et al. 1999). Conversely, these low communities would experience more extreme flooding in the spring.

Fire

Evidence of fire was seen at many of the Manitoba alvar sites (14/20 sites, 23/103 plots) and more frequently observed in areas with standing trees and shrubs (P.K. Catling, Pers. Obs. 2014). Fire was not included in this classification since data on fire is difficult to quantify for each plot and data on the time and size of these fires is lacking.

Fire plays an important role in the vegetation dynamics of boreal forest (Kenkel 1986; Ryan 2002) and prairie ecosystems (Hartnett et al. 1996). Since Manitoba alvars occur in the boreal-prairie transition zone, disturbance by fire may play an important role in maintaining and perpetuating these ecosystems (Kenkel 1986; Ryan 2002). Research on alvars has produced mixed opinions of the influence of fire but indicates that the importance and effects may vary between vegetation communities, which vary in their proportion of boreal and prairie influence (Reschke *et al.* 1999; Jones and Reschke 2005). In the Great Lakes region, fire was more correlated with savannas and woodlands than grassland alvars (Jones and Reschke 2005), showing that physiognomic characteristics also correlate to fire frequency. Further research may endeavor to use historical fire records in Manitoba to compare vegetation composition on a community and site level.

Vegetation Dynamics

It is misleading to impose a classic successional model (sensu Clements) on alvars, as these are dynamic ecosystems with a patchy distribution of vegetation communities that are susceptible to frequent disturbances such as drought, flooding, frost heaving, fire and grazing (Gilman 1995; Reschke *et al.* 1999; Brownell and Riley 2000). This study on Manitoba alvars does not provide any evidence to support a traditional model of succession between communities. Burbanck and Platt (1964) comment that all rock barren ecosystems lack long term stability because disturbance events are frequent and the types of disturbance are variable. The western boreal/mixed wood forest, which is the prominent habitat surrounding alvars in Manitoba, also occurs as a continuum of species composition where small-scale disturbances create pockets of new vegetation (Levac 2012).

Traditional successional stages possess stable ‘climactic vegetation’ communities that are usually dominated by woody vegetation and trees (Johnson 1979; Philips 1981; Pärtel and Zobel 1995). By the older concepts of succession, alvar woodland and savanna communities would be the most comparable to a typical ‘climactic’ vegetation community within alvar ecosystems (Pärtel and Zobel 1995). Manitoba lacks these ‘climactic’ alvar woodland communities (alvar communities with 25-60% tree cover) and savannas are usually restricted to edge habitats or patches on the alvars without becoming a dominant community at any site (P.K. Catling, Pers. Obs. 2014).

In grassland ecosystems, climactic communities may be dominated by graminoids or associated shrubs (Coupland 1961). Community classification on grasslands in North America have showed that the ‘climactic’ vegetation communities, which are the communities present when disturbance is lacking and the community reaches its last stage in succession, are dominated by a few species of high cover (Looman 1963; Coupland 1961). Many regions of alvars can be uninhabitable for trees and a long lasting ‘climactic’ vegetation community may appear as graminoid or shrubland. This is also the case for alvars in Ontario where open graminoid and shrubland communities are long lasting (Vivian R. Brownell, Pers. Comm. 2016). On an open shrubland alvar in Ontario, Catling (2014) found that some *Juniperus* shrubs were 90 years old, demonstrating how potentially long-lived these open communities can be. Although no dating of woody vegetation was completed, it is expected that Manitoba alvars also contain long-lived woody plants. Within this study, composition of communities is determined by edaphics and dynamics is determined by recurrent disturbances such as fire, grazing, drought and flooding.

In Europe, studies showed that species distributions moved around the alvar grassland community through local immigration and extinction (‘carousel’ model of succession) (van der Maarel and Sykes 1993; Pärtel and Zobel 1995). This indicates that most species use the majority of micro-sites within a community but do not occur in all of them simultaneously (van der Maarel and Sykes 1993; Pärtel and Zobel 1995). The current study showed that environmental factors are important in determining vegetation community types and likely restrict what species can establish or become dominant in terms of cover. It is suspected that a species distribution may change within the vegetation types it is present in but that environmental conditions and plant-plant interactions (competition) restrict it from occurring in other vegetation types. More long-term studies that incorporate pre- and post-disturbance data are necessary to observe patterns of vegetation dynamics on alvars while incorporating the suite of factors affecting alvar vegetation.

3.4.4 Comments on methods and future directions

Collection of vegetation data in such a diverse ecosystem that varies significantly due to microclimate and microtopographical, poses a number of challenges. Data collected from plots need to be comparable between open graminoid dominated areas and savannas, and a consistent plot size and methodology must be used. Making plots too large impedes the amount of data that can be collected, whereas small plots will not accurately capture the variation within a vegetation community. A plot size of 10 X 10 m is useful for capturing the slight variations in topography within open alvars that may not be captured as easily with a smaller plot size. A plot size of 10 X 10 m was also adequate for capturing diversity in savannas. The methodology used here is consistent with methods used on alvars in the Great Lakes region (Reschke *et al.* 1999) and would be useful as a universal standard for alvar classification so that these areas may be compared globally.

Cryptogams, such as lichens and mosses, are a large component of alvar ecosystems and can be very diverse within the ecosystem (Caners 2011; Brodo *et al.* 2013). This chapter provides a comprehensive quantitative summary of vascular plant communities while incorporating some data on cryptogams. A survey of vascular and non-vascular flora of limestone cliffs associated with alvars is given in Appendix 5. To increase our knowledge of alvars in Manitoba, studies focusing on cryptogams should be completed. Although cryptogams could not be accurately recorded quantitatively to species for use in this classification, lists of identified non-vascular plants and lichens are given in Appendix 6 and Appendix 7, respectively. High bryophyte and lichen diversity is common of alvars (Witte 1906; Krahulec *et al.* 1986; Fröberg 1988; Brodo *et al.* 2013) and many disjunct or unusual species can be found (Caners 2011; Catling 2013). It is expected that, like vascular plant diversity, the lichen and moss diversity of Manitoba is also diverse and unique. The cryptogamic diversity of alvars in Manitoba requires further study.

3.4.5 Conclusions

Alvar ecosystems in Manitoba contain a unique combination of boreal and prairie species that distinguish them from alvars in the rest of North America (Catling and Brownell 1995; Catling 2009). In the Great Lakes region, alvars in the south contain few boreal species and a strong influence by deciduous forest (Catling and Brownell 1995). Alvars in the northern regions of the Great Lakes and in the Northwest Territories contain a boreal element and are more similar to alvars in Manitoba but these do not have as strong of a prairie affinity and contain additional floristic elements from eastern deciduous forest and the arctic respectively (Catling and Brownell 1995; Catling 2009). Vegetation composition on alvars is determined largely by soil depth and moisture regime. Varying topography and environmental conditions cause a patchy mixture of vegetation communities, a pattern consistent with alvars found in other parts of the world. It is still uncertain how disturbance by fire, drought, flooding, browsing and grazing affect this ecosystem although it is expected that influences vary with environmental conditions and thus community. These varying factors of environment and disturbance have lead to eight distinct vegetation communities within alvar ecosystems in Manitoba. The standardized methodology used in this study is effective and should continue to be adopted for alvar research. Much is still unknown about alvars in Manitoba and long-term study is necessary to fully understand the ecological processes (i.e. disturbance and succession). For example, in order to adequately manage these areas as pasture lands the effects of disturbances, such as grazing, must be understood for all alvar vegetation communities. Additional surveys of cryptogamic flora are necessary to fully document alvar biodiversity in Manitoba.

3.5 References

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Table 3.1: Life form distribution of the 231 vascular plant species encountered in the 103 sampled plots. The 231 species are also classified as native or introduced, following the PLANTS USDA Database (USDA 2016).

Life Form	Total Number of Species	Percentage of Total Species	Number of Native Species	Number of Introduced Species
Ferns	3	1.30	3	0
Annual Forbs	21	9.09	12	9
Perennial Forbs	119	51.51	99	20
Graminoids	58	25.11	51	7
Woody (Trees and Shrubs)	30	12.99	30	0
Total	231	100	195	36

Table 3.2: Mean (with standard deviations, brackets) values for diversity per plot (species richness, Shannon diversity index and effective diversity), and percent cover of life forms (lichen, moss, graminoid, forb, shrub, tree) for all eight alvar vegetation types (I-VIII) in Manitoba (Figure 3.2). See Appendix 4 for descriptions of vegetation types.

VARIABLE	**I** [n = 5]	**II** [n = 13]	**III** [n = 22]	**IV** [n = 9]	**V** [n = 21]	**VI** [n = 10]	**VII** [n = 14]	**VIII** [n = 9]
Species Richness per plot	**20** (7.05)	**39** (6.20)	**45** (7.23)	**45** (7.87)	**55** (8.82)	**60** (5.72)	**49** (7.31)	**53** (5.68)
Shannon Diversity (H) per plot	**1.55** (0.33)	**2.03** (0.40)	**2.19** (0.40)	**1.67** (0.46)	**2.43** (0.31)	**2.55** (0.21)	**2.27** (0.22)	**2.04** (0.67)
Effective Richness (e^H) per plot	**4.9** (1.42)	**8.2** (3.40)	**9.6** (3.79)	**5.8** (2.29)	**11.9** (3.70)	**13.1** (2.47)	**9.9** (2.11)	**9.0** (4.38)
Introduced Species (% Cover)	**4.30** (4.05)	**21.31** (23.06)	**16.67** (14.06)	**3.39** (2.63)	**5.57** (8.21)	**18.57** (17.40)	**10.80** (24.44)	**0.10** (0.10)
Annuals (% Cover)[*]	**0.14** (0.19)	**0.79** (1.53)	**1.62** (3.82)	**0.25** (0.32)	**0.36** (0.39)	**0.57** (0.49)	**0.27** (0.30)	**0.01** (0.01)
Bryophytes (% Cover)	**23.97** (7.98)	**9.75** (9.88)	**4.24** (5.55)	**9.07** (5.61)	**6.59** (5.73)	**0.90** (0.82)	**3.50** (1.85)	**4.63** (3.56)
Lichens (% Cover)	**0.12** (0.27)	**3.76** (4.84)	**8.02** (10.56)	**22.04** (11.28)	**17.75** (15.26)	**2.05** (4.10)	**1.40** (3.28)	**11.71** (9.89)
Graminoids (% Cover)[*]	**82.60** (25.65)	**59.23** (26.10)	**38.07** (14.66)	**14.15** (7.89)	**21.97** (12.42)	**34.74** (15.55)	**36.01** (41.45)	**32.37** (30.48)
Herbaceous Perennials (% Cover)[*]	**6.05** (5.28)	**17.60** (9.44)	**33.33** (13.59)	**8.91** (5.05)	**19.30** (10.92)	**24.62** (7.25)	**33.96** (15.02)	**10.45** (3.57)
***Arctostaphylos uva-ursi* (% Cover)**	**0.00** (0.00)	**0.10** (0.35)	**7.37** (17.17)	**1.88** (2.14)	**17.87** (13.25)	**12.86** (6.98)	**27.12** (18.18)	**16.72** (7.66)
***Juniperus* spp. (% Cover)**	**1.05** (2.35)	**1.20** (3.71)	**4.55** (10.28)	**36.11** (27.15)	**17.61** (13.14)	**3.06** (7.83)	**2.55** (5.44)	**15.55** (13.65)
Woody Shrubs (% Cover)[†]	**1.04** (1.04)	**12.96** (16.32)	**5.46** (7.44)	**19.33** (17.77)	**12.73** (11.69)	**28.37** (13.75)	**18.09** (16.21)	**12.73** (6.45)
Trees (% Cover)	**0.00** (0.00)	**0.00** (0.00)	**0.02** (0.11)	**0.02** (0.05)	**11.83** (9.87)	**13.23** (11.00)	**3.09** (7.45)	**9.16** (11.35)

[*] includes Introduced Species.

[†] excluding *Arctostaphylos uva-ursi* and *Juniperus* spp.

Table 3.3: Mean (with standard deviations, brackets) values for soil chemistry (PO4, EC, exchangeable K, NO3-N and pH), substrate (soil depth, percent cover bare soil, percent cover bare rock, percent cover litter and moisture regime) and intensity of grazing and browsing (estimated by percent cover of patties or pellets). See Appendix 4 for descriptions of vegetation types (I-VIII).

VARIABLE	**I** [n = 5]	**II** [n = 13]	**III** [n = 22]	**IV** [n = 9]	**V** [n = 21]	**VI** [n = 10]	**VII** [n = 14]	**VIII** [n = 9]
Soil Depth (mm)	**49.10** (13.51)	**51.50** (29.13)	**55.68** (26.45)	**19.90** (15.88)	**36.05** (20.82)	**74.48** (22.17)	**81.13** (19.61)	**41.86** (13.03)
Soil Moisture Class (rank 1-10)	**8.60** (0.55)	**5.23** (2.05)	**5.32** (1.46)	**3.11** (1.17)	**4.19** (1.29)	**5.30** (0.82)	**5.71** (1.27)	**3.67** (1.22)
NO_3-N (mg/kg)	**97.18** (119.27)	**56.90** (65.43)	**73.26** (106.74)	**152.26** (205.70)	**94.17** (76.67)	**19.37** (18.67)	**24.16** (18.47)	**84.42** (95.66)
PO_4-P (mg/kg)	**29.00** (18.17)	**11.75** (3.99)	**12.30** (5.92)	**13.72** (5.62)	**10.44** (3.33)	**8.15** (2.91)	**14.49** (10.07)	**10.22** (6.06)
Exchangeable K (mg/kg)	**238.00** (85.26)	**232.31** (122.35)	**253.18** (94.59)	**222.22** (67.41)	**209.52** (58.35)	**236.00** (138.58)	**188.57** (42.94)	**204.44** (44.47)
pH	**7.26** (0.19)	**7.48** (0.19)	**7.35** (0.19)	**7.49** (0.19)	**7.30** (0.17)	**7.13** (0.28)	**7.30** (0.30)	**7.39** (0.26)
Electrical Conductivity (mS/cm)	**0.64** (0.32)	**0.54** (0.16)	**0.53** (0.25)	**0.72** (0.39)	**0.57** (0.18)	**0.33** (0.09)	**0.38** (0.08)	**0.49** (0.17)
Bare Rock Cover (%)	**1.93** (2.63)	**4.72** (6.56)	**5.64** (9.35)	**14.08** (9.20)	**8.85** (9.24)	**5.32** (9.44)	**0.30** (0.50)	**4.65** (5.33)
Bare Soil Cover (%)	**0.90** (0.78)	**4.81** (10.64)	**2.53** (3.67)	**2.75** (4.18)	**1.74** (2.00)	**0.50** (0.46)	**0.44** (0.54)	**1.50** (2.09)
Organic Litter Cover (%)	**0.98** (1.44)	**3.06** (4.47)	**0.80** (0.91)	**2.72** (3.44)	**2.49** (1.56)	**2.11** (1.54)	**1.62** (1.17)	**2.71** (1.76)
Grazing Intensity (% cover dung)	**1.51** (2.37)	**0.63** (0.82)	**1.80** (1.44)	**0.39** (0.49)	**0.79** (0.78)	**1.77** (2.53)	**0.16** (0.43)	**0.00** (0.00)
Browsing Intensity (% cover dung)	**0.00** (0.00)	**0.00** (0.00)	**0.04** (0.08)	**0.03** (0.06)	**0.13** (0.20)	**0.09** (0.10)	**0.11** (0.21)	**1.13** (1.10)

Table 3.4: Indicator species values of alvar vegetation types I and II in Manitoba (Figure 3.2; Appendix 4). The highest five indicator values of each type are highlighted yellow followed by the next highest ten highlighted in blue. See Appendix 4 for descriptions of vegetation types.

SPECIES	**I**	II	III	IV	V	VI	VII	VIII
Rumex aquaticus var. *fenestratus*	**0.790**	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Deschampsia caespitosa	**0.735**	0.159	0.000	0.000	0.000	0.000	0.027	0.000
Carex tenera	**0.731**	0.036	0.001	0.000	0.000	0.000	0.007	0.000
Carex pellita	**0.600**	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Juncus balticus	**0.589**	0.002	0.000	0.000	0.000	0.000	0.001	0.000
Symphyotrichum lanceolatum	**0.581**	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Carex praegracilis	**0.514**	0.000	0.039	0.000	0.000	0.000	0.040	0.000
Carex brevior	**0.462**	0.045	0.003	0.001	0.000	0.000	0.000	0.000
Epilobium leptophyllum	**0.400**	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mentha arvensis var. *villosa*	**0.400**	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Typha latifolia	**0.400**	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hordeum jubatum	**0.395**	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Salix pediolaris	**0.395**	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Carex bebbii	**0.279**	0.000	0.028	0.000	0.000	0.000	0.000	0.000
Agrostis stolonifera	**0.262**	0.013	0.020	0.083	0.075	0.000	0.000	0.000

SPECIES	I	**II**	III	IV	V	VI	VII	VIII
Eleocharis compressa	0.207	**0.717**	0.002	0.003	0.000	0.000	0.000	0.000
Packera paupercula	0.000	**0.525**	0.020	0.093	0.006	0.000	0.005	0.002
Poa compressa	0.117	**0.458**	0.041	0.114	0.037	0.002	0.000	0.000
Juncus dudleyi	0.225	**0.442**	0.110	0.000	0.002	0.000	0.000	0.000
Prunella vulgaris	0.015	**0.377**	0.008	0.086	0.001	0.000	0.000	0.000
Potentilla gracilis	0.174	**0.358**	0.011	0.003	0.000	0.000	0.000	0.000
Koeleria macrantha	0.001	**0.352**	**0.307**	0.100	0.060	0.047	0.049	0.004
Allium stellatum	0.000	**0.317**	0.117	0.105	0.019	0.011	0.074	0.005
Potentilla bipinnatifida	0.001	**0.308**	0.201	0.048	0.001	0.000	0.000	0.000
Veronica peregrina	0.018	**0.293**	0.002	0.011	0.001	0.000	0.000	0.000
Poa alpina	0.000	**0.281**	0.207	0.028	0.015	0.000	0.000	0.000
Ranunculus rhomboideus	0.000	**0.280**	0.039	0.003	0.000	0.000	0.015	0.000
Ditrichum flexicaule	0.000	**0.273**	0.043	**0.243**	0.055	0.000	0.000	0.046
Lepidium densiflorum	0.000	**0.258**	0.056	0.113	0.001	0.000	0.000	0.000
Brachythecium sp.	0.000	**0.252**	0.037	0.000	0.050	0.118	0.175	0.073

Table 3.4 (Continued): Indicator species values of alvar vegetation types III and IV in Manitoba (Figure 3.2; Appendix 4). The highest five indicator values of each type are highlighted yellow followed by the next highest ten highlighted in blue. See Appendix 4 for descriptions of vegetation types.

SPECIES	I	II	**III**	IV	V	VI	VII	VIII
Geum triflorum	0.001	0.073	**0.497**	0.018	0.090	0.073	0.175	0.015
Agrostis scabra	0.001	0.004	**0.400**	0.003	0.021	0.030	0.231	0.000
Elymus trachycaulus ssp. *subsecundus*	0.000	0.017	**0.394**	0.026	0.043	0.188	0.182	0.006
Festuca saximontana	0.000	0.006	**0.353**	0.043	0.124	0.037	0.142	0.136
Antennaria howellii ssp. *neodioica*	0.000	0.147	**0.326**	0.033	0.152	0.068	0.144	0.034
Achillea millefolium	0.000	0.215	**0.323**	0.091	0.049	0.181	0.083	0.004
Koeleria macrantha	0.001	**0.352**	**0.307**	0.100	0.060	0.047	0.049	0.004
Arenaria serpyllifolia	0.001	0.022	**0.251**	0.039	0.083	0.010	0.000	0.000
Medicago lupulina	0.000	0.075	**0.242**	0.070	0.155	0.132	0.000	0.000
Trifolium pratense	0.000	0.081	**0.242**	0.000	0.021	0.010	0.000	0.000
Poa pratensis	0.025	0.152	**0.237**	0.000	0.042	0.340	0.108	0.000
Danthonia spicata	0.000	0.070	**0.230**	0.127	0.185	0.243	0.024	0.016
Sisyrinchium montanum	0.000	0.186	**0.227**	0.049	0.038	0.024	0.215	0.078
Symphyotrichum ericoides var. *ericoides*	0.000	0.078	**0.211**	0.000	0.000	0.000	0.021	0.000
Poa alpina	0.000	0.281	**0.207**	0.028	0.015	0.000	0.000	0.000

SPECIES	I	II	III	**IV**	V	VI	VII	VIII
Tortella sp.	0.000	0.016	0.023	**0.556**	**0.294**	0.000	0.028	0.014
Anthyllis vulneraria	0.000	0.002	0.000	**0.479**	0.008	0.000	0.002	0.000
Solidago simplex ssp. *simplex*	0.000	0.001	0.016	**0.462**	0.010	0.000	0.000	0.000
Cirsium arvense	0.000	0.000	0.001	**0.437**	0.000	0.000	0.000	0.000
Minuartia dawsonensis	0.000	0.001	0.023	**0.398**	0.193	0.007	0.001	0.046
Elymus trachycaulus ssp. *trachycaulus*	0.000	0.053	0.012	**0.376**	0.002	0.008	0.020	0.004
Foliose lichens	0.000	0.057	0.112	**0.357**	**0.239**	0.025	0.008	0.142
Juniperus horizontalis	0.003	0.006	0.029	**0.352**	0.169	0.021	0.011	0.177
Arabis hirsuta	0.000	0.035	0.144	**0.292**	0.199	0.022	0.006	0.031
Solidago nemoralis	0.000	0.013	0.030	**0.288**	0.188	0.074	0.049	0.120
Small Carex	0.000	0.001	0.005	**0.270**	0.049	0.216	0.018	0.067
Dasiphora fruticosa ssp. *floribunda*	0.003	0.172	0.052	**0.255**	0.100	0.081	0.196	0.083
Carex scirpoidea	0.000	0.157	0.019	**0.254**	0.035	0.000	0.001	0.004
Cerastium arvense	0.000	0.061	0.193	**0.249**	**0.224**	0.167	0.020	0.005
Ditrichum flexicaule	0.000	**0.273**	0.043	**0.243**	0.055	0.000	0.000	0.046

Table 3.4 (Continued): Indicator species values of alvar vegetation types V and VI in Manitoba (Figure 3.2; Appendix 4). The highest five indicator values of each type are highlighted yellow followed by the next highest ten highlighted in blue. See Appendix 4 for descriptions of vegetation types.

SPECIES	I	II	III	IV	**V**	VI	VII	VIII
Juniperus communis	0.000	0.000	0.004	0.075	**0.472**	0.000	0.005	0.047
Symphoricarpos albus	0.000	0.000	0.028	0.010	**0.329**	**0.462**	0.030	0.029
Crustose lichens	0.001	0.013	0.052	0.172	**0.304**	0.045	0.002	0.011
Tortella sp.	0.000	0.016	0.023	**0.556**	**0.294**	0.000	0.028	0.014
Heuchera richardsonii	0.000	0.000	0.025	0.030	**0.286**	0.066	0.012	**0.221**
Apocynum androsaemifolium	0.000	0.000	0.000	0.000	**0.284**	0.123	0.000	0.002
Fruticose lichens	0.000	0.000	0.018	0.044	**0.246**	0.001	0.030	**0.309**
Anemone cylindrica	0.000	0.000	0.056	0.015	**0.243**	**0.377**	0.080	0.040
Foliose lichens	0.000	0.057	0.112	**0.357**	**0.239**	0.025	0.008	0.142
Piptatheropsis pungens	0.000	0.000	0.000	0.000	**0.237**	0.047	0.000	0.023
Quercus macrocarpa	0.000	0.000	0.000	0.000	**0.234**	**0.522**	0.000	0.010
Pulsatilla patens ssp. *patens*	0.000	0.000	0.028	0.000	**0.230**	0.023	0.021	**0.258**
Cerastium arvense	0.000	0.061	0.193	**0.249**	**0.224**	0.167	0.020	0.005
Arctostaphylos uva-ursi	0.000	0.000	0.028	0.012	**0.213**	0.138	**0.277**	0.199
Carex richardsonii	0.000	0.001	0.024	0.027	**0.202**	0.000	0.000	0.011

SPECIES	I	II	III	IV	V	**VI**	VII	VIII
Prunus virginiana	0.000	0.000	0.001	0.001	0.134	**0.708**	0.004	0.014
Amelanchier alnifolia	0.000	0.000	0.015	0.012	0.106	**0.656**	0.127	0.002
Lysimachia ciliata	0.000	0.000	0.000	0.001	0.000	**0.594**	0.000	0.000
Sanicula marilandica	0.000	0.000	0.000	0.000	0.000	**0.575**	0.005	0.012
Quercus macrocarpa	0.000	0.000	0.000	0.000	**0.234**	**0.522**	0.000	0.010
Hieracium umbellatum	0.000	0.001	0.001	0.000	0.007	**0.489**	0.231	0.017
Corylus cornuta	0.000	0.000	0.000	0.000	0.006	**0.483**	0.000	0.000
Symphyotrichum ciliolatum	0.000	0.000	0.000	0.000	0.056	**0.480**	0.134	0.012
Symphoricarpos albus	0.000	0.000	0.028	0.010	**0.329**	**0.462**	0.030	0.029
Artemisia ludoviciana	0.000	0.001	0.059	0.000	0.003	**0.453**	0.038	0.000
Monarda fistulosa	0.000	0.000	0.010	0.015	0.166	**0.416**	0.151	0.083
Schizachne purpurascens	0.000	0.000	0.000	0.000	0.074	**0.408**	0.001	0.000
Thalictrum venulosum	0.000	0.001	0.031	0.000	0.048	**0.392**	0.125	0.000
Maianthemum canadense	0.000	0.000	0.001	0.000	0.063	**0.378**	0.000	0.001
Anemone cylindrica	0.000	0.000	0.056	0.015	**0.243**	**0.377**	0.080	0.040

Table 3.4 (Continued): Indicator species values of alvar vegetation types VII and VIII in Manitoba (Figure 3.2; Appendix 4). The highest five indicator values of each type are highlighted yellow followed by the next highest ten highlighted in blue. See Appendix 4 for descriptions of vegetation types.

SPECIES	I	II	III	IV	V	VI	**VII**	VIII
Oligoneuron rigidum	0.000	0.002	0.000	0.002	0.003	0.193	**0.616**	0.065
Agoseris glauca	0.000	0.000	0.016	0.000	0.000	0.023	**0.590**	0.029
Symphyotrichum laeve	0.001	0.027	0.058	0.023	0.083	0.038	**0.570**	0.085
Bromus porteri	0.000	0.000	0.003	0.000	0.089	0.161	**0.491**	0.067
Phleum pratense	0.016	0.024	0.014	0.000	0.020	0.001	**0.486**	0.000
Gaillardia aristata	0.000	0.003	0.009	0.038	0.018	0.017	**0.426**	0.158
Potentilla arguta	0.000	0.001	0.038	0.000	0.055	0.058	**0.331**	0.000
Liatris ligulistylis	0.000	0.000	0.000	0.000	0.009	0.078	**0.322**	0.129
Rosa acicularis	0.000	0.041	0.094	0.058	0.135	0.159	**0.322**	0.050
Hesperostipa spartea	0.000	0.000	0.000	0.000	0.000	0.020	**0.320**	0.001
Vicia americana	0.000	0.004	0.112	0.000	0.117	0.152	**0.315**	0.064
Erigeron glabellus	0.000	0.001	0.081	0.000	0.157	0.232	**0.294**	0.021
Arctostaphylos uva-ursi	0.000	0.000	0.028	0.012	**0.213**	0.138	**0.277**	0.199
Oligoneuron album	0.000	0.073	0.041	0.174	0.134	0.011	**0.272**	0.052
Fragaria virginiana	0.000	0.000	0.000	0.000	0.011	0.368	**0.262**	0.100
SPECIES	I	II	III	IV	V	VI	VII	**VIII**
Andropogon gerardii	0.000	0.000	0.000	0.003	0.000	0.028	0.006	**0.864**
Dalea purpurea	0.000	0.000	0.000	0.000	0.000	0.042	0.034	**0.615**
Populus tremuloides	0.000	0.000	0.001	0.000	0.004	0.012	0.021	**0.514**
Betula glandulosa	0.000	0.000	0.000	0.000	0.000	0.102	0.000	**0.513**
Pediomelum esculentum	0.000	0.000	0.000	0.000	0.000	0.000	0.004	**0.419**
Lilium philadelphicum	0.000	0.000	0.000	0.000	0.058	0.004	0.022	**0.377**
Picea glauca	0.000	0.000	0.000	0.000	0.052	0.000	0.000	**0.360**
Solidago hispida	0.000	0.003	0.001	0.024	0.191	0.180	0.019	**0.336**
Fruticose lichens	0.000	0.000	0.018	0.044	**0.246**	0.001	0.030	**0.309**
Rudbeckia hirta var. pulcherrima	0.000	0.000	0.002	0.000	0.006	0.000	0.011	**0.286**
Shepherdia canadensis	0.000	0.000	0.000	0.000	0.025	0.065	0.039	**0.268**
Pulsatilla patens ssp. *patens*	0.000	0.000	0.028	0.000	**0.230**	0.023	0.021	**0.258**
Linum lewisii	0.000	0.000	0.009	0.000	0.002	0.000	0.022	**0.233**
Astragalus laxmanii var. *robustior*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.222**
Heuchera richardsonii	0.000	0.000	0.025	0.030	**0.286**	0.066	0.012	**0.221**

Table 3.5: Vegetation types of the current classification compared to communities described in previous classifications by the Manitoba Alvar Initiative (2012; Table 2.2), Reschke *et al.* (1999; Appendix 2) and Brownell and Riley (2000).

Current Classification			**Previous Classifications**		
Type	Sub-type	Association	Mantioba Alvar Initiative (2012)	Reschke et al (1999)	Brownell and Riley (2000)
I	N/A	*Deschampsia caespitosa - Carex pellita - Juncus balticus- Carex tennera*	alvar wetland	tufted hairgrass wet alvar grassland	tufted hairgrass wet alvar grassland
II	1	*Poa pratensis- Poa compressa- Poa alpina*	alvar grassland	poverty grass dry grassland	Canada bluegrass grassland
II	2	*Deschampsia caespitosa- Alliuum stellatum- Packera paupercula- Dasiphora fruiticosa*	alvar wetland	tufted hairgrass wet alvar grassland	tufted hairgrass wet alvar grassland
III	1	*Poa pratensis- Geum triflorum- Achillea millefolium*	alvar grassland	poverty grass dry grassland	Canada bluegrass grassland
III	2	*Festuca hallii- Festuca saximontanta, Danthina spicata*	alvar grassland	poverty grass dry grassland	poverty oat grassland
IV	N/A	*Juniperus horizontalis- Dasiphora fruiticosa- Solidago simplex- Solidago nemoralis*	prairie shrubland	creeping juniper- shrubby cinquefoil alvar pavement	dwarf shrubland (creeping juniper) or creeping juniper pavement
V	1	*Pinus banksianana- Acrtostaphylos uva-ursi- Arenaria serpyllifolia*	jack pine savanna	scrub conifer/ dwarf lake iris alvar shrubland *	jack pine/ bearberry and jack pine/common juniper
V	2	*Juniperus communis - Juniperus horizontalis- Quercus macrocarpa*	boulder/exposed ridge shrubland, intermediate shrubland	juniper alvar shrubland or creeping juniper shrubby cinqufoil alvar pavement	bur oak/ common juniper
VI	N/A	*Quercus macrocarpa- Amelanchier alnifolia- Prunus virginiana*	bur oak savanna	juniper alvar shrubland	bur oak deciduous tall shrubland
VII	N/A	*Pinus banksiana- Acrostaphylos uva-ursi- Dasiphora fruiticosa- Olgioneuron rigidum*	jack pine savanna	scrub conifer/ dwarf lake iris alvar shrubland *	jack pine/ bearberry savanna
VIII	1	*Andropogon gerardii - Dalea candida- Hesperostipa spartea*	spruce savanna	scrub conifer/dwarf lake iris alvar shrubland*	bluestem grassland
VIII	2	*Picea glauca- Arctostaphlos uva-ursi - Betula glandulosa*	spruce savanna	mixed conifer/ common juniper alvar woodland	spruce savanna

* lack species such as *Iris lacustris* and *Thuja occidentalis*

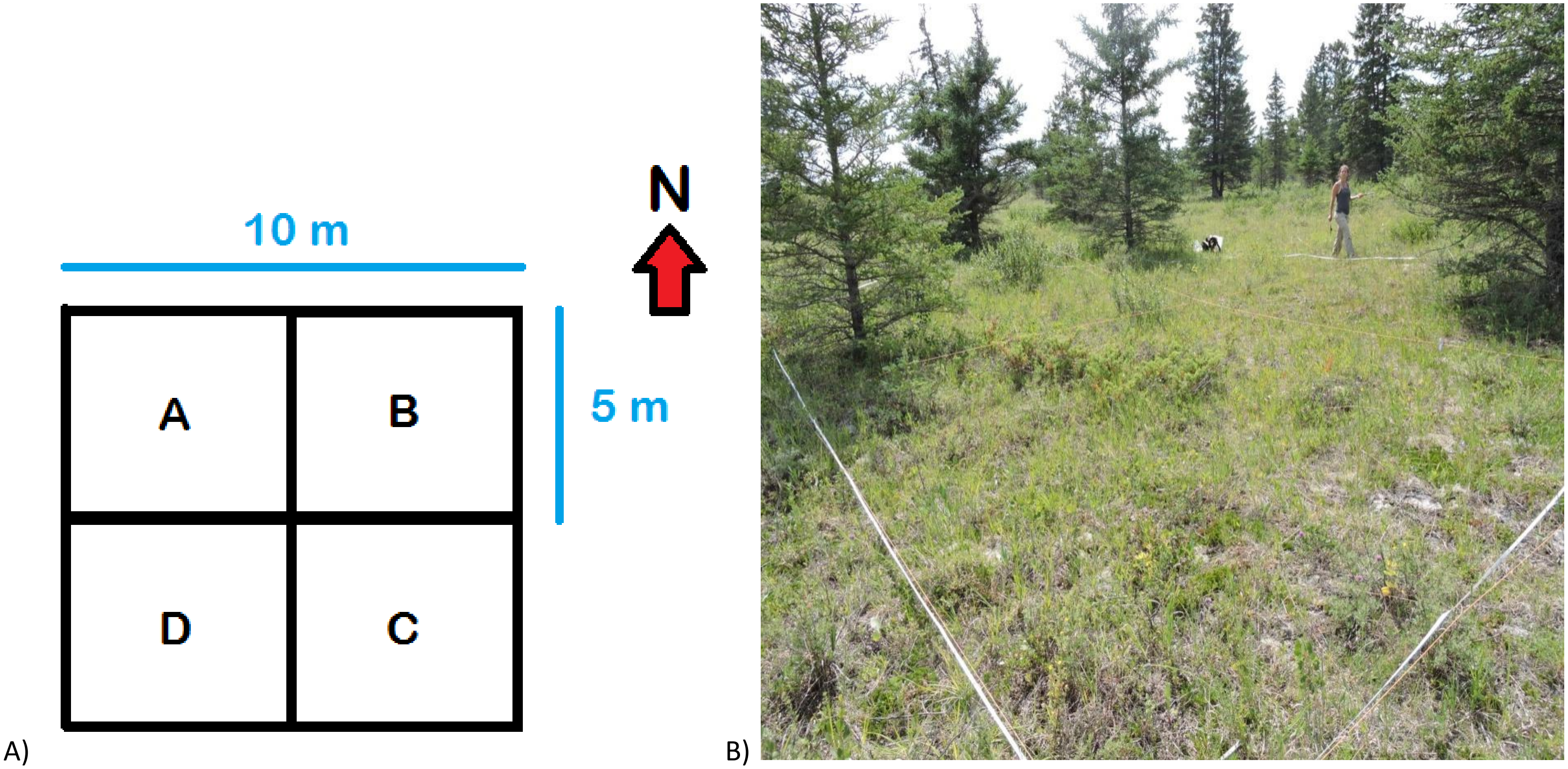


Figure 3.1: Plot methodology showing division of 10X10m plot into 5X5m sections in form of a diagram (A) and photo from in the field (B). Plots were oriented in a consistent direction and permanently marked with copper tags and nails in corners A, B and C. GPS locations were taken at corner D, which was marked with a metal stake and flagging tape.

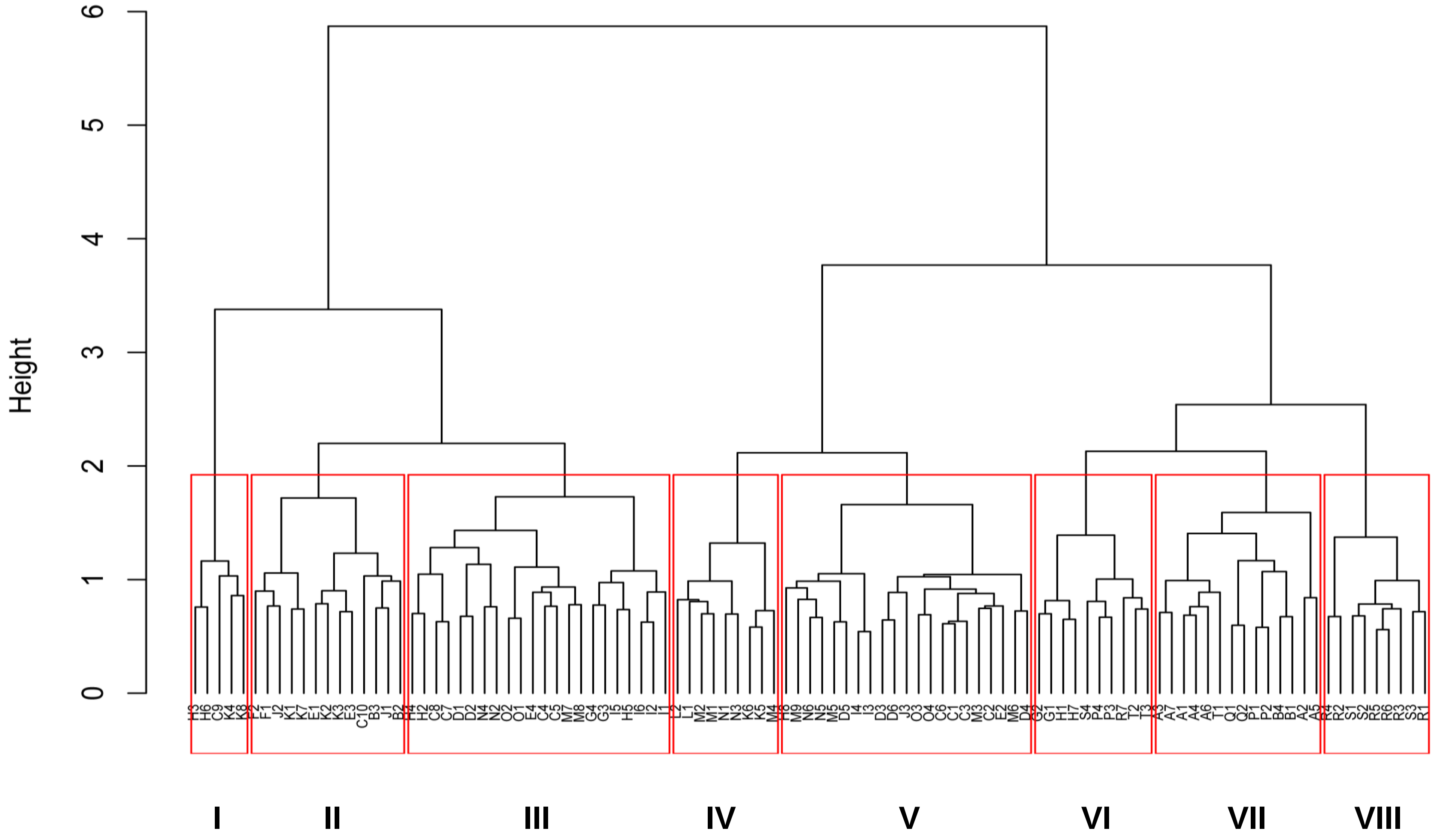


Figure 3.2: Cluster analysis (chord distance, Ward's hierarchical clustering) dendrogram of the 103 vegetation plotsbased on log-transformed cover-abundance values for 246 species. The partitioning of the dendrogram resulted in eight groups (vegetation types) that are shown as red boxes (from I on the left to VIII on the right). Types are described in detail in Appendix 4. The letters associated with terminal branches refer to sites shown in Figure 2.1. Numbers reference individual plots at each of these sites.

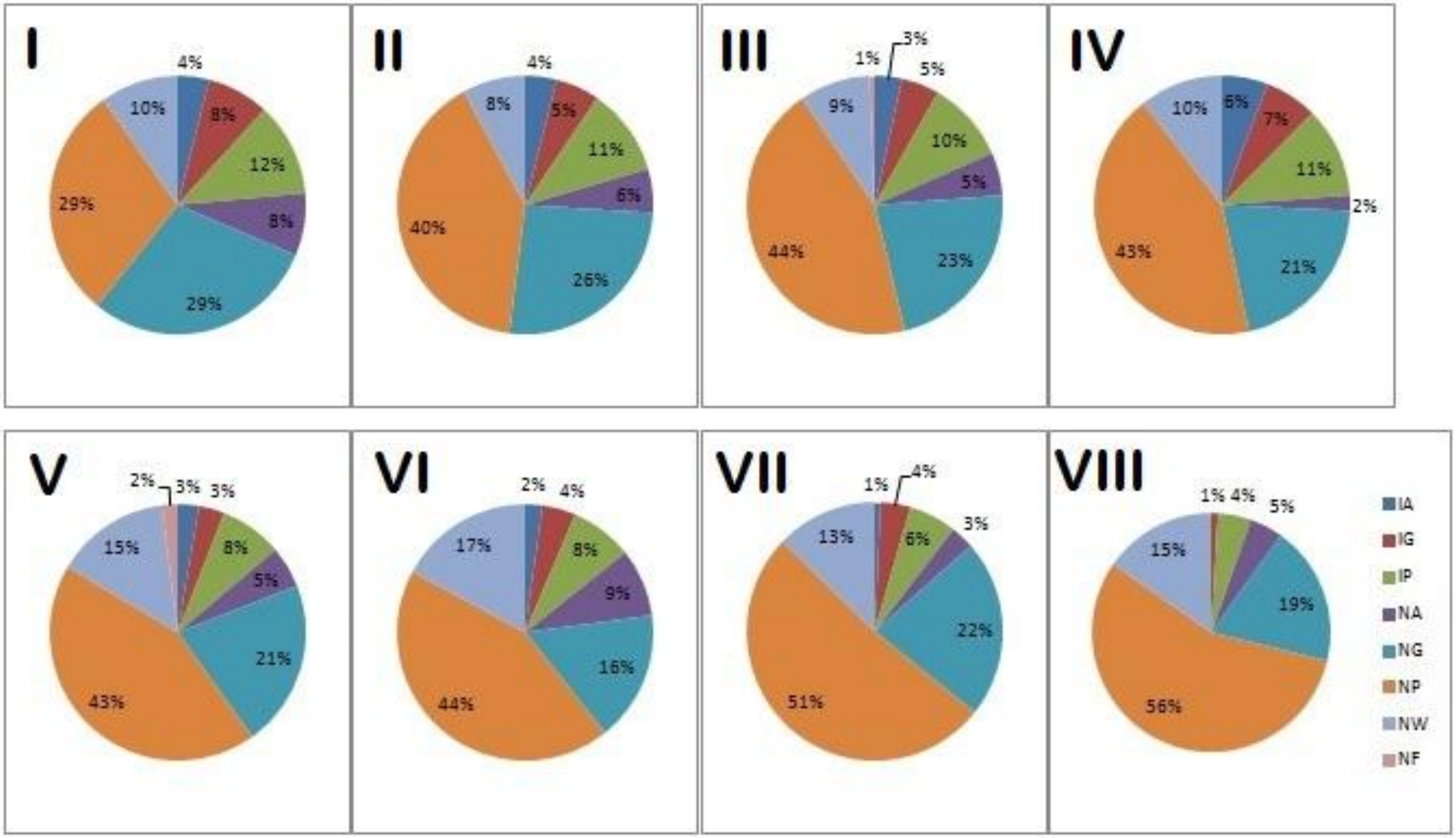


Figure 3.3: Proportions species belonging to various life forms (IA=introduced annual, IG= introduced graminoid, IP=introduced perennial, NA= native annual, NG=native graminoid, NP= native perennial, NW=native woody and NF=native fern) for each of the eight alvar vegetation communities (Appendix 4).

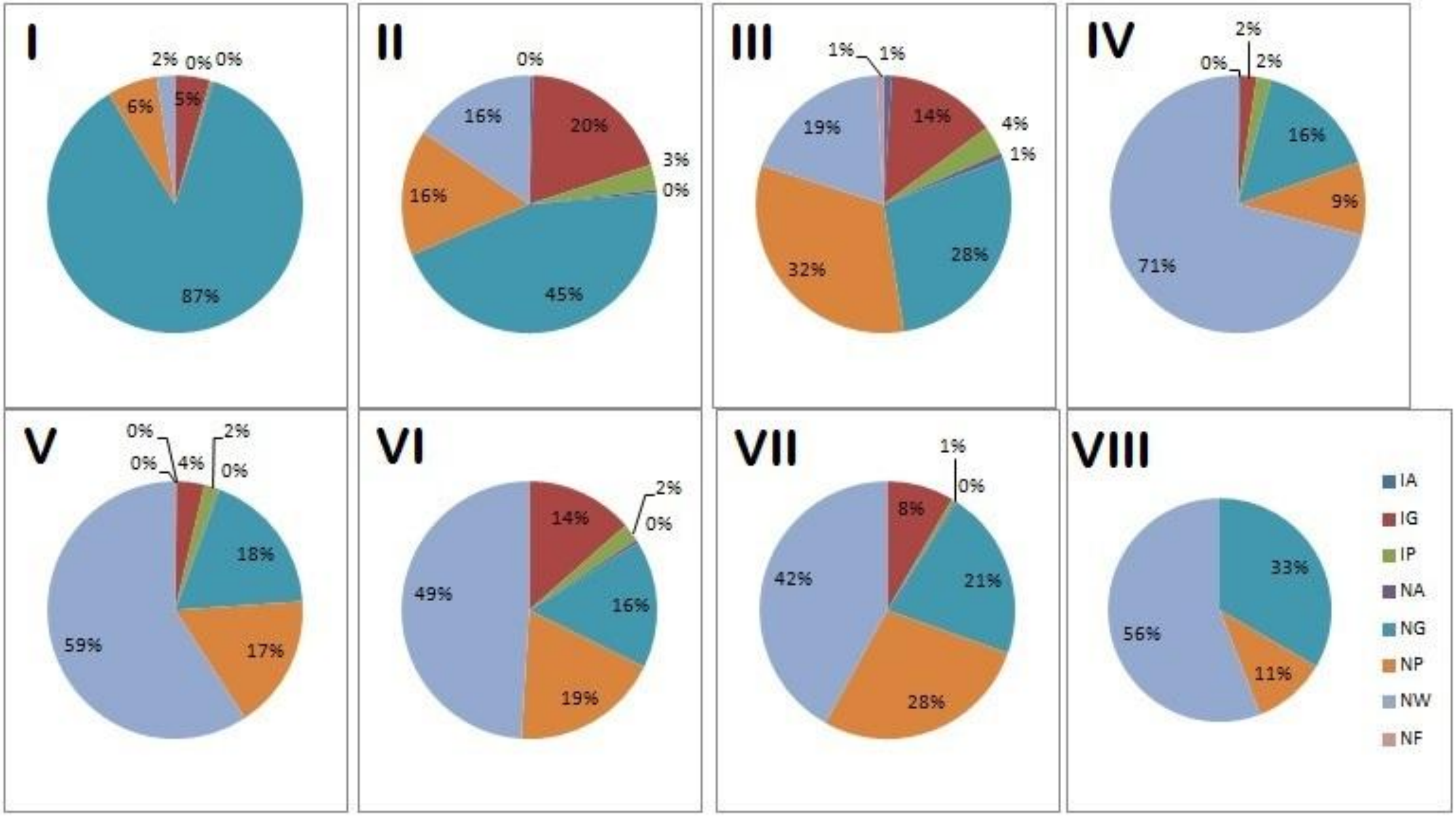


Figure 3.4: Proportions of vegetation cover by life forms (IA=introduced annual, IG= introduced graminoid, IP=introduced perennial, NA= native annual, NG=native graminoid, NP= native perennial, NW=native woody and NF=native fern) for each of the eight alvar vegetation communities (Appendix 4).

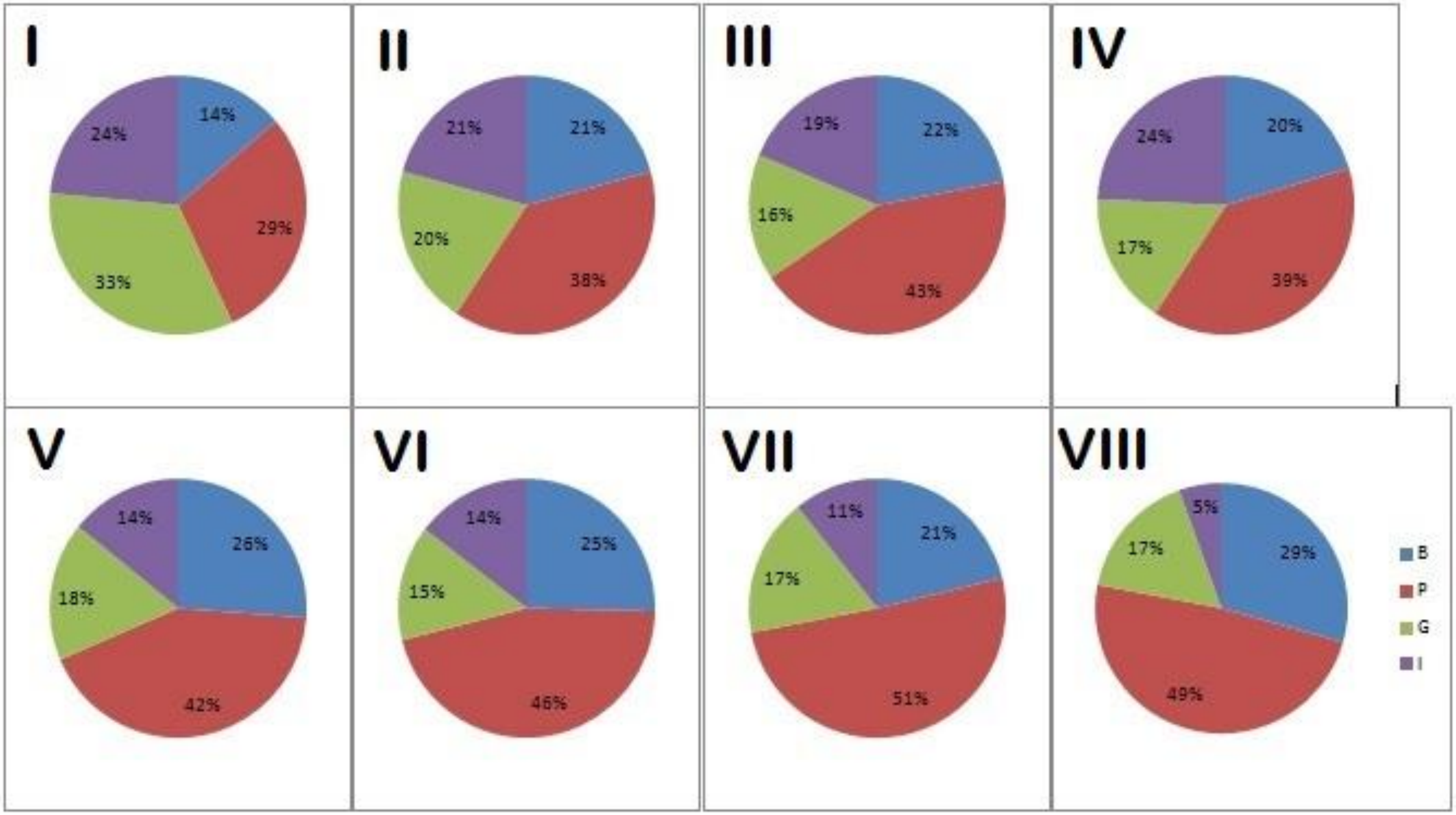


Figure 3.5: Affinity of eight vegetation communities (Appendix 4) calculated by proportion of species with boreal (B), prairie (P), generalist (G) and introduced (I) affinities.

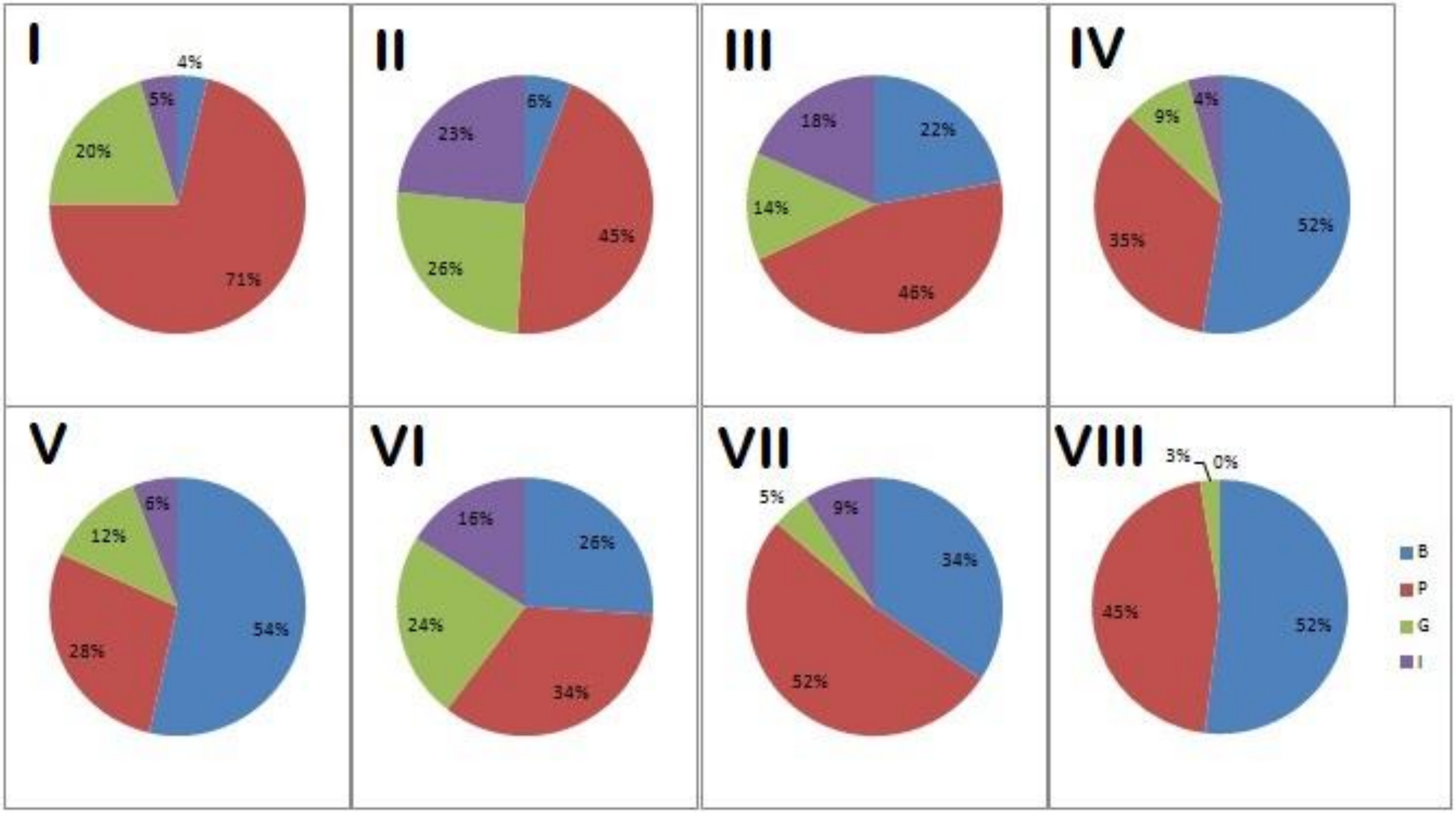


Figure 3.6: Affinity of eight vegetation communities (Appendix 4) calculated by percent cover of boreal (B), prairie (P), generalist (G) and introduced (I) species.

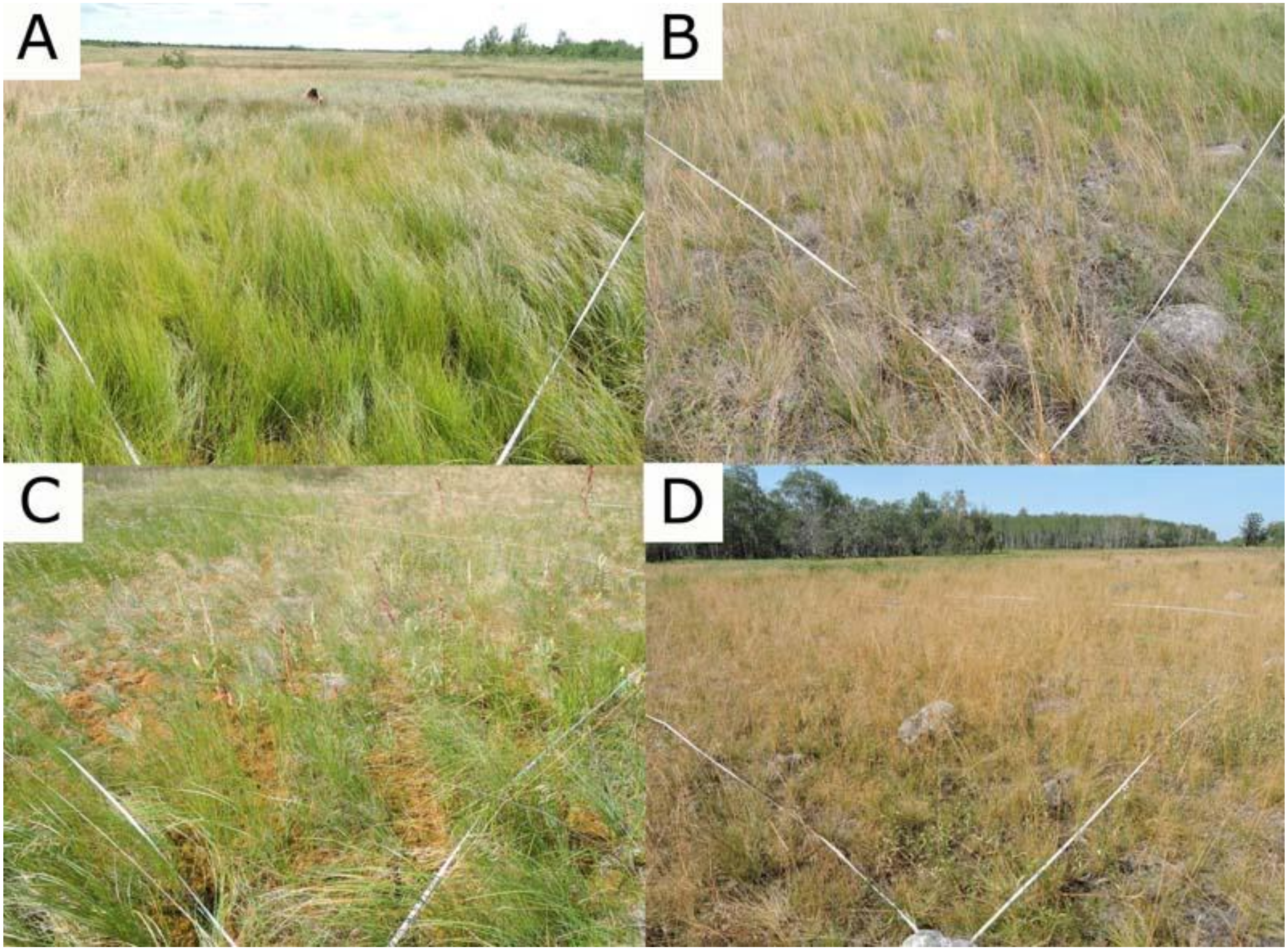


Figure 3.7: Type I, Wet graminoid meadow alvar at A) Sylvan alvar at plot H3, B) Fisher alvar at plot K8, C) Fisher alvar at plot K4 and D) Marble Ridge alvar at plot C9. Site locations are shown in Figure 2.1.

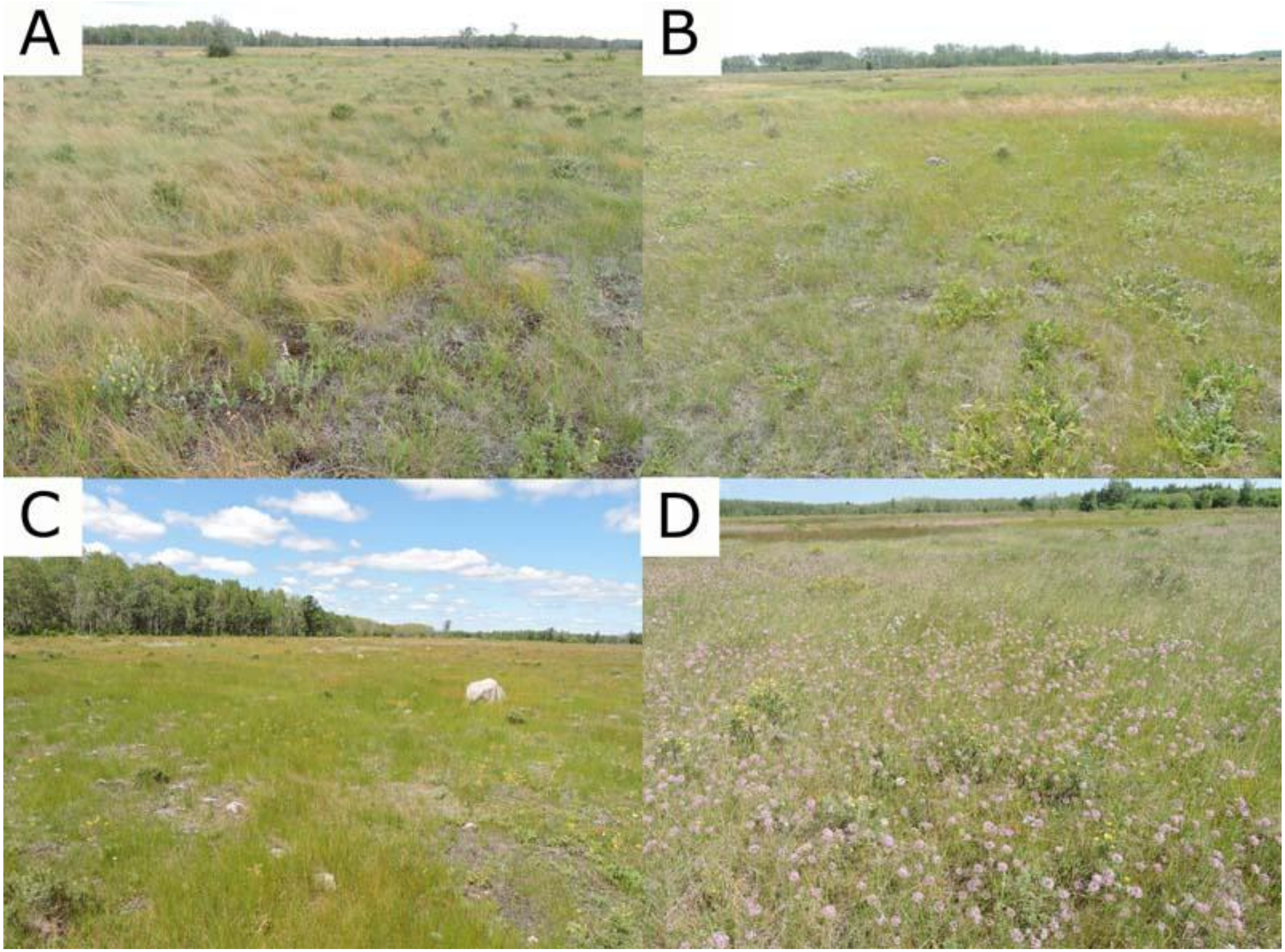


Figure 3.8: Type II, moist graminoid meadow alvar at A) Marble Ridge alvar plot E3, B) Fisher alvar plot K7, C) Marble Ridge alvar plot F2 and D) Peguis alvar plot B2. Site locations are shown in Figure 2.1.

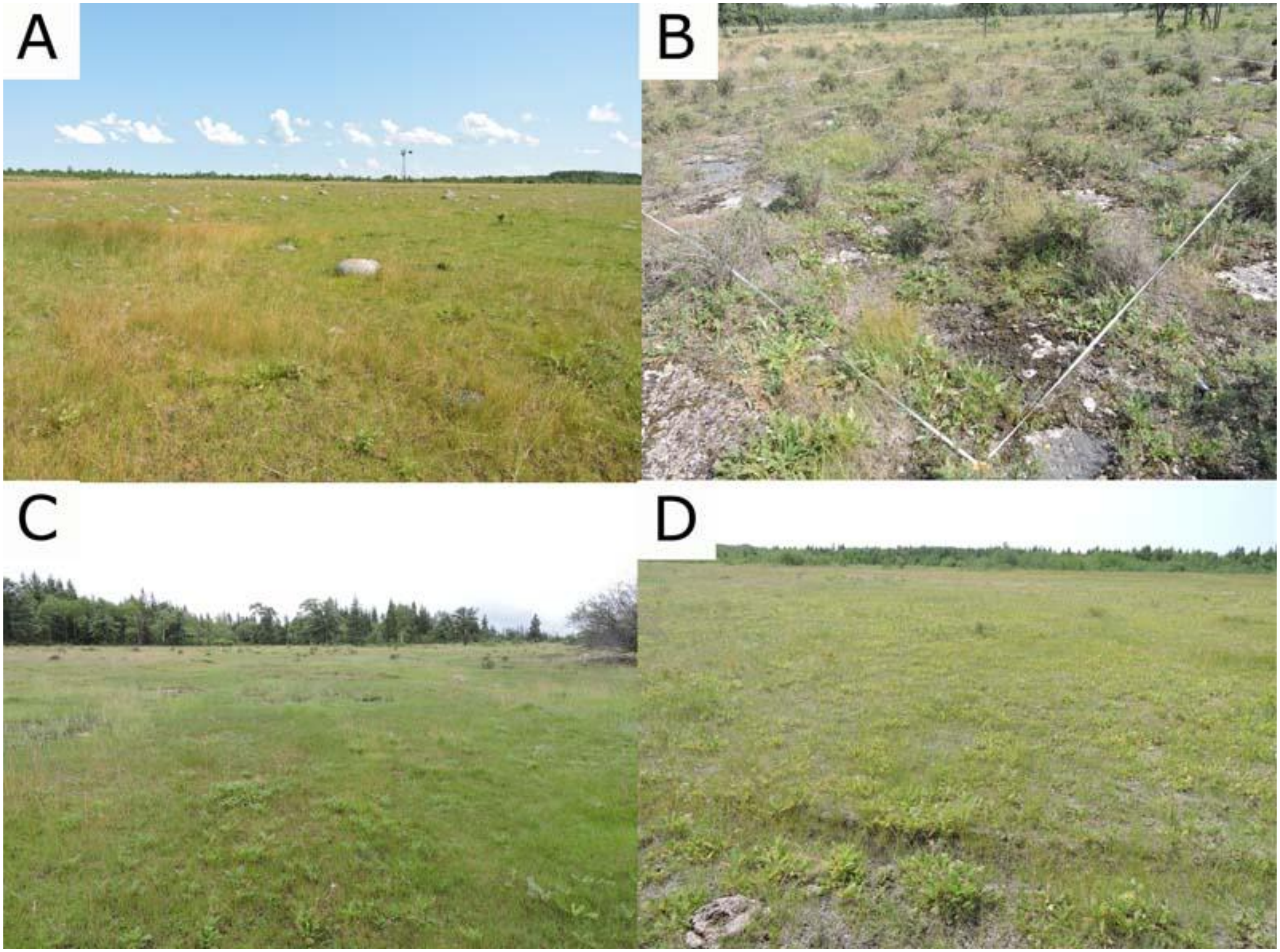


Figure 3.9: Type III, Dry alvar grassland at the Sylvan alvar at A) Sylvan alvar at plot H2, B) Marble Ridge alvar at plot C4, C) Marble Ridge alvar at plot D1 and D) Sylvan alvar at plot I1. Site locations are shown in Figure 2.1.

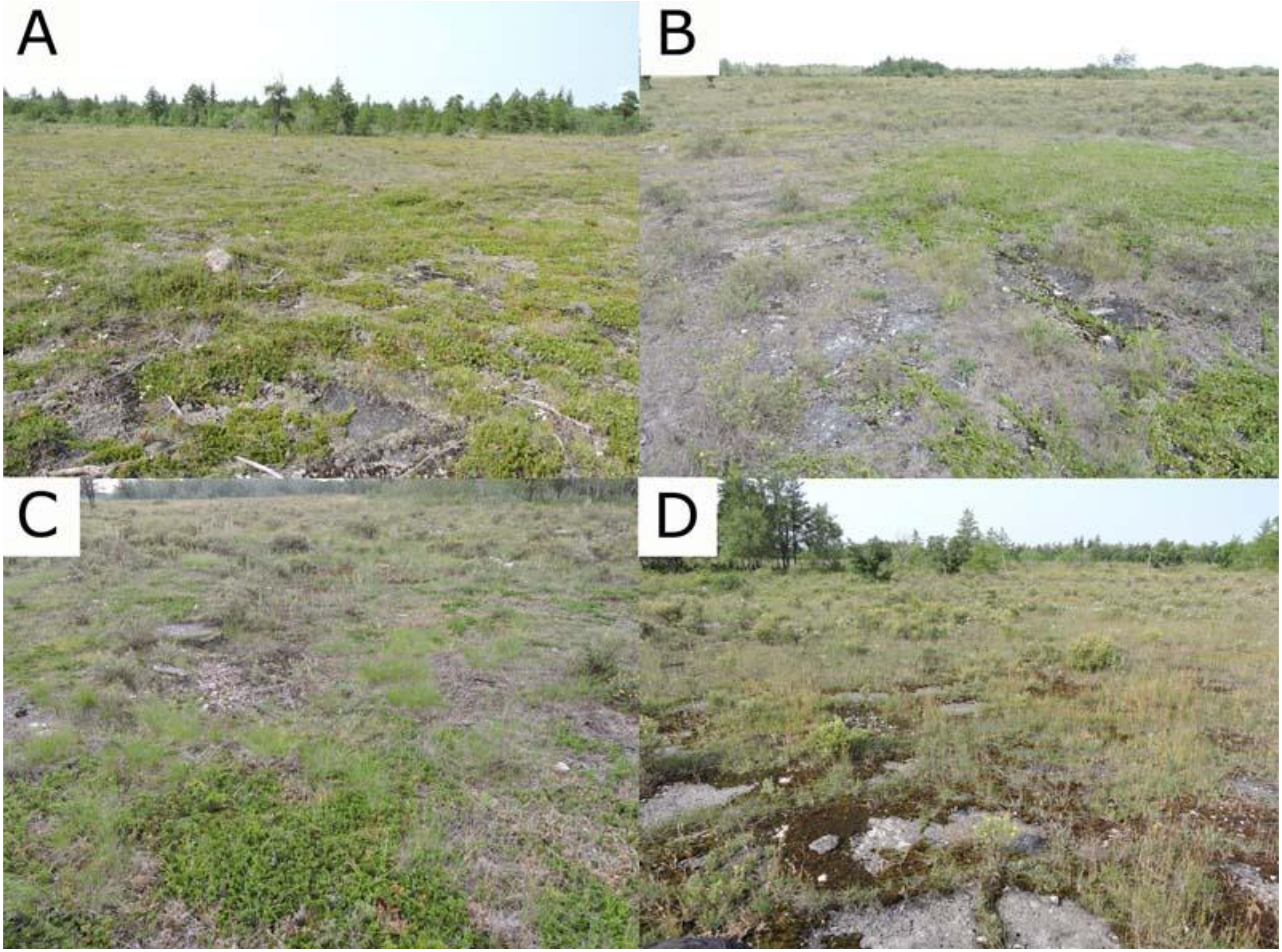


Figure 3.10: Type IV, rocky dwarf shrubland alvar at the Fisher alvar plots A) N3, B) K6, C) L1 and D) M1. Site locations are shown in Figure 2.1.

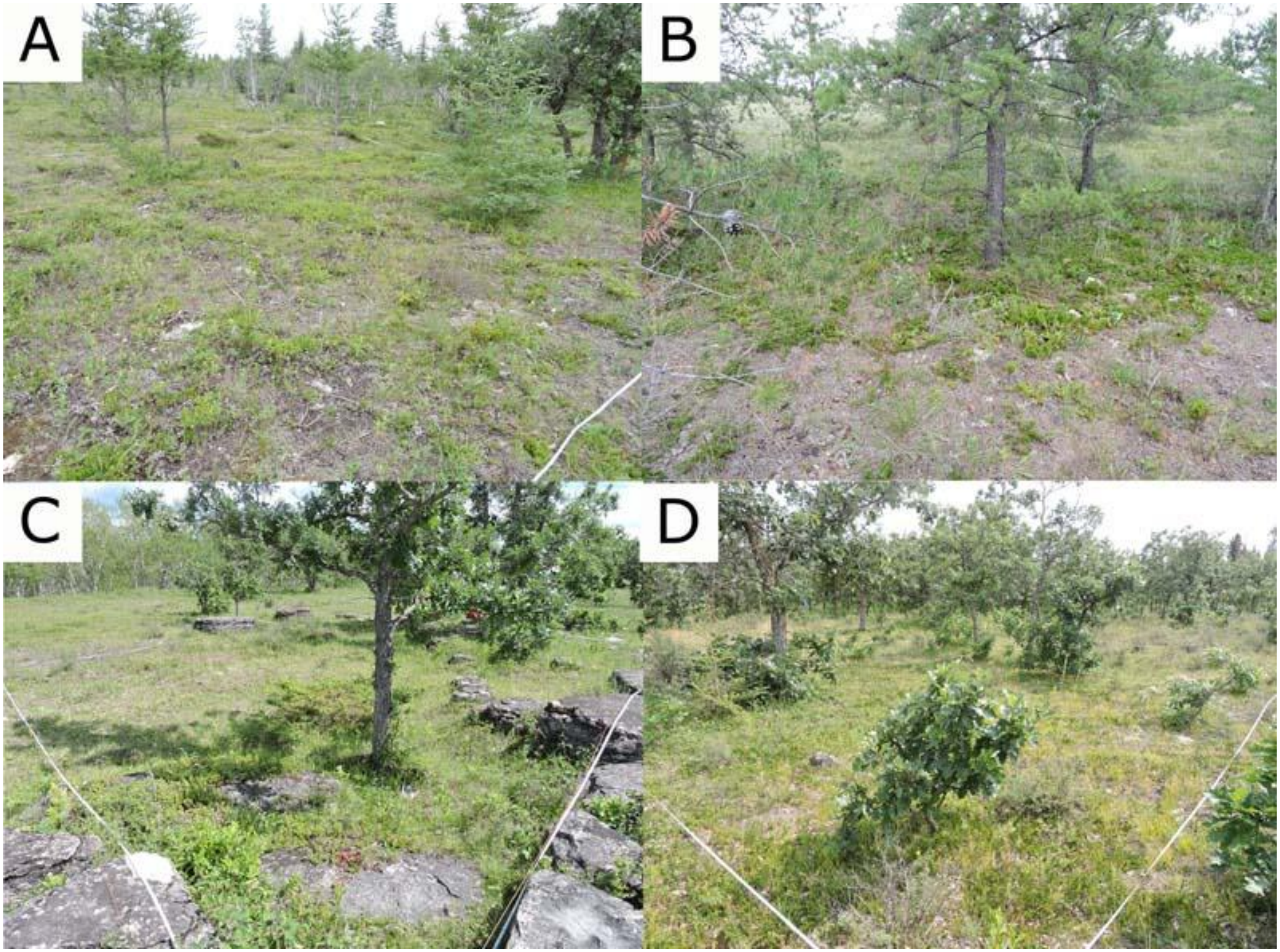


Figure 3.11: Type V, Boreal -Bur oak-Jack pine-Low shrub alvar at the A) Marble Ridge alvar plot D5, B) Fisher alvar plot M9, C) Marble Ridge alvar plot C1 and D) Poplarfield alvar plot O4. Site locations are shown in Figure 2.1.

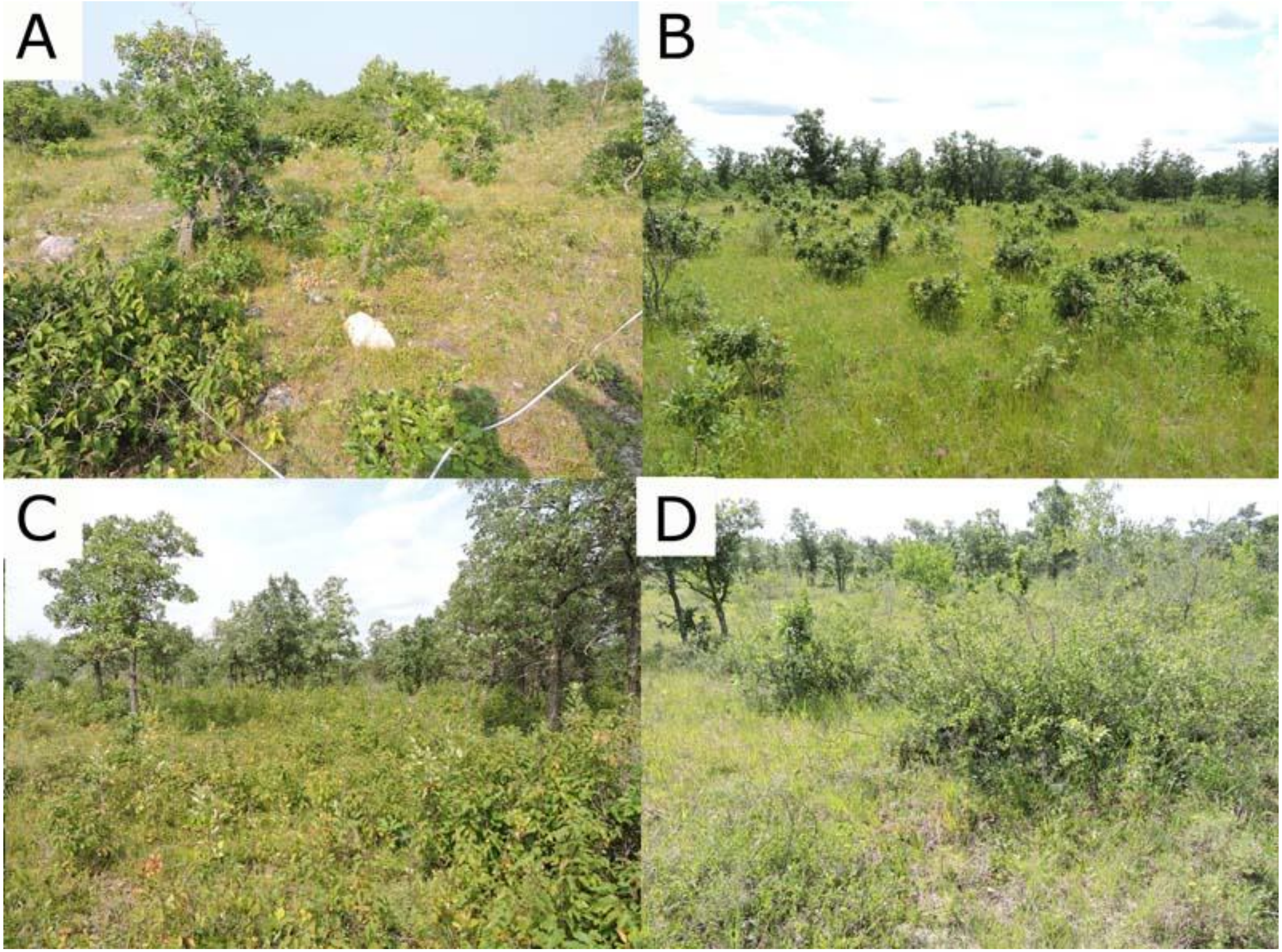


Figure 3.12: Type VI, bur oak- tall shrub at A) the Sylvan alvar at plot H7, B) Poplarfield alvar at plot P3, C) Clematis alvar at plot R7 and D) Sandridge alvar at plot T2. Site locations are shown in Figure 2.1.

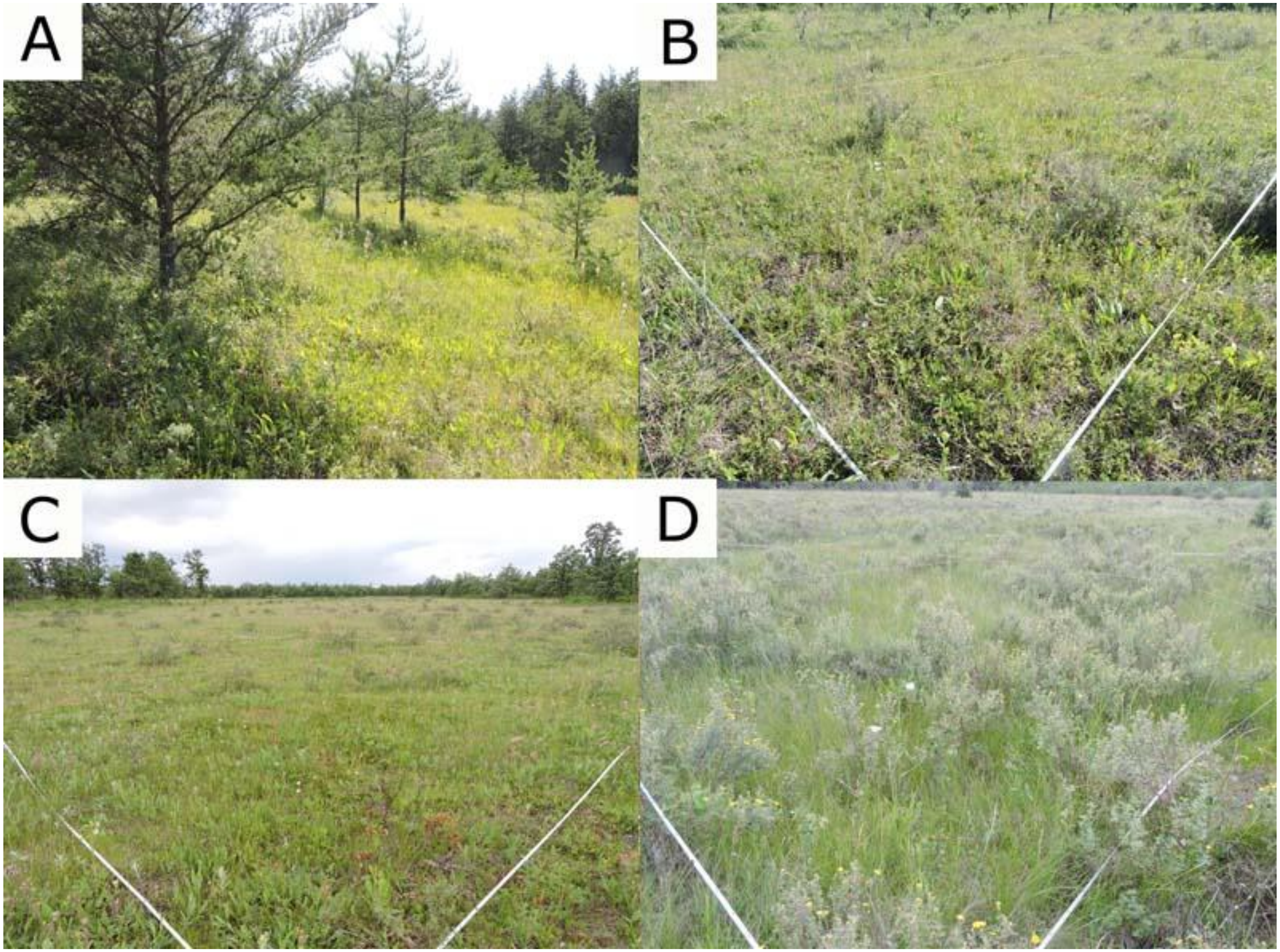


Figure 3.13: Type VII, prairie-jack pine-low shrub A) the Peguis alvar at plot A7, B) the Sandridge alvar at plot T1, C) the Poplarfield alvar at plot P1 and D) the Peguis alvar at plot A5. Site locations are shown in Figure 2.1.

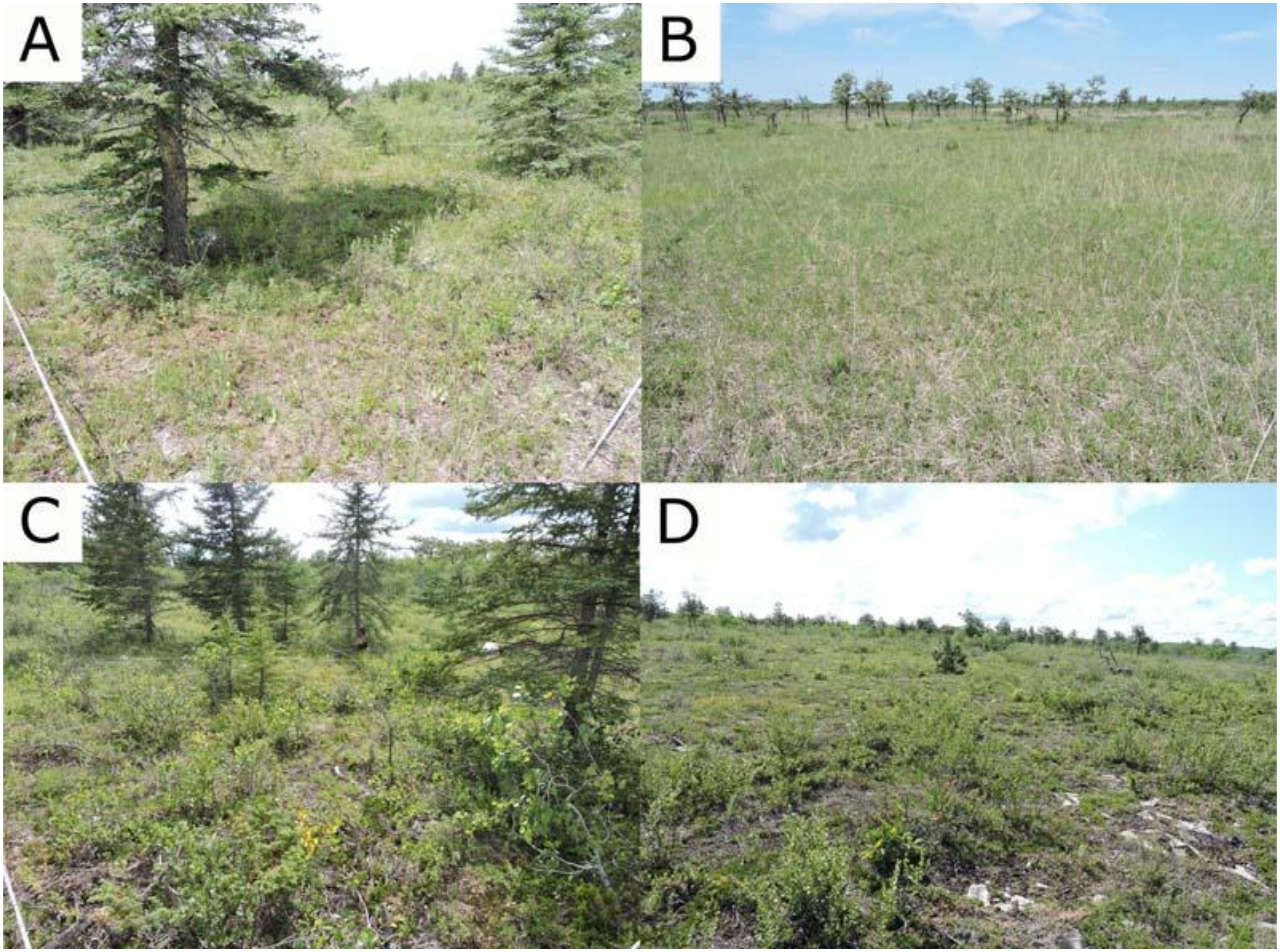


Figure 3.14: Type VIII, spruce savanna-bluestem grassland at the Clematis alvar at plots A) S2, B) R2, C) R6 and D) R3. Site locations are shown in Figure 2.1.

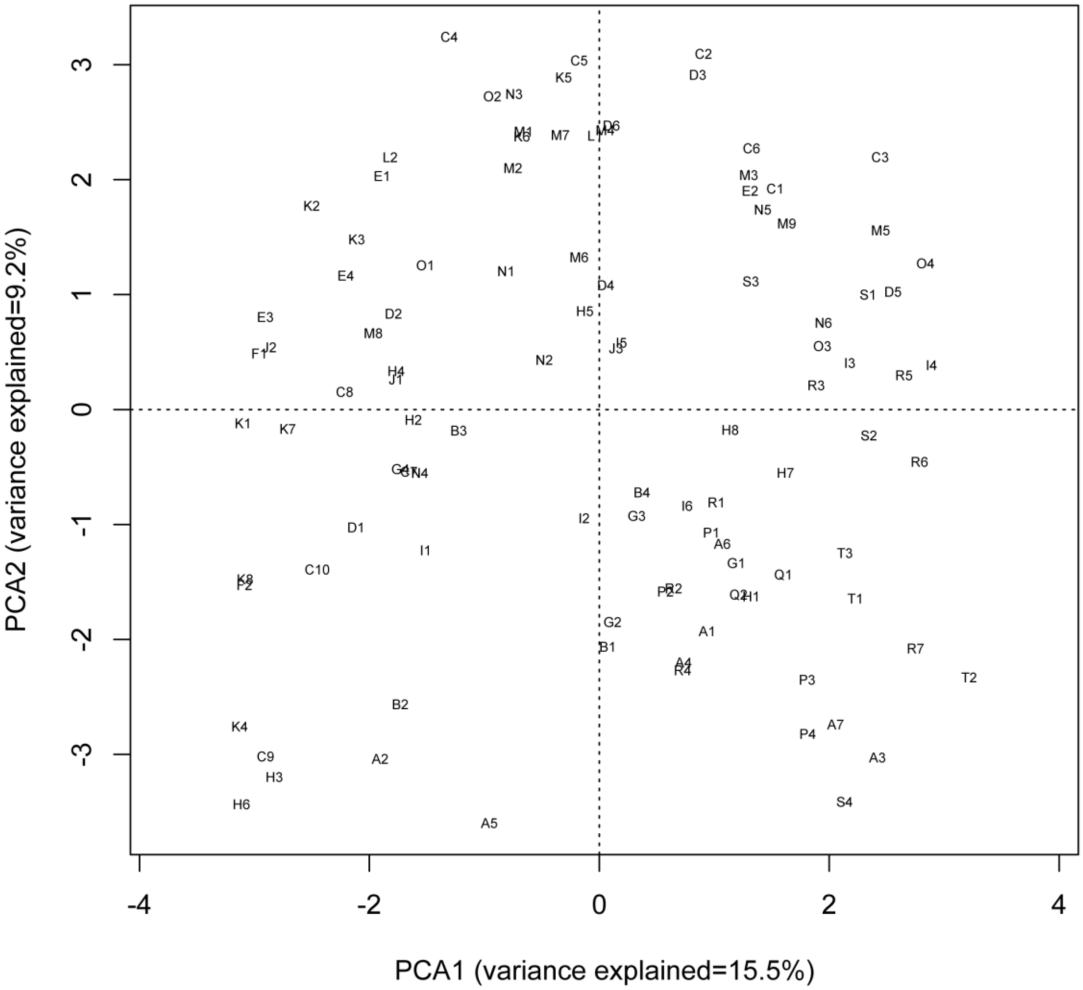


Figure 3.15: Principal component analysis (PCA): species data for 103 plots. The scattergram displays the 103 plots, coded by site location (letters A-T) and plot number, on the first two component axes PCA1 and PCA2. Site locations are shown in Figure 2.1.

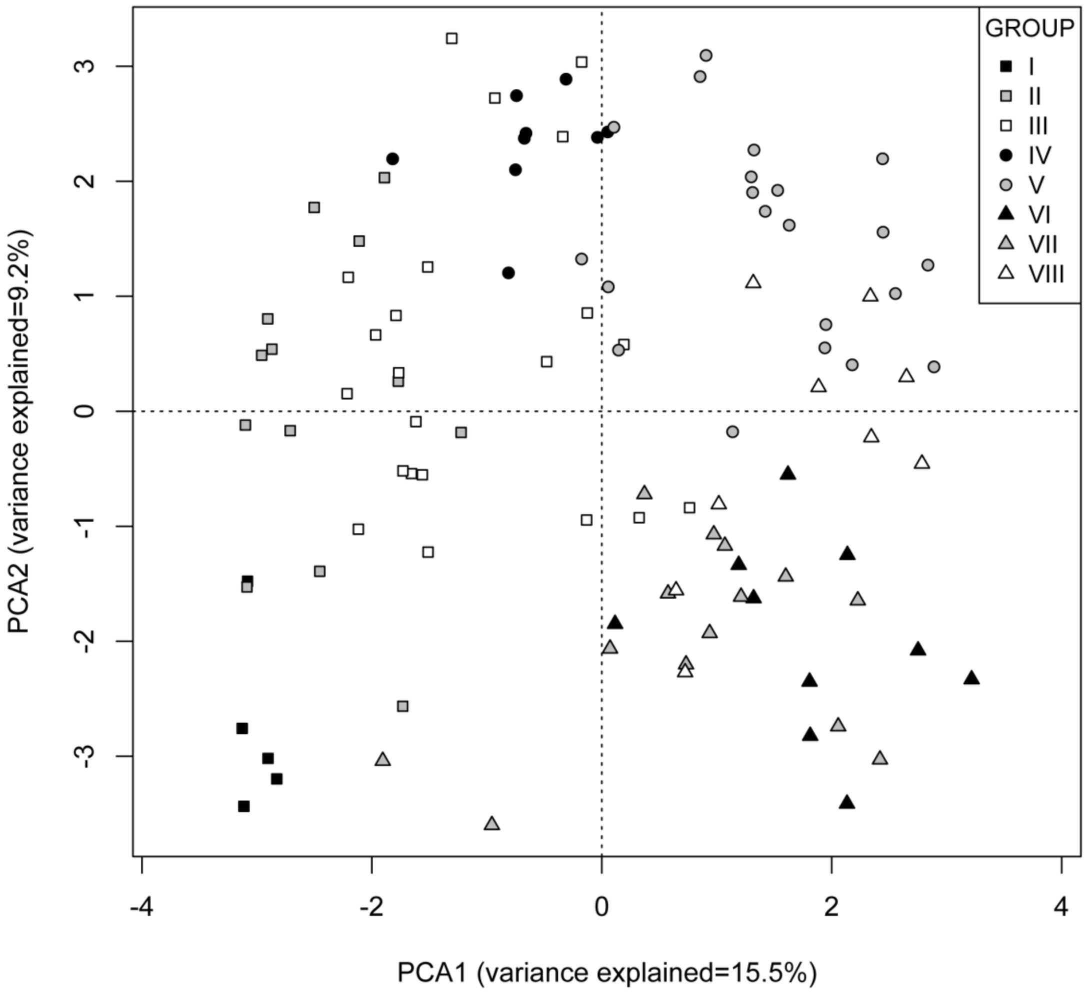


Figure 3.16: Principal component analysis (PCA): species data for 103 plots. The scattergram displays the 103 plots (coded by cluster group affinity in Figure 3.2) on the first two component axes PCA1 and PCA2.

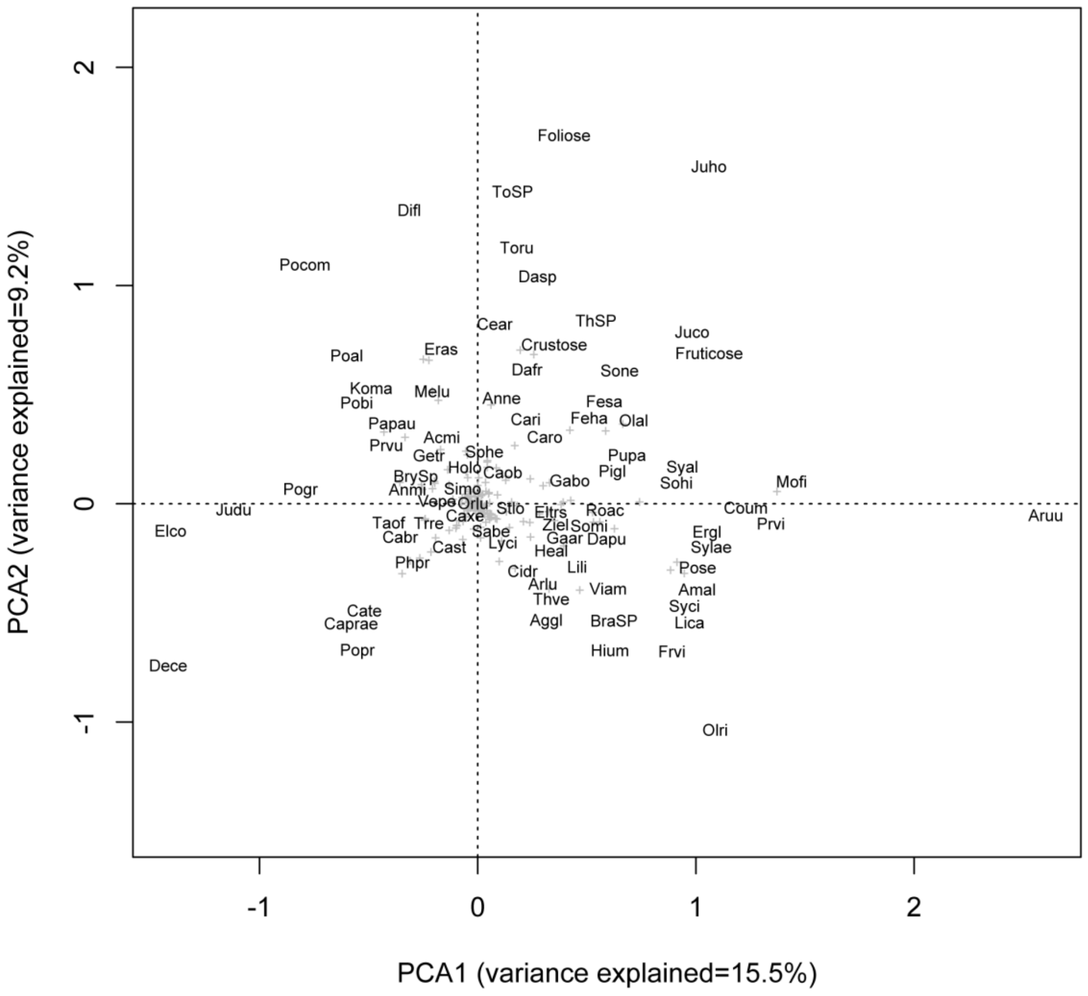


Figure 3.17: Principal component analysis: data from 103 plots including 231 vascular plant species, 11 non-vascular plant genera and 3 lichen growth forms. For clarity, the scattergram displays only the 85 most abundant species only (for species code labels, see Appendix 3) on the first two component axes PCA1 and PCA2.

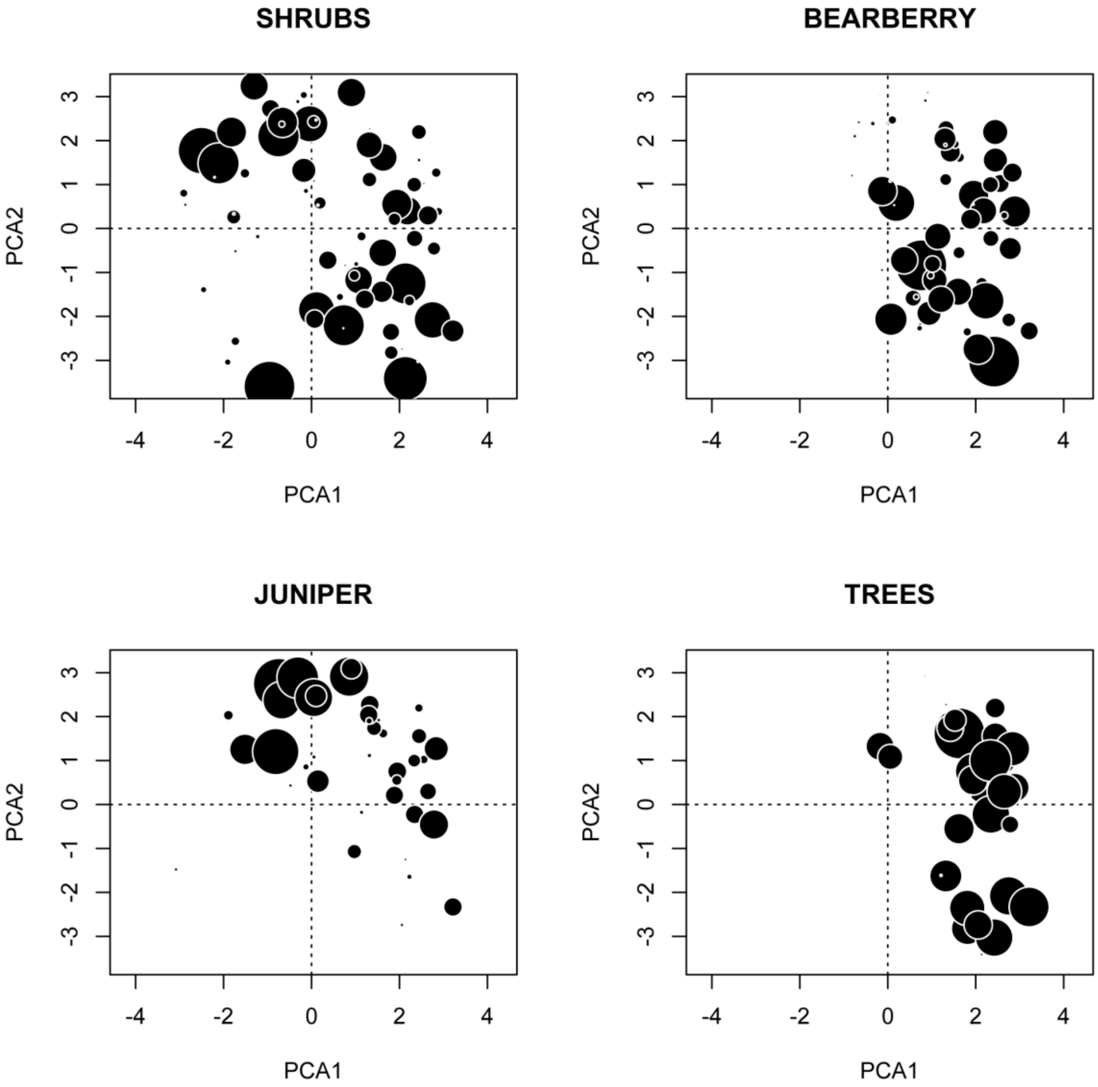


Figure 3.18: Relative cover-abundance of (a) shrubs (excluding *Arctostaphylos uva-ursi* and *Juniperus* spp.), (b) *Arctostaphylos uva-ursi*, (c) *Juniperus* spp., and (d) trees superimposed on principal component analysis scattergram of the 103 sites. Larger circles denote higher relative cover-abundance.

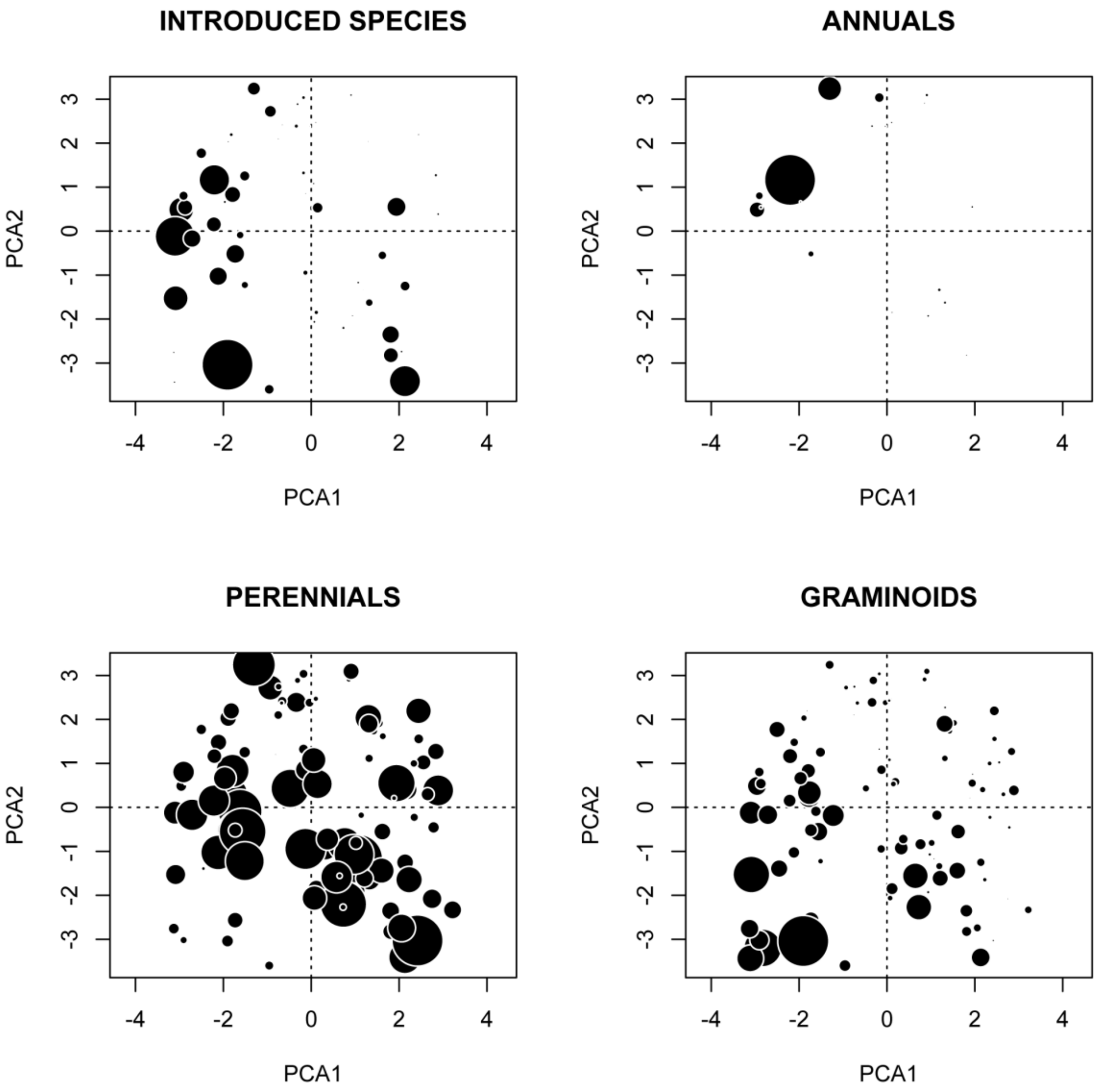


Figure 3.19: Relative cover-abundance of (a) introduced species, (b) annuals, (c) herbaceous perennials, and (d) graminoids superimposed on principal component analysis scattergram of the 103 sites. Larger circles denote higher relative cover-abundance.

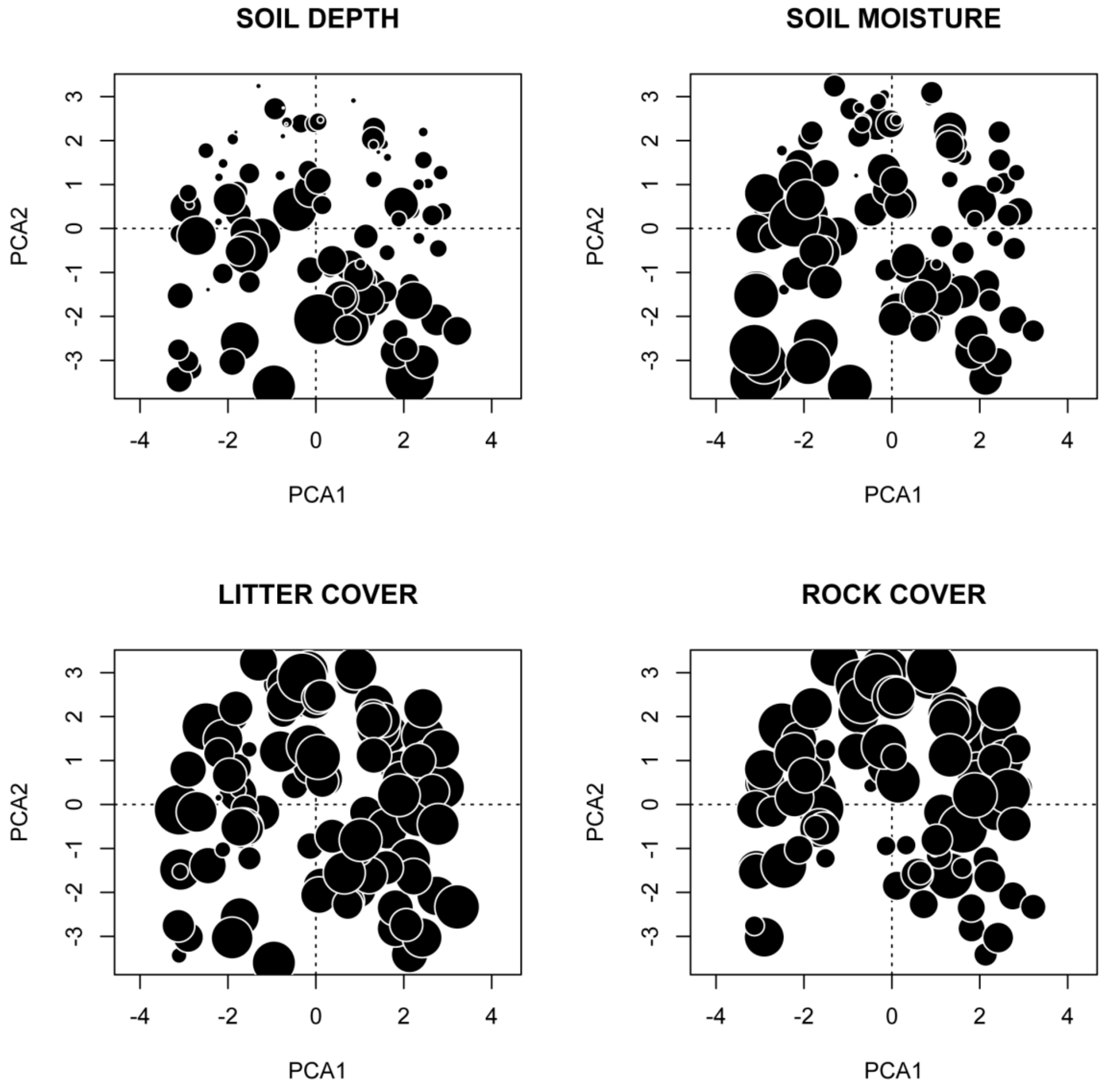
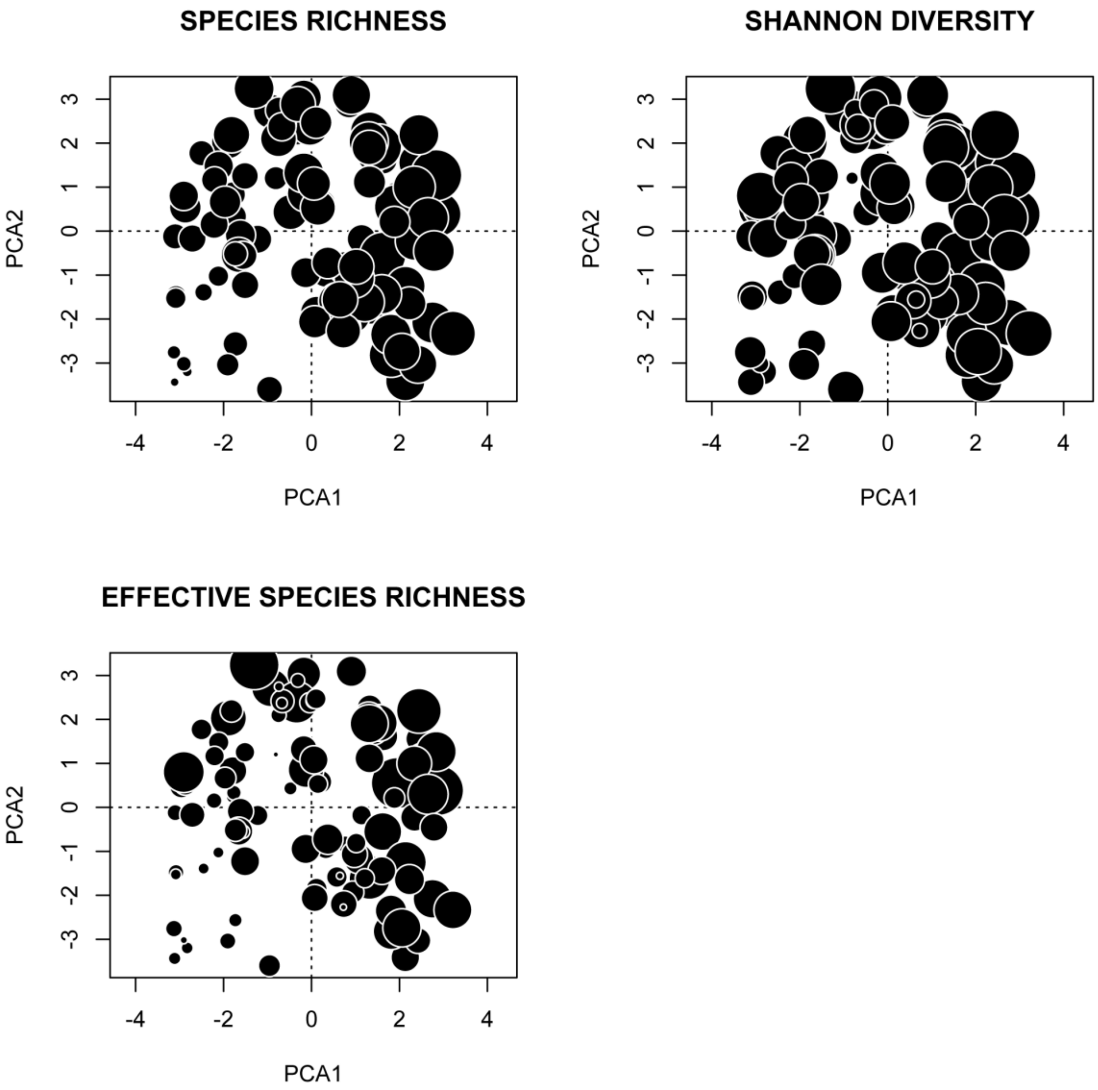


Figure 3.20: Values of (a) soil depth, (b) soil moisture, (c) litter cover, and (d) rock cover superimposed on principal component analysis scattergram of the 103 sites. Larger circles denote higher values. For rock cover, the smallest circles represent zero values.


SPECIES RICHNESS

SHANNON DIVERSITY

EFFECTIVE SPECIES RICHNESS

Figure 3.21: Values of (a) species richness, (b) Shannon diversity, and (c) effective species richness superimposed on principal component analysis scattergram of the 103 sites. Larger circles denote higher values.

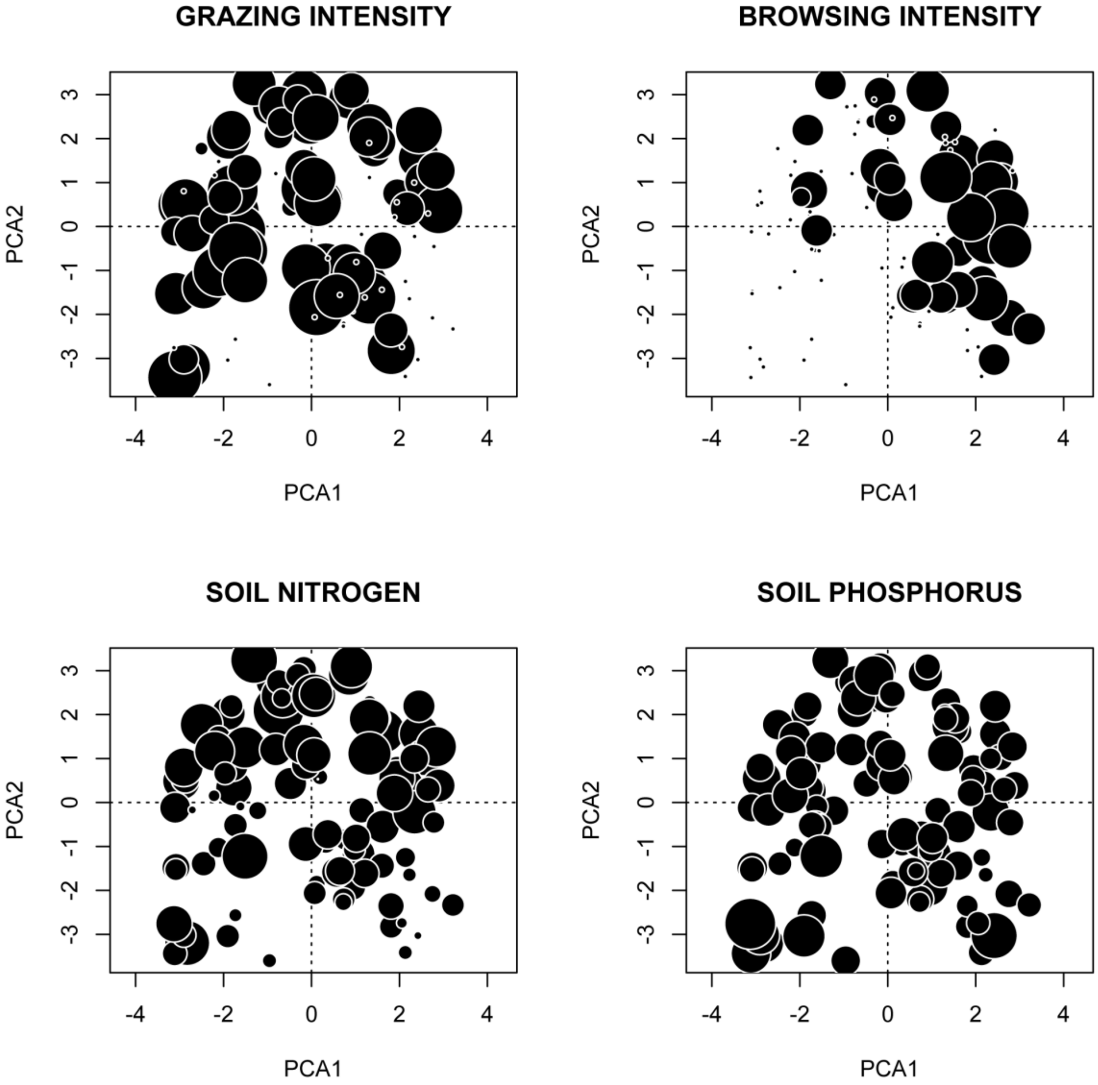


Figure 3.22: Values of (a) grazing intensity, (b) browsing intensity, (c) soil nitrogen content, and (d) soil phosphorus content superimposed on principal component analysis scattergram of the 103 sites. Larger circles denote higher values. For grazing and browsing intensity, the smallest dots represent zero values.

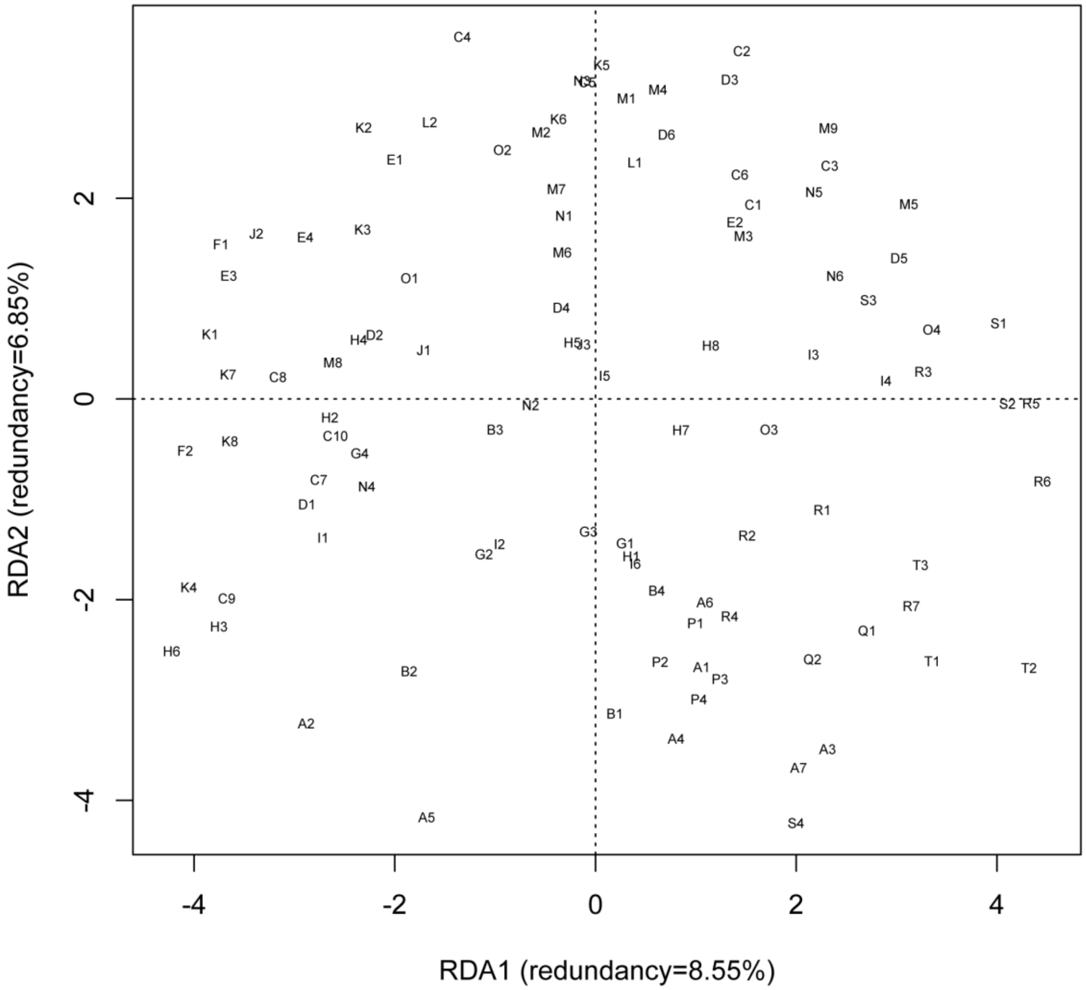


Figure 3.23: Redundancy analysis: species data for 103 plots constrained by 11 environmental variables. The scattergram displays the 103 sites (coded by site location (letters A-R and plot number) on the first two canonical axes RDA1 and RDA2. Site locations are shown in Figure 2.1.

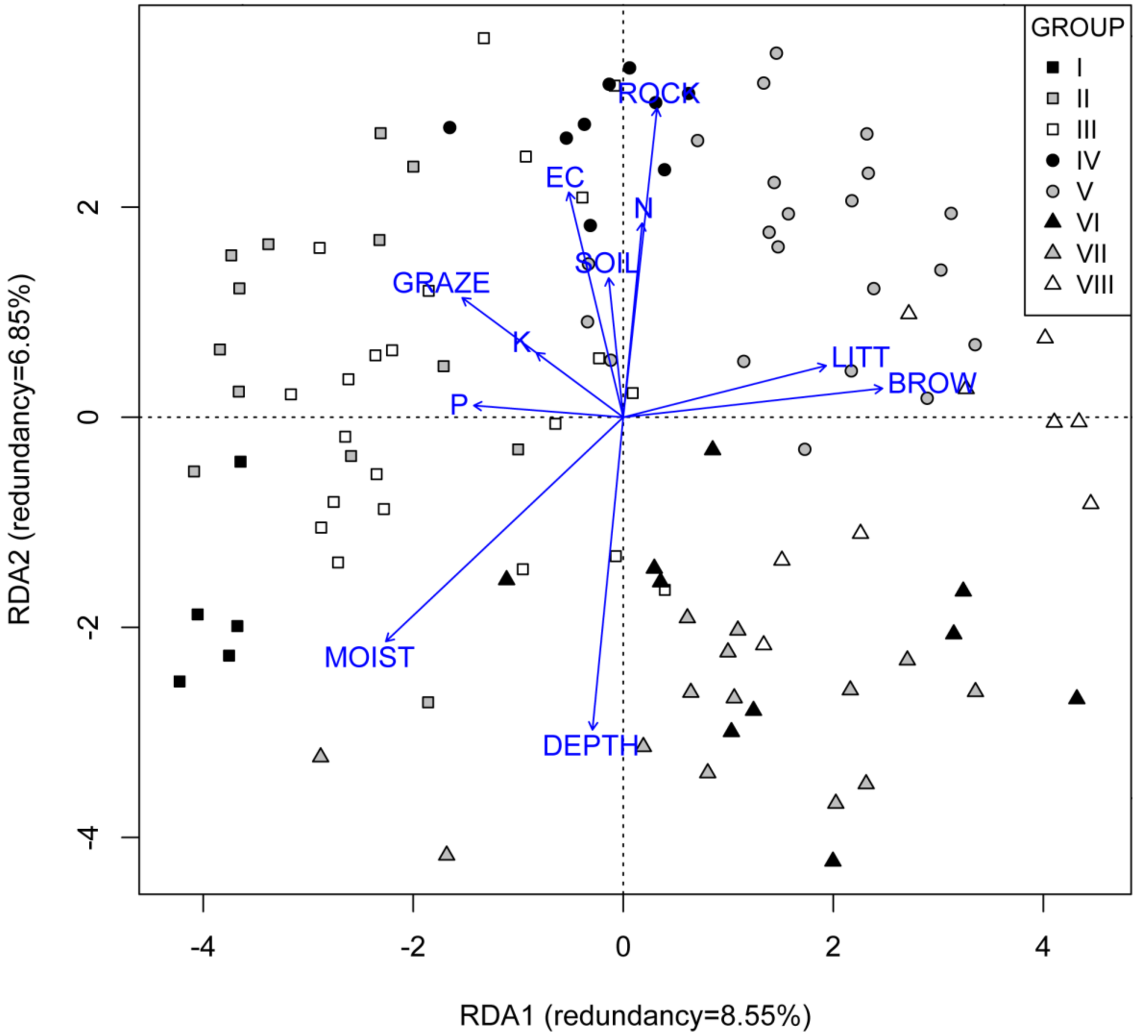


Figure 3.24: Redundancy analysis: species data for 103 plots constrained by 11 environmental variables. The scattergram displays the 11 environmental vectors and the 103 sites (coded by cluster group affinity according to Figure 3.2) on the first two canonical axes RDA1 and RDA2. Environmental variable codes: N = total soil nitrogen; P = total soil phosphorus; K = total soil potassium; EC = soil electrical conductivity; MOIST = soil moisture; DEPTH = soil depth; SOIL = percent bare soil; ROCK = percent bare rock; GRAZE = intensity of cattle grazing; BROW = intensity of browse (mainly deer).

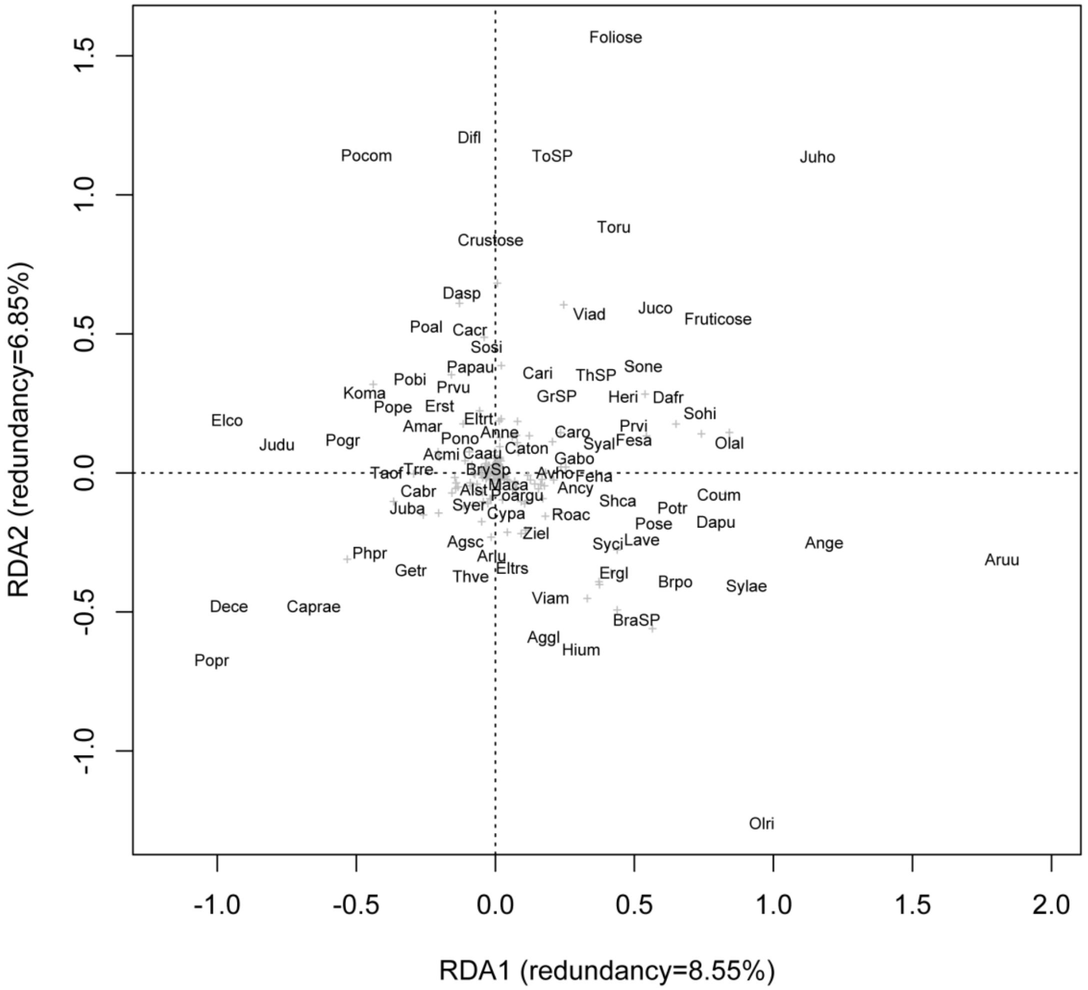


Figure 3.25: Redundancy analysis: species data (231 vascular species, 11 non-vascular genera and 3 lichen forms) for 103 plots constrained by 11 environmental variables. For clarity, the scattergram displays the 83 most abundant species only (for species code labels, see Appendix 3) on the first two canonical axes RDA1 and RDA2. Positions of the less abundant species are shown as grey crosses.

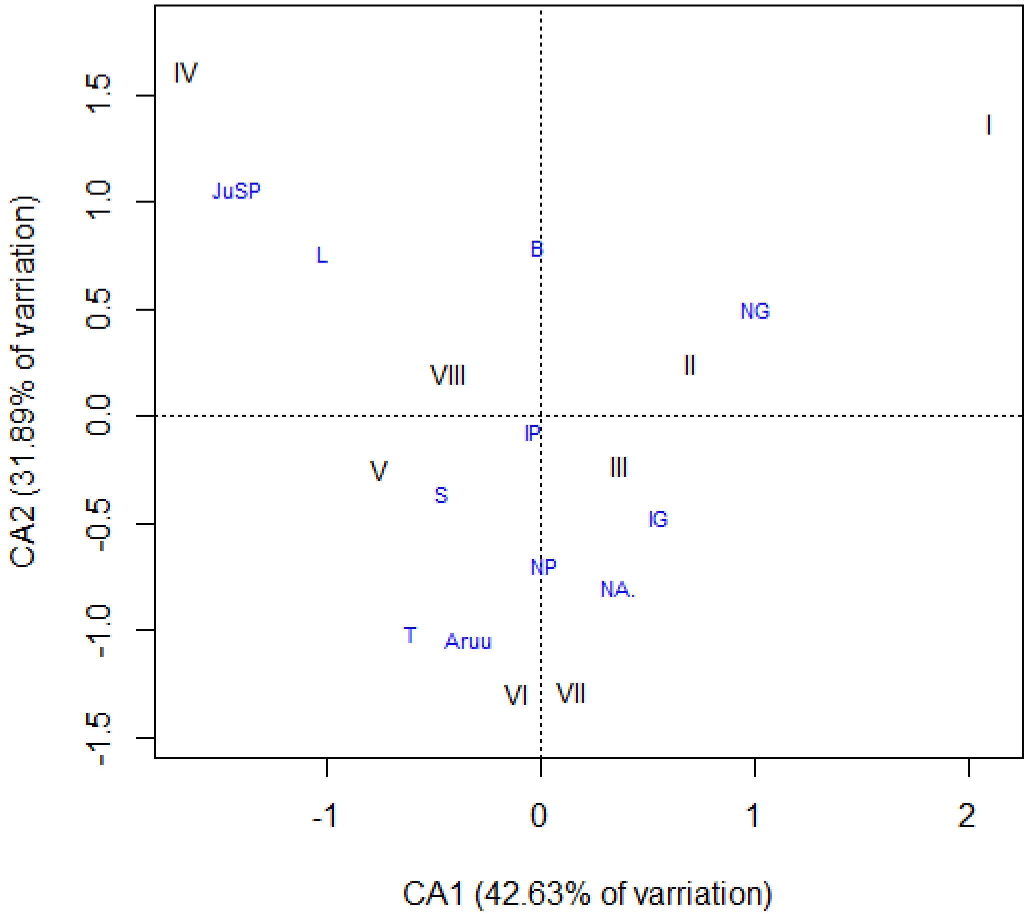


Figure 3.26: Correspondence analysis of eight vegetation communities (Figure 3.2; Appendix 4) by average cover of life form groups and characteristic shrubs: T=tree, Aruu= *Arctostaphylos uva-ursi*, JuSP= *Juniperus* spp., S=shrubs other than *Juniperus* spp. and *Arctostaphylos uva-ursi*, NP= native perennial, IP= introduced perennial, NG= native graminoid, NA= native annual, IG= introduced graminoid, B= bryophyte and L= lichen.

Chapter 4: Effects of Cattle Grazing on Alvar Plant Communities in Manitoba: A Long-term Natural Experiment

4.1 Introduction

Functioning of ecosystems is changing worldwide as a result of biodiversity loss associated with land-uses. Disturbances include intensive grazing and nutrient addition, but impact depends on how such drivers influence diversity (Isbell *et al.* 2013). Grasslands are among the most extensively used landscapes on Earth (Laliberté and Tylianakis 2012) and the risk of degradation is high due to growing demands of an increasing population that will increase agricultural practices in these areas (Bouwman *et al.* 2005; Tietjen and Jeltsch 2007). Although grasslands have been extensively studied worldwide for the effects of grazing (Laliberté and Tylianakis 2012), alvars (a globally rare ecosystem that is frequently grazed) have received no study on the effects of grazing in North America. Alvars are flat open areas (<50% tree cover) with thin soil over limestone bedrock that can be dominated by either graminoids or woody vegetation (Catling *et al.* 1975). The majority of alvars are grassland (Rosén and van der Maaurel 2000). Like grasslands, alvars are threatened by ever increasing demands for livestock production (Bouwman *et al.* 2005). A major threat from livestock production is the risk of degrading unproductive areas, such as alvars, with low carrying capacities (Bouwman *et al.* 2005).

Studies of alvar vegetation in Europe have focused on the effects of sheep grazing, which has been historically common on the alvars of Öland and Gotland, Sweden since the 16th century (Rosén 1982). Grazing has been shown to create, maintain and restore open alvar grasslands by reducing shrub cover of species such as *Dasiphora fruitisocsa* and *Juniperus* *communis* (Kasari et. al. 2013, Kalamees et. al. 2012, Znamenskiy et. al 2006). The long term (25 year or more) abandonment of grazing on alvars in Estonia resulted in a decrease in species richness, but this was not observed in sites abandoned for shorter periods (Kalamees *et al.* 2012). Approximately 30% shrub cover maximizes species richness on Estonian alvars and this can be maintained through grazing (Kasari *et al.* 2013). Certain alvar communities are more negatively impacted by grazing than others, and shrub encroachment (by *Juniperus* and *Dasiphora*) is more problematic in wetter areas of the alvar since summer droughts cause shrub to die back in dry areas (Rosén and van der Maaurel 2000). While grazing can be beneficial in maintaining alvar openness, overgrazing can degrade the ecosystem by reducing species richness, increasing the abundance of ruderal or introduced species, and the selective grazing of species unique to alvars (Rosén and Sjören 1973; Rosen 1982; Rosén and van der Maaurel 2000). The balance between a beneficial level of grazing and the negative effects of overgrazing is difficult to determine, and continual field observations are necessary to develop adaptive management schemes (Rosén and van der Maaurel 2000).

Grazing can change biodiversity in terms of number of species present, as well as cause changes in vegetation composition (Bardgett and Wardle 2003) and spatial heterogeneity (Adler *et al.* 2001). Since grazing is a complex primary driver that varies geographically, it cannot be assumed that findings from grazing studies in Europe can be applied uncritically to alvars in North America (Hejcman *et al.* 2013). There are currently no published studies to quantify the effects of grazing on alvars in North America, although some studies have commented on its effects. Reschke *et al.* (1999) suggested that browsing by rabbits and voles has minimal effects on alvars, but that high numbers of white-tailed deer or livestock could alter plant communities. Brownell and Riley (2000) observed that low levels of cattle grazing increased richness while higher levels led to a decline in native species with replacement by exotic species. Brownell (1998) noted that intense cattle grazing reduced grass abundance and increased the abundance of species unfavoured by cattle. This contrasts with observations from European alvars, where grazing reduced shrub cover and increased grass abundance (Kalamees *et al.* 2012).

Landscapes of low commercial value, such as alvars, are often representative of pre-settlement vegetation since they are subject to limited human disturbance (Stahle and Chaney 1994). They are therefore useful in studying the effects of disturbance on vegetation structure and composition. North American alvars have little economic value and remain fairly undisturbed (Schaefer 1996), but are a valuable resource for studying the effects of disturbance and as a refuge for rare species. Since over 75% of the alvar sites in the Interlake region of Manitoba are currently grazed, understanding the effects of grazing on this unique and rare ecosystem in Canada is of the utmost importance for conservation and management (Manitoba Alvar Initiative 2012). The objective of this study is to determine the impact of long term cattle grazing on natural alvar vegetation. By comparing adjacent grazed and ungrazed sections of two alvar sites I will determine how long term (30+ years) cattle grazing affects alvar vegetation by examining:

1) Changes in plant community composition.
2) Changes in plant physiognomy (life form, ie shrub, graminoid, etc).
3) Changes in overall richness and diversity.
4) Changes in abundance (cover) and richness (number) of introduced species.

4.2 Methods

4.2.1 Study Area: A Natural Grazing Experiment

The study was completed on two alvar sites within the Interlake Region of Manitoba (between 51°04’02” N, -97°27’15” W and 51°03’33” N, -97°25’45” W). Note that for conservation reasons exact site and plot coordinates are not included here but are on file at the Nature Conservancy of Canada and Manitoba Conservation. Both sites had established fence lines dividing grazed and ungrazed areas of alvar vegetation that allowed for a long-term natural grazing experiment at both sites (Figures 4.1 and 4.2). These sites are on crown land and have been leased for 31 (Site J) and 37 (Site D) years. The main agricultural use for land the study area (Figure 2.1) is for pasture and the main grazers of alvars in Manitoba are cattle (Table 2.3). It is assumed that the sites had been used for grazing for the duration of the lease and that the fenceline was established at the start of the lease.

4.2.2 Vegetation Sampling

Sampling of all vascular plant species along transects took place in August 2015. Ten (site D) or fifteen (site J) pairs of 1 x 1 m plots were positioned 5 m apart along parallel transects on either side of a fence line separating grazed and ungrazed areas. Since animals prefer to walk along fence lines, plots were all 5 m away from the fence line in order to reduce trampling effects (Pavlu *et al.* 2003). Vascular plants were identified to species and their abundance quantified using a ten point cover scale: 1=trace, 2= 0.1–<1%, 3= 1–<2%, 4= 2–<5%, 5= 5–<10%, 6= 10–<25%, 7= 25–<50%, 8= 50–<75%, 9= 75–<95%, 10= >95% (Grossman *et al.* 1998). Moss cover was recorded at the genus level due to difficulty identifying to species in the field. Lichen cover was recorded for each growth form (crustose, foliose and fruticose). Values used in the statistical analysis were the median of the cover class. Vascular flora was identified using Flora of Manitoba (Scoggan 1957). Specimens collected as part of this study have been deposited in the University of Manitoba Vascular Plant Herbarium (WIN).

4.2.3 Statistical Analyses

All statistical analyses were run in R (R Core Team 2013) using the following packages; vegan (Oksanen et. al. 2013), ade4 (Thioulouse *et al.* 1997), gclus (Kaufman and Rousseeuw 1990), graphics (R Core Team 2014) and labdsv (Roberts 2015). In a manner according to Anderson *et al.* (2006), all data were transformed ($y'=\log2(y)+1$) unless $y = 0$ in which case $y'=0$. Principal component analysis (PCA; Orlóci 1978) on a covariance matrix was used to determine the relation between plots in grazed and ungrazed areas, and to determine what species are more associated with these. Plant species were classified as either introduced or native (according to USDA 2016) as well as being classified by life form (moss, lichen, graminoid, annual, perennial, shrubs and trees).

Redundancy analysis (RDA; Legendre and Legendre 1998) was used to determine the proportion of variation in floristic composition that was influenced by grazing. Used in this way, RDA is analogous to a multivariate t-test (Morrison 1990) allowing for a comparison of the overall floristic composition of grazed versus ungrazed plots. A Monte Carlo permutation test (Legendre and Legendre 2012) was used to determine whether floristic composition was significantly different between grazed and ungrazed plots.

Shannon diversity index (H) and species richness (S) was determined for each plot (Rényi 1961). Shannon diversity index was chosen as a diversity measure since it can be additively partitioned. This ability was used to portion out diversity based on life form, and to portion out the diversity contribution of native versus introduced species. A t-test using the Welch correction, which accounts for non-normal distribution by adjusting the degrees of freedom (Welch 1938, 1947), was used to determine the significance of differences in life-form composition, richness and diversity between grazed and ungrazed areas by introduced and native species.

4.3 Results

This study found 76 species, 15 of which are introduced according to the USDA PLANTS Database (USDA 2016): (1) grasses: *Agrostis stolonifera, Phleum pretense, Poa pratensis, P. compressa, P. alpina*; (2) annuals: *Arenaria serpyllifolia, Lepidium densiflorum*; (3) perennials: *Arabis hirsuta, Achillea millefolium, Cirsium arvense, Cerastium arvense, Medicago lupulina*, *Prunella vulgaris, Taraxacum officinale, Trifolium repens.* Species that are considered both native and introduced, such as *Poa pratensis* and *Achillea millefolium*, were included in the introduced group.

4.3.1 Floristic Composition Pre-grazing

A PCA ordination comparing ungrazed areas at sites J and D distinctly separated the two sites showing that vegetation composition of the two sites was quantifiably different before the effects of grazing (Figure 4.3). Table 4.1 summarizes differences in bare rock cover and life form abundance between the ungrazed areas of the two sites. Bare rock cover was approximately equal between sites, although site D had frequent granite erratics over the limestone pavement while the rock cover at site J was predominately exposed limestone pavement (P.K. Catling, Pers. Obs. 2015). Site D had higher cover of lichens and non-vascular plants. Graminoid diversity and cover was much higher at site J than at site D. Perennial cover was somewhat higher at site D although the differences were small. Shrub cover was much higher at site D than at site J and the dominant species also differ (Table 4.2).

Ungrazed plots at site J belonged to moist graminoid meadow plant community (Type II in Chapter 3). This community had a dominant cover of graminoids including: *Sporobolus heterolepis* (mean cover= 25.17%)*, Eleocharis compressa* (mean cover= 3.23%)*, Danthonia spicata* (mean cover= 1.24%) and *Carex crawei* (mean cover= 1.29%). Dominant forbs were *Galium boreale* (mean cover= 4.00%)*, Geum triflorum* (mean cover= 2.87%)*, Antennaria howellii* ssp. *neodioica* (mean cover= 5.48%) and *Symphyotrichum laeve* (mean cover= 2.47%). Shrubs were not as common as site D; however *Dasiphora fruisticosa* (mean cover= 9.17%) and *Prunus susquehanae* were most frequent. The mosses *Ditrichum flexicaule* (mean cover= 14.54%)*, Tortella* sp. and *Bryum* sp. were most common at site J. Crustose lichen was the most common lichen form at site J.

The ungrazed plots located at site D belong to the rocky alvar shrubland plant community (Type IV in chapter 3). The higher shrub cover at site D was *Juniperus horizontalis* (mean cover= 41%)*, Dasiphora fruiticosa* (mean cover= 11.6%) and *Arctostaphylos uva-ursi* (mean cover= 3.75%). Dominant forbs were *Oligoneuron album* (mean cover= 4.26%)*, Oligoneuron rigidum* (mean cover= 3.35%), *Geum trifolium* (mean cover= 6.60%)*, Galium* *boreale* (mean cover= 1.16%), *Solidago nemoralis* (mean cover= 1.80%), *Antennaria howellii* ssp. *neodioica* (mean cover= 1.91%) and *Symphyotrichum laeve* (mean cover= 1.31%). *Carex crawei* (mean cover= 3.71%) and *Poa compressa* (mean cover= 0.47%) were the dominant graminoid cover. Moss cover was predominately *Thuidium* sp. (mean cover= 16.51%) and *Bryum* spp. Lichen cover was higher at site D than site J. Fruticose lichen was the most common lichen form at site D.

4.3.2 Site J: Grazing effects

Floristic Composition

Grazed and ungrazed plots were separated along the first principal component axis indicating distinct floristic differences in vegetation composition between grazed vs ungrazed areas (Figure 4.4). A total of 40.85% of the variation was explained by the first two axes (PCA1=25.7%, PCA2=15.1%). This indicates that long-term grazing does quantitatively change vegetation composition on alvar grasslands.

This was confirmed by the redundancy analysis, which showed that a total of 23.66% of the variation in floristic composition was explained by grazing; this difference was statistically significant (permutation test, $F_{1,28} = 8.68$, $p<0.001$). Species scores on the RDA axis separate species occurring in ungrazed areas from species preferring grazed areas (Table 4.3). Species with positive scores, such as *Poa alpina, Agrostis stolonifera, Poa pratensis, Ditrichum flexicaule* and *Taraxacum officinale* were much more abundant in the grazed plots. For example, *Agrostis stolonifera* was absent in the ungrazed plots but present in a majority (67%, mean cover =10.51%) of grazed plots (Table 4.3). *Taraxacum officinale* was only found in a single ungrazed plot but was present in about half of the grazed plots. The following species had high frequency and cover in ungrazed plots but were absent in grazed plots (i.e. locally extirpated by grazing): *Sporobolus heterolepis, Oligoneuron album, Carex crawei* and *Symphiotrichum laeve* (Table 4.3). For example, *Sporobolus heterolepis* occurred in 13/15 ungrazed plots with a mean cover of 25% but was completely absent on the grazed side of the fence line. Those species that were negatively impacted by grazing also had highly negative RDA values (Table 4.3). Other species adversely affected by grazing (highly reduced cover and frequency, but not entirely extirpated by grazing) include: *Galium boreale, Packera paupercula, Festuca hallii*, *Antennaria howellii* ssp. *neodioica, Comandra umbellata* and *Tortella* sp. (Table 4.3). Although they are not dominant species, *Erigeron asper* and *Potentilla bipinnatifida* showed a positive response to grazing by increasing in both frequency and cover in the grazed treatment (Table 4.3).

Physiognomic Differences

Total cover of various life form groups in grazed and ungrazed plots, and the associated t-test results are shown in Table 4.4. Grazing increased bryophyte cover (mean = 46.4% in grazed plots, vs. 19.83% in ungrazed plots) and this difference was statistically significant (t_{19} = 3.06, p = 0.006). This increase was largely attributed to *Ditrichum flexicaule,* which colonizes open soil and rock (mean = 14.54%, in ungrazed plots, mean = 44.38% in grazed plots). This moss was found in all grazed plots (often at high cover), but only in 2/3 of the ungrazed plots (generally at lower cover). Total cover of woody perennials (shrubs) declined with grazing (12.04% in ungrazed plots, vs. 3.47% in grazed plots), and this was statistically significant (t_{18} = 2.57, p = 0.019). Most of this decline was attributable to reduced cover (but not frequency) of

Dasiphora fruticosa, which was reduced from 9.17% mean cover in the ungrazed plots to 2.74% mean cover in the grazed plots (Table 4.3). *Rosa acicularis*, which was present in four of the ungrazed plots (mean cover=0.54%), was not found in any of the grazed plots (Table 4.3). Total cover of native graminoids declined greatly under grazing (33.39% in ungrazed plots, vs. 0.78% in grazed plots), a difference that is statistically significant (t_{14} = 11.07, $p < 0.001$). The grass *Sporobolus heterolepis* was frequent and often abundant in ungrazed plots (mean = 25.17%, present in 13/15 plots), but was entirely absent in grazed plots ($p < 0.001$). The sedge *Carex crawei* occurred in 13/15 ungrazed plots (mean cover =1.29%), but was absent from the grazed plots (Table 4.3). Forb species most adversely affected by grazing include *Oligoneuron album, Symphiotrichum laeve, Galium boreale, Comandra umbellata, Packera paupercula* and *Allium stellatum* (Table 4.3).

Native vs Introduced Species

The abundance (mean cover) of native vascular plant species was significantly greater in ungrazed plots (66.3%, vs. 10.7% in grazed plots, t_{23} = 10.03, $p < 0.001$), while the abundance of introduced vascular species was significantly higher in grazed plots (22.8%, vs. 2.2% in ungrazed plots, t_{14} = 4.51, $p < 0.0004$). This indicates that the abundance of introduced species on alvars does increase with long-term cattle grazing (Table 4.4). This was predominantly due to an increased cover of the introduced grasses, *Agrostis stolonifera, Poa alpina* and *Poa pratensis*, which represented 20.20% of the introduced cover in grazed plots. *Agrostis stolonifera* was completely absent in the ungrazed plots but had a mean cover of approximately 11% in the grazed plots ($p < 0.05$). *Poa alpina* also increased from less than 1% mean cover (freq=7%) in ungrazed plots to almost 9% cover (freq=73%) in grazed plots ($p < 0.05$).

Species Richness and Diversity

Mean species diversity (Shannon H) per plot was greater in ungrazed plots ($H = 1.667$) compared to grazed plots ($H = 1.236$), significantly ($t_{24} = 2.79$, $p < 0.05$). Portioning the introduced and native species showed that 6.2% of total species diversity in ungrazed plots was attributed to introduced species ($H = 1.667$, $H_{intro} = 0.104$, $H_{native} = 1.563$.). Conversely, almost half (49%) of total species diversity in grazed plots was attributed to introduced species ($H=1.236$, $H_{intro} = 0.605$, $H_{native} = 0.631$). Overall, mean vascular plant species richness per plot experienced a significant decrease (14.3 to 8.9) due to grazing ($t_{26} = -5.09$, $p < 0.0001$) (Table 4.5). Native vascular plant richness decreases (from a mean per plot of 12.3 to 4.3) were statistically significant ($t_{26} = -9.77$, $p < 0.0001$). Conversely, species richness of introduced vascular plants increased in grazed plots (from a mean per plot of 1.93 to 4.53) with statistically significant differences ($t_{26} = 4.42$, $p < 0.001$). Richness and diversity results at site J show a replacement of native species with introduced species.

4.3.3 Site D: Grazing Effects

Floristic Composition

Grazed and ungrazed plots were separated along the first principal component axis, indicating strong floristic differences between grazed and ungrazed areas (Figure 4.5). A total of 38.37% of variation was explained by two axes (PCA1 = 22.6%, PCA2 = 17.1%). This indicates that a large amount of variation in vegetation composition can be explained by two dimensions.

Such a distinct separation of grazed and ungrazed plots along the first axis shows that long-term grazing does quantitatively change vegetation composition on alvar shrublands.

This was confirmed by the redundancy analysis, which showed that 19.07% of the variation in floristic composition is explained by grazing; this difference is statistically significant (permutation test, $F_{1,18} = 4.24$, $p < 0.01$). Species scores on the RDA axis separate species occurring in ungrazed areas from those species preferring grazed areas (Table 4.6). *Poa pratensis, Antenaria neodioca, Taraxacum officinale* and crustose lichens were positively associated with grazing. For example, *Poa pratensis* only occurred in a single ungrazed plot but was present in all grazed plots (Table 4.6). Conversely, species such as *Dasiphora fruiticosa, Oligoneuron album, Oligoneuron rigidum, Galium boreale, Solidago nemoralis* and *Juniperus horizontalis* were negatively impacted by grazing, being much more frequent and abundance in ungrazed plots.

Physiognomic differences

Total cover of various life form groups in grazed and ungrazed plots and the associated t-test results are shown in Table 4.7. Total cover of woody perennials (shrubs) declined with grazing (56.4% in ungrazed plots, vs. 21.91% in grazed plots), and this was statistically significant ($t_{17} = -3.27$, $p = 0.004$). Most of this decline was attributable to reduced cover (and frequency) of *Dasiphora fruiticosa* (Ungrazed: mean cover = 11.6%, freq = 6/10; but absent in grazed plots)*, Arctostaphylos uva-ursi* (Ungrazed: mean cover = 3.75%, freq = 1/10; but absent in grazed plots) and *Juniperus horizontalis* (Ungrazed: mean cover = 41%, freq = 9/10; Grazed: mean cover= 21.85%, freq = 7/10) (Table 4.6). Total cover of graminoids increased under grazing (4.7% in ungrazed plots, vs. 19.4% in grazed plots), a difference that is statistically significant (t_{11} = 2.29, p = 0.04). This increase is due to significantly (t_9 = 2.37, p = 0.04) increased cover by introduced graminoids (0.11% in ungrazed plots, vs. 15.2% in grazed plots) while native graminoids do not differ significantly. The predominant introduced graminoids of grazed areas were *Poa pratensis* (mean = 12.36%, present in all grazed plots) and *Poa alpina* (mean = 2.85%, present in 3 grazed plots). The sedge *Carex crawei* occurred in four ungrazed plots and five grazed plots with cover not differing significantly. Forb species most adversely affected by grazing include *Oligoneuron album, Olgoneuron rigidum, Galium boreale, Solidago nemoralis, Monarda fistulosa* and *Symphiotrichum laeve* (Table 4.6). At site D, *Antennaria howellii* ssp. *neodioica* increased in cover in grazed areas (Table 4.6). Unlike site J, grazing decreased bryophyte cover at site D (23% to 10%, t_{15} = -2.22, p = 0.042).

Native vs Introduced Species

Overall, the total cover of native vascular plant species was greater in ungrazed plots (83.2%, vs. 42.7 % in grazed plots, t_{11} = -4.00, p =0.002), while cover of introduced vascular species was higher in grazed plots (17.2%, vs. 0.1% in ungrazed plots, t_9= 2.68, p = 0.025) (Table 4.7). This was predominately due to increased cover of the introduced grasses, *Poa pratensis* and *Poa alpina* that together represented 15.21% of the cover of introduced species in the grazed plots. *Poa pratensis* was almost absent from ungrazed plots (a mean cover of less than 1%) but increased to approximately 12% cover in grazed plots. Introduced forbs, such as *Achillea millefolium* and *Taraxacum officinale,* also increased in cover (Table 4.6).

Species Diversity and Richness

Mean total species diversity (Shannon H) was approximately equal ($t_{17} = -0.07$, $p = 0.941$) in ungrazed plots (H = 1.238) compared to grazed plots (H = 1.255). Portioning the diversity between introduced and native species showed that 0.6% of total species diversity in ungrazed plots was attributed to introduced species (H = 1.238, $H_{intro} = 0.008$, $H_{native} = 1.230$). A significantly greater proportion (31.6%) of total species diversity in grazed plots was attributed to introduced species (H = 1.255, $H_{intro} = 0.392$, $H_{native} = 0.863$) with the difference being significant ($t_{11} = -4.0$, $p < 0.005$). Total species richness of vascular plants did not change but long-term grazing increased the portion of richness due to invasive species from 4% (mean per plot of 0.4) to 37% (mean per plot of 3.5) (Table 4.5). Despite the total richness remaining unchanged at this site there was a significant replacement of native vascular plant richness ($t_{16}=-2.43$, $p = 0.027$) with richness of introduced vascular plants ($t_{10} = 4.98$, $p < 0.001$).

4.4 Discussion

4.4.1 Physiognomic composition and species composition changes

Alvars in Manitoba are severely impacted by long-term cattle grazing as shown by changes in species composition, functional group composition and diversity. This is consistent with studies of alvars in Sweden where it has been observed that long-term sheep grazing significantly alters vegetation by changing physiognomic structure and species composition (Rosén 1982). This study showed significant changes in both the species and physiognomic composition of vegetation on Manitoba alvars due to long-term grazing. Cover by functional groups including shrubs, graminoids, forbs and bryophytes were altered due to grazing.

Reducing shrub encroachment

Consistent with studies of European alvars (Rosén 1982; Partel *et al.* 1998), grazing on North American alvars reduced shrub cover. At both sites, shrub cover decreased by approximately half. In the shrub dominated community at site D, prostrate shrubs, such as *Juniperus horizontalis* and *Arctostaphylos uva-ursi,* did not decrease in frequency but grazing did reduce their cover significantly. It is suspected that *Arctostaphylos uva-ursi* and *Juniperus horizontalis* are not eaten extensively by cattle but rather experience damaging effects from trampling due to their creeping morphology. This is supported by the observations of Rosén (1982). Areas with thinner soil (as at site D) experience more severe effects of trampling (Rosén 1982). At site J, frequency of *Dasiphora fruitiscosa* did not appear to be strongly influenced by grazing although cover was decreased. Conversely, at site D this species was entirely removed from the grazed plots. Rosén and van der Maarel (2000) observed that grazing animals selectively eat the new shoots of *Dasiphora fruiticosa,* which explains the reduced cover and relatively unchanged frequency for this species at site J due to grazing. The total disappearance of this species at site D might be due to increased shrub consumption due to a reduced amount of graminoid cover in this community. This is supported by Clarke *et al.* (1995) who observed that when graminoid height is lower sheep and deer eat more shrubs. Previous studies on alvars in Sweden have shown that although shrub encroachment is a natural process and unlikely to completely take over alvar areas, the overgrowing of shrubs (such as *Juniperus* spp.) decreases diversity and changes the alvar structure (Rosén 1982; Bakker *et al.* 2012). Reschke *et al.* (1999) suggested that, as done on European alvars, grazing can be used to reduce shrub encroachment and promote higher biodiversity in North America. Shrub encroachment in

Manitoba is likely reduced by frequent disturbances such as grazing, drought and fire. Further study on vegetation dynamics of alvars would be necessary to determine if shrub encroachment is a threat to alvars in Manitoba. It was observed that *Populus tremuloides* is less frequent on grazed alvars and appears to be negatively impacted by grazing, which causes soil compaction and severs root systems (Dockrill *et al.* 2004). Consistent with studies in Europe (Rosén 1982; Partel *et al.* 1998), this supports that grazing reduces the encroachment of this species.

Changes in forbs and graminoids

Brownell (1998) observed that in alvar grasslands, intense grazing leads to a reduction of grasses while less palatable species such as *Eleocharis compressa* remain present or increased in abundance. This trend is consistent with observations by Hartnett *et al.* (1996), Cingolani *et al.* (2003) and Pavlu *et al.* (2003), which found bison and cattle grazing altered species composition by removing taller grasses and increasing abundance of prostrate or unpalatable graminoids. The current study observed that within graminoid dominated habitats (site J) total graminoid cover decreased in response to grazing. This also corresponded with a decrease in native graminoids (*Sporobolus heterolepis, Carex crawei* and *Festuca hallii*) and an increase in introduced graminoids (*Agrostis stolonifera, Poa alpina* and *Poa pratensis*) due to long-term grazing.

Conversely, at site D, long-term cattle grazing increased graminoid cover although this was due to increased cover by introduced grasses (predominantly *Poa pratensis*) rather than native graminoids. This is consistent with the effects of grazing on other shrub dominated communities in Europe. Studies on grazing by reindeer (Olofsson *et al.* 2001), red deer and sheep (Clarke *et al.* 1995) on European heath and heather moorelands respectively, found that ericoid shrubs were replaced by graminoids in grazed areas. Although this was not consistent at all sites, graminoid replacement occurred when shrubs and bryophytes were severely reduced (Olofsson *et al.* 2001). This transition to grassland furthers grazing pressure since these graminoid areas are more appealing to herbivores (Olofsson *et al.* 2001). Clarke *et al.* (1995) observed that herbivores may trample or consume shrubs on the edges of graminoid communities, increasing the area of the graminoid community. This selective grazing may partially explain the differing results of grazing effects on graminoid abundance in the alvar communities of North America. The current study suggests that different community types (graminoid dominated and shrub dominated) respond differently to grazing in terms of graminoid cover. The lack of replication of communities gives little ability to ascertain if this trend is significant and this speculation requires further study. Consistently, in both communities, the cover of introduced graminoids increased due to long-term cattle grazing. At site J, total graminoid cover decreased significantly while site D experienced a loss of shrub cover and graminoid replacement.

Studies of Swedish alvars found that specific forbs are more strongly affected by sheep grazing than others (Rosén 1982). Species with tuberous roots were removed due to trampling and species with weak root systems were pulled from the ground (Rosén 1982). In the current study, *Cypripedium parviflorum* only occurred on the ungrazed side of the shrubland community. Although it was infrequent, this species' complete absence from the grazed area supports the suggestion that species with tuberous roots are removed by trampling on thin soils. Common composites (Asteraceae) such as *Oligoneuron rigidum, Oligoneuron album, Oligoneuron rigida* and *Symphiotrichum laeve* were almost completely removed due to grazing and frequently appeared eaten on the grazed side (Tables 5.3 and 5.6). For the most part forbs that benefited from grazing were introduced species such as *Achillea millefolium, Taraxacum officinale* and *Prunella vulgaris*. Traits of these species (such as quick reproduction or high seed set) may lead to their increased success in recently disturbed grazed areas. The seeds of these species might be introduced to the alvar through the addition of hay bales for supplemental feed, since higher abundance was observed where supplemental feeding had taken place on the alvar (P.K. Catling, Pers. Obs. 2015). The native species *Antennaria howellii* ssp. *neodioca* may benefit from the reduction of creeping shrubs due to grazing since it showed a positive response to grazing in the shrubland community (Site D, Table 4.6) but responded negatively to grazing in the grassland community (Site J, Table 4.3).

Cryptogams

In arid and semi-arid ecosystems (like alvars) cryptogamic plants provide enhanced stability from erosion, drought and nitrogen deficiencies (Harper and Marble 1988). Lichens and mosses are particularly sensitive to grazing on alvars with certain species being more tolerant than others (Rosén 1982). This study showed that at two alvar sites in Manitoba, grazing had mixed influences on mosses and lichens. Site J contained *Ditrichum flexicaule,* a species which has an affinity for open, recently disturbed areas, and contributed to an increase in moss cover after grazing. This is supported by Rosén (1982) who remarked that *Ditrichum flexicaule* is a species that is able to withstand grazing. In contrast, at site D where the dominant moss is a pleurocarp (*Abietinella abietina*), moss cover decreased significantly. The results of this study showed that certain bryophyte taxa may benefit from cattle grazing while others experience negative impacts.

Intensive sheep grazing on alvars in Sweden completely removed lichen cover (Rosén 1982). This study found that lichen cover was not removed entirely. At both sites, foliose lichens experienced a decline in cover. Conversely, crustose lichens experienced an increase in cover. These trends correspond to the effects of trampling having harmful effects to foliose lichens and causing an increased cover of bare rock, favouring crustose lichens (Rosén 1982). When developing a management strategy for Manitoba alvars it is important to choose a management strategy that considers cryptogams as well (Harper and Marble 1988).

4.4.2 Increased Abundance of Introduced Species

For the most part, studies on grazing determine the effects on sward height or productivity without considering the portion of this due to native and introduced species (Hartnett *et al.* 1996; Olofsson *et al.* 2001), but observations from multiple studies on alvar vegetation (Partel *et al.* 1998; Reschke *et al.* 1999) suggest that introduced species are more frequent in grazed areas and may replace characteristic alvar vegetation. This consistency applies to Manitoba alvars, since long-term cattle grazing caused a statistically significant increase in cover of introduced species. Specific species such as *Achillea millefolium* and *Agrostis stolonifera* were more tolerant of sheep grazing on Swedish alvars (Rosén 1982). Both of these species also increased in frequency and cover due to long-term cattle grazing in the current study. After grazing, both sites had an introduced cover of approximately 20%. This is less than the 50%

nitrophilous weed cover observed by Rosén (1982) after long-term intensive sheep grazing. The increase in introduced species is also consistent with observations on Ontario alvars where grazing increased the abundance of quick-germinating introduced species and reduced native abundance (Brownell and Riley 2000). A large majority of the increase in introduced cover on Manitoba alvars was due to introduced grasses (*Poa* spp. and *Agrostis stolonifera*). It was expected that introduced species might have a hard time surviving in the harsh alvar environment with limited soil and water (D'Antonio *et al.* 2001); however, the alvars in Manitoba are heavily invaded by these species after long-term grazing. Frequent anthropogenic levels of long-term grazing may be altering the alvar environment to allow for this invasion. Studies have shown that long-term grazing can transform the soil layer through erosion, compaction and nutrient addition that alters the potential vegetation composition (Dockrill *et al.* 2004; Cingolani *et al.* 2003). In Garry Oak ecosystems, MacDougall and Turkington (2005) found that exotic species were 'passengers' (species that are present due to non-interactive factors, such as the ability to reproduce quickly, rather than competitive exclusion) to repeated levels of anthropogenic disturbance and the suppression of natural disturbance regimes. Further experimental study is needed to determine if the increased richness and abundance of introduced species on alvars is due to introduced species having an increased ability to compete for nutrients or if the native species are removed by cattle consumption with introduced species filling empty disturbed areas due to fast colonization. With the unique environmental conditions found on alvars, further study of invasion processes in these areas can provide useful insight into mechanisms for invasion and how environmental factors affect invasion processes.

4.4.3 Species Richness and Diversity

Multiple studies on a variety of herbivores (Clarke *et al.* 1995; Hertnett *et al.* 1996; Pärtel *et al.* 1998) have shown support for intermediate levels of grazing promoting higher levels of diversity. In European grasslands, it has been observed that there is an initial increase in species richness due to grazing, although this is not always maintained (Pavlu *et al.* 2003). The results at site J, which showed a decrease in richness and diversity due to grazing (Table 4.5), are consistent with those of Rosén (1982), Rosén and van der Maaurel (2000) and Pavlu *et al.* (2003) who found that continuous grazing of European grasslands by cattle or sheep decreases species richness. A study by Wang *et al.* (2001) focused on the different influences of grazing regime (constant vs. rotational) and showed that rotational grazing increased biodiversity but constant grazing decreases biodiversity.

In contrast to site J, the richness at site D did not change (Table 4.5). However, this study showed that although long-term cattle grazing does not always alter total species richness and diversity, it does consistently shift vegetation composition by increasing the proportion of species richness due to introduced species (Table 4.5). At site J, approximately half of the mean richness and diversity of the grazed area was due to introduced species (an increase of 42% richness). At site D, an increase of 37% introduced richness was observed. Conversely, in the highly managed grasslands of the Rocky Mountain National Park (Colorado, Wyoming, Montana and South Dakota), an exclosure study found that grazing (species varied by site and included: cattle, bison, elk, horses, sheep and deer) did not reduce species richness or increase the presence of introduced species showing that proper management can remove these negative effects of grazing (Stholgren *et al.* 1999). Like alvars, these grasslands are also graminoid dominated. Dominant species of the Rocky Mountain National Park grasslands include *Bromus* spp., *Eleocharis* spp., *Festuca* spp., *Koeleria nitida, Stipa richardsonii* and *Poa pratensis* with forbs species such as *Antennaria* spp., *Artemisia ludoviciana, Melilotus officinalis* and *Solidago missouriensis* being frequent (Stholgren *et al.* 1999). Manitoba is in need of an adaptive grazing management plan for alvars since the current grazing activities on Manitoba alvars are having a profound effect on the vegetation by drastically increasing the proportion of richness and diversity of introduced species.

Fire regime and topography have been shown to also influence the effects of bison grazing in tall grass prairie ecosystems (Hartnett *et al.* 1996) and the effects of drought combined with grazing can cause a dramatic decrease in species richness (Pavlu *et al.* 2003). This shows that environmental factors interact with grazing and that environmental data and a comprehensive view of disturbance are required to determine the effects of grazing. The unique environmental conditions on alvars provide an opportunity for future work to examine how environment and disturbance interact to influence biodiversity.

4.4.4 Variation in the effects of grazing by continent and site

Disturbances such as grazing have become somewhat natural for alvar ecosystems in Europe that have been grazed at anthropogenic levels since the 16th century (Rosén 1982). In North America, the prairie and alvar grasslands have been historically grazed by native species such as bison, deer, caribou and moose but intensity of grazing (historical) is unknown. Hartnett *et al.* (1996) showed that cattle and bison have different grazing habits and resulting in different effects on vegetation composition and diversity. It has been shown that grazing bison are selective of C_4 grasses and that forbs are not consumed, resulting in more diverse ecosystems (Knapp *et al.* 1999). This selective grazing creates dynamic patches on the landscape from the intensive grazing of an area followed by patch abandonment that gives vegetation a chance to regrow before the bison return (Knapp *et al.* 1999). Due to increased stocking rates and the confinement to small pasture areas that doesn't allow for roaming behaviour, the modern livestock grazing regime is well above the impacts from native herbivores (Brownell and Riley 2000). Since alvars are unproductive ecosystems and supplemental feed for livestock was often observed on sites, it is expected the alvars in Manitoba are stocked over their carrying capacity. Other than the reduction of shrub encroachment, the benefits of grazing (increased species richness) were not observed on Manitoba alvars. The benefits of grazing are very dependent on multiple interacting factors and cannot be assumed to be consistent in North America where the flora has not experienced or adapted to this long-term cattle grazing regime at the current intensity and duration. Alvars are already a sparse and unproductive ecosystem and their shallow soils make them increasingly susceptible to the disturbances of grazing (Rosén 1982).

The different responses to grazing among sites could be attributed to differences in initial vegetation composition, environment, grazing history and current grazing activities. Since site explained the highest amount of variation in vegetation patterns, it supports that initial community type has a large effect on the response of vegetation to grazing. Initial site differences are likely due to different environmental conditions that lead to varying vegetation communities in that specific region of the site where the fence line occurred (See Chapter 3). These results suggest that graminoid dominated alvars (site J) may experience more drastic negative effects of grazing than shrubland alvars (site D) although further study is necessary to confirm this observation. This theory is supported by Clarke *et al.* (1995) who stated that herbivores will selectively graze grassland communities and their edges and therefore have a stronger impact on these communities.

The effects of drought combined with grazing can have a severely negative effect on biodiversity (Pavlu *et al.* 2003). Re-colonization of alvars is slow and can be further impeded by exotic vegetation (Rosén 1982) suggesting that the replacement of native vegetation by introduced species is highly detrimental to this ecosystem. Estimates say that it can take up to 100 years to restore an alvar to pre-grazing conditions (Sjögren 1971; Rosén 1982). It is far better to reduce all of the damages from grazing so that sites can more easily restore during rotational periods.

4.4.5 Additional effects of grazing

There are many additional disturbances associated with grazing other than the effects of consuption and trampling. These aspects were outside of the scope of this study but should be considered in future studies. Grazing not only changes the biodiversity and composition of vegetation but also has profound effects on environmental conditions such as soil compaction, soil nutrients, creation of bare patches and microclimatic changes from the removal of vegetation (Rosén 1982; Cingolani *et al.* 2003). Although not seen directly within transects from this study, it was observed that grazed alvars had additional disturbance from off-road vehicle use associated with the grazing activities (but potentially recreational as well). At some sites, water holes had been cut through the limestone bedrock (P.K. Catling, Pers. Obs. 2014). The complete effects of these activities are unknown, although it is expected that both off-road vehicle use and creating pits will affect drainage on the alvar, which is characteristically flat with no deep areas where water can collect. Dai (2000) showed that cattle grazing can also affect vegetation dynamics on alvars through the deposition of dung via changing the soil seed bank or by adding patches of nutrients that increase growth. Providing supplemental feed for cattle distributes seeds of ‘weedy’ species throughout the site via dung. This increases the amount of nutrients that in turn increases the presence of these species.

4.5 Significance, future directions and management

It is important to incorporate biodiversity and conservation objectives into agricultural methods (Hopkins and Holz 2006). Vegetation communities in areas with thin soil are more susceptible to being negatively impacted by overgrazing and trampling (Rosén 1982; Konigsson 1968; Krahulec *et al.* 1986). Studies by Richardson *et al.* (2010) showed that more diverse communities are more resistant to drought. Since alvars are characteristically prone to extremes of flooding and drought, maintaining the native biodiversity of grazed alvars is important to both preserving a unique ecological area and for ensuring viability of the area as pastureland. The current grazing regime has drastic effects on the alvar vegetation in Manitoba in terms of both species and functional group compositions. Most significantly, the proportion of richness and diversity due to introduced species drastically increased due to long-term grazing. Introduced species increased in abundance (cover) and richness due to long-term grazing. Within alvar ecosystems, it is uncertain if this increase is following the removal of native species or if these introduced species are out-competing the native ones.

It is still possible that a grazing regime that benefits alvar vegetation could be found in order to reduce negative impacts and maintain the use of these areas as leased or public pastures. Manitoba's alvars are in need of a management strategy; however, different grazing regimes have a significant effect on vegetation composition (Pavlu *et al.* 2003). For alvars in Europe, Rosén (1982) suggested that rotational grazing regimes with short grazing periods (2-3 days) and long recovery periods (3-5 weeks) should be used on alvars since it gives vegetation adequate time to recover. However, this is not practical for community pastures, but lowering grazing intensity by grazing at low stocking rates has been suggested to help maintain biodiversity (Collins *et al.* 1998). Drought has been considered an issue for managing grasslands in North America and management practices alter annual stocking rates based on the yield of the pasture lands (Coupland 1961). This method of adaptable management may be useful on Manitoba alvars since it accounts for the ecosystems susceptibility to drought, which increases the negative effects of grazing on biodiversity (Coupland 1961; Pavlu *et al.* 2003).

It is very difficult to assess the effects of grazing when the complete history of the site is unknown since factors such as successional stage, the grazing animal, intensity of grazing, duration of grazing and environmental variations can all have an effect on the influence grazing has on vegetation (Rosén 1982; Gibson and Brown 1992; Klimek *et al.* 2007). Due to these factors, this study can only describe the drastic effects of long-term cattle grazing on alvar vegetation without providing an understanding of its mechanisms. A lack of grazing history and monitoring of stocking rates on crown land meant information on grazing history and intensity was outside of the scope of this study and it was assumed that the sites were grazed for the duration of the lease. It would be highly beneficial if there were annual records for stocking rates on leased crown lands so that future studies can consider this data. Future studies should endeavor to determine the proportional representation of native and introduced species as a means of evaluating community degredation due to grazing. Incorporating a larger number of variables, including environmental data, would greatly benefit the rhobustness of future studies and determine if/how grazing is altering edaphic conditions on alvars. Long-term monitoring and the recording and regulating of stocking rates will be necessary to further understand the effects of grazing on the vegetation of alvar communities and to determine the proper balance of grazing intensity and rotation time for Manitoba's alvars.

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Table 4.1: Pre-grazing species richness and mean cover (standard deviations, brackets) for bare rock and plant life forms (lichen, moss, graminoids, annual forbs, perennial forbs, shrubs and tree). Note that lichens were not identified to species.

	SITE D		SITE J	
FORM	**# Species**	**Cover (%)**	**# Species**	**Cover (%)**
Bare rock	-	**4.25** (7.36)	-	**4.58** (10.13)
Lichen	-	**20.21** (2.76)	-	**9.36** (0.97)
Moss	**3**	**23.16** (5.77)	**5**	**19.83** (4.95)
Graminoid	**6**	**4.66** (0.74)	**15**	**34.17** (5.01)
Annual	**1**	**0.06** (0.02)	**1**	**0** (0)
Perennial	**19**	**28.49** (1.37)	**19**	**22.28** (1.26)
Shrub	**3**	**56.35** (13.59)	**4**	**12.04** (2.98)
Tree	**1**	**0.01** (0.02)	**0**	**0** (0)

Table 4.2: Dominant species (highest percent cover) in the ungrazed plots of sites D and J.

FORM	SITE J	SITE D
Shrubs	*Dasiphora fruiticosa* *Prunus susquehane*	*Juniperus horizontalis* *Arctostaphylos uva-ursi* *Dasiphora fruiticosa*
Graminoids	*Carex crawei* *Sporobolus heterolepis* *Eleocharis compressa* *Danthonia spicata*	*Poa compressa* *Carex crawei*
Forbs	*Geum trifolium* *Galium boreale* *Antennaria howellii* ssp. *neodioicc* *Symphyotrichum laeve*	*Oligoneuron album* *Oligoneuron rigidum* *Solidago nemoralis* *Geum triflorum* *Galium boreale* *Symphyotrichum laeve* *Antennaria howellii* ssp. *neodioica*
Mosses	*Bryum* spp. *Ditrichum flexicaule* *Tortella* spp.	*Thuidium* spp. *Bryum* spp.

Table 4.3: RDA scores (principal axis) for the most common species, in order of association with grazing (negative scores indicates association with ungrazed, positive with grazed) at site J. Percent frequency and mean cover for grazed and ungrazed plots

SPECIES	**RDA Score**	**Frequency (%)**		**Mean Cover (%)**	
		UNGRAZED	**GRAZED**	**UNGRAZED**	**GRAZED**
Sporobolus heterolepis	-2.370	87	0	25.17	0.00
Oligoneuron album	-1.629	87	0	3.24	0.00
Galium boreale	-1.591	93	20	4.00	0.14
Carex crawei	-1.241	87	0	1.29	0.00
Symphyotrichum laeve	-0.857	40	0	2.47	0.00
Foliose lichen	-0.665	47	13	2.17	0.07
Packera paupercula	-0.638	73	7	0.43	0.00
Bryum sp.	-0.619	33	0	1.77	0.00
Antennaria howellii ssp. *neodioica*	-0.611	80	47	5.48	3.91
Tortella tortuosa	-0.601	53	27	1.94	0.18
Festuca hallii	-0.490	33	7	1.04	0.04
Comandra umbellata	-0.484	40	0	0.61	0.00
Dasiphora fruticosa	-0.473	60	53	9.17	2.74
Danthonia spicata	-0.471	67	27	1.24	0.41
Eleocharis compressa	-0.434	20	13	3.23	0.01
Rosa acicularis	-0.421	27	0	0.54	0.00
Geum triflorum	-0.398	40	20	2.87	0.57
Muhlenbergia racemosa	-0.296	20	0	0.24	0.00
Allium stellatum	-0.271	53	0	0.09	0.00
Achillea millefolium	-0.221	93	73	0.96	0.99
Festuca saximontana	-0.208	53	0	0.06	0.00
Campanula rotundifolia	-0.198	47	20	0.09	0.01
Juniperus communis	-0.172	7	0	1.17	0.00
Prunus susquehanae	-0.172	7	0	1.17	0.00
Potentilla bipinnatifida	0.237	0	13	0.00	0.33
Ceratodon purpureus	0.279	0	13	0.00	1.27
Prunella vulgaris	0.279	0	13	0.00	0.73
Erigeron glabellus	0.300	27	53	0.34	0.75
Poa compressa	0.340	33	47	0.02	0.28
Poa pratensis	0.389	33	67	0.71	1.19
Taraxacum officinale	0.656	7	47	0.23	1.24
Ditrichum flexicaule	0.934	67	100	14.54	44.38
Crustose lichens	0.983	60	93	4.11	11.17
Agrostis stolonifera	1.291	0	67	0.00	10.51
Poa alpina	1.524	7	73	0.04	8.50

Table 4.4: Mean percent cover (with standard deviations, brackets) of life form classes in grazed and ungrazed plots (n=15) at site J. Statistical significance of difference in mean cover between grazed and ungrazed plots is also given (Welsh t-test, with degree of freedom and P-values).

FORM	UNGRAZED	GRAZED	Welsh t-test	
Mosses	**19.83** (13.27)	**46.41** (30.75)	$t_{19} = 3.06$	$P = 0.0064$
Vascular Plants (all)	**68.49** (19.16)	**33.46** (22.17)	$t_{27} = -4.75$	$P < 0.0001$
Vascular Plants (native)	**66.33** (18.13)	**10.67** (11.55)	$t_{23} = -10.03$	$P < 0.0001$
Vascular Plants (introduced)	**2.16** (2.97)	**22.79** (17.45)	$t_{14} = 4.51$	$P < 0.001$
Graminoids (all)	**34.17** (10.73)	**20.99** (16.30)	$t_{24} = -2.62$	$P = 0.015$
Graminoids (native)	**33.39** (11.37)	**0.78** (0.94)	$t_{14} = -11.07$	$P < 0.0001$
Graminoids (introduced)	**0.79** (1.51)	**20.20** (16.77)	$t_{14} = 4.47$	$P < 0.001$
Perennials (all)	**22.28** (10.22)	**8.91** (8.17)	$t_{26} = -3.96$	$P < 0.001$
Perennials (native)	**20.9** (8.88)	**6.42** (8.47)	$t_{27} = -4.57$	$P < 0.0001$
Perennials (introduced)	**1.38** (2.08)	**2.49** (2.25)	$t_{27} = 1.41$	$P = 0.1704$
Woody Plants	**12.04** (11.90)	**3.47** (5.06)	$t_{18} = -2.57$	$P = 0.019$

Table 4.5: Mean values per plot (with standard deviations, brackets) for vascular plant species richness and Shannon diversity (H) in grazed and ungrazed plots at sites D and J. Statistical differences between grazed and ungrazed plots are also given (Welsh t-tests, with degrees of freedom and P-values).

SITE	TREATMENT	SPECIES RICHNESS			SHANNON DIVERSITY (H)		
		Total	Native	Introduced	Total	Native	Introduced
D (n = 10)	Ungrazed	**9.40** (2.37)	**9.00** (2.40)	**0.40** (0.52)	**1.24** (0.54)	**1.23** (0.54)	**0.01** (0.01)
	Grazed	**9.40** (4.12)	**5.90** (3.25)	**3.50** (1.90)	**1.26** (0.47)	**0.86** (0.45)	**0.39** (0.36)
Welch t-test		$t_{14} = 0.00$ $P = 1.000$	$t_{16} = 2.43$ $P = 0.027$	$t_{10} = 4.98$ $P < 0.001$	$t_{17} = 0.07$ $P = 0.941$	$t_{17} = 1.66$ $P = 0.116$	$t_{9} = 3.36$ $P = 0.008$
J (n = 15)	Ungrazed	**14.27** (3.26)	**12.33** (2.47)	**1.93** (1.39)	**1.67** (0.29)	**1.56** (0.23)	**0.11** (0.11)
	Grazed	**8.87** (2.50)	**4.33** (1.99)	**4.53** (1.81)	**1.24** (0.53)	**0.63** (0.46)	**0.61** (0.32)
Welch t-test		$t_{26} = 5.09$ $P < 0.001$	$t_{26} = 9.77$ $P < 0.001$	$t_{26} = 4.42$ $P < 0.001$	$t_{21} = 2.79$ $P = 0.011$	$t_{20} = 6.99$ $P < 0.001$	$t_{17} = 5.73$ $P < 0.001$

Table 4.6: RDA scores (principal axis) for the most common species, in order of association with grazing (negative scores indicate association with ungrazed plots, positive scores indicate association with grazed plots) at site D. Percent frequency and mean cover for grazed and ungrazed plots are also shown. Invasive species are bolded.

		Frequency (%)		**Mean Cover (%)**	
SPECIES	**RDA Score**	**UNGRAZED**	**GRAZED**	**UNGRAZED**	**GRAZED**
Dasiphora fruticosa	-1.370	60	0	11.60	0.00
Oligoneuron album	-1.349	80	0	4.26	0.00
Oligoneuron rigidum	-0.964	50	0	3.35	0.00
Galium boreale	-0.897	70	10	1.16	0.15
Juniperus horizontalis	-0.670	90	70	41.00	21.85
Poa compressa	-0.667	60	0	0.47	0.00
Symphyotrichum laeve	-0.655	40	0	1.31	0.00
Solidago nemoralis	-0.604	40	10	1.80	0.15
Monarda fistulosa	-0.471	40	0	0.56	0.00
Foliose lichen	-0.417	50	30	4.26	1.25
Comandra umbellata	-0.409	30	0	0.46	0.00
Abietinella abietina	-0.364	90	90	16.15	5.66
Arctostaphylos uva-ursi	-0.269	10	0	3.75	0.00
Artemisia campestris	-0.227	20	0	0.11	0.00
Carex sp.	-0.182	10	0	0.35	0.00
Erigeron glabellus	-0.182	10	0	0.35	0.00
Cypripedium parviflorum	-0.150	10	0	0.15	0.00
Carex crawei	0.150	40	50	3.71	3.86
Danthonia spicata	0.150	0	10	0.00	0.15
Campanula rotundifolia	0.151	50	40	0.03	0.12
Cerastium arvense	0.153	0	60	0.00	0.03
Geum triflorum	0.210	80	90	6.60	6.55
Potentilla bipinnatifida	0.210	0	10	0.00	0.75
Koeleria macrantha	0.304	0	50	0.00	0.13
Erigeron glabellus	0.389	10	30	0.01	0.36
Syntrichia ruralis	0.425	0	20	0.00	2.13
Achillea millefolium	0.466	20	50	0.01	0.32
Poa alpina	0.632	0	30	0.00	2.85
Crustose lichen	0.635	30	60	6.25	8.90
Taraxacum officinale	0.723	0	40	0.00	1.60
Antennaria howellii ssp. *neodioica*	1.150	40	90	1.91	8.35
Poa pratensis	1.758	10	100	0.06	12.36

Table 4.7: Mean percent cover (with standard deviations, brackets) of life form classes in grazed and ungrazed plots (n = 10) at site D. Statistical significance of difference in mean cover between grazed and ungrazed plots is also given (Welsh t-tests, with degrees of freedom and P-values).

FORM	**UNGRAZED**	**GRAZED**	**Welsh t-test**	
Mosses	**23.16** (16.00)	**9.76** (10.36)	$t_{15} = -2.22$	P = 0.042
Vascular Plants (all)	**83.31** (11.97)	**59.87** (18.49)	$t_{15} = -3.37$	P = 0.004
Vascular Plants (native)	**89.13** (11.94)	**42.67** (29.75)	$t_{11} = -4.00$	P = 0.002
Vascular Plants (introduced)	**0.12** (0.23)	**17.20** (20.12)	$t_{9} = 2.68$	P = 0.025
Graminoids (all)	**4.66** (6.95)	**19.40** (19.08)	$t_{11} = 2.29$	P = 0.042
Graminoids (native)	**4.55** (7.01)	**4.19** (7.11)	$t_{17} = -0.12$	P = 0.909
Graminoids (introduced)	**0.11** (0.23)	**15.21** (20.16)	$t_{9} = 2.37$	P = 0.042
Perennials (all)	**22.24** (15.55)	**18.56** (10.59)	$t_{15} = -0.62$	P = 0.545
Perennials (native)	**22.23** (15.54)	**16.58** (9.86)	$t_{15} = -0.97$	P = 0.347
Perennials (introduced)	**0.01** (0.02)	**1.98** (2.26)	$t_{9} = 2.36$	P = 0.042
Woody Plants	**56.36** (22.69)	**21.91** (24.42)	$t_{17} = -3.27$	P = 0.004

Figure 4.1: Fence line used for grazing study at site D.

Figure 4.2: Fence line used for grazing study at site J.

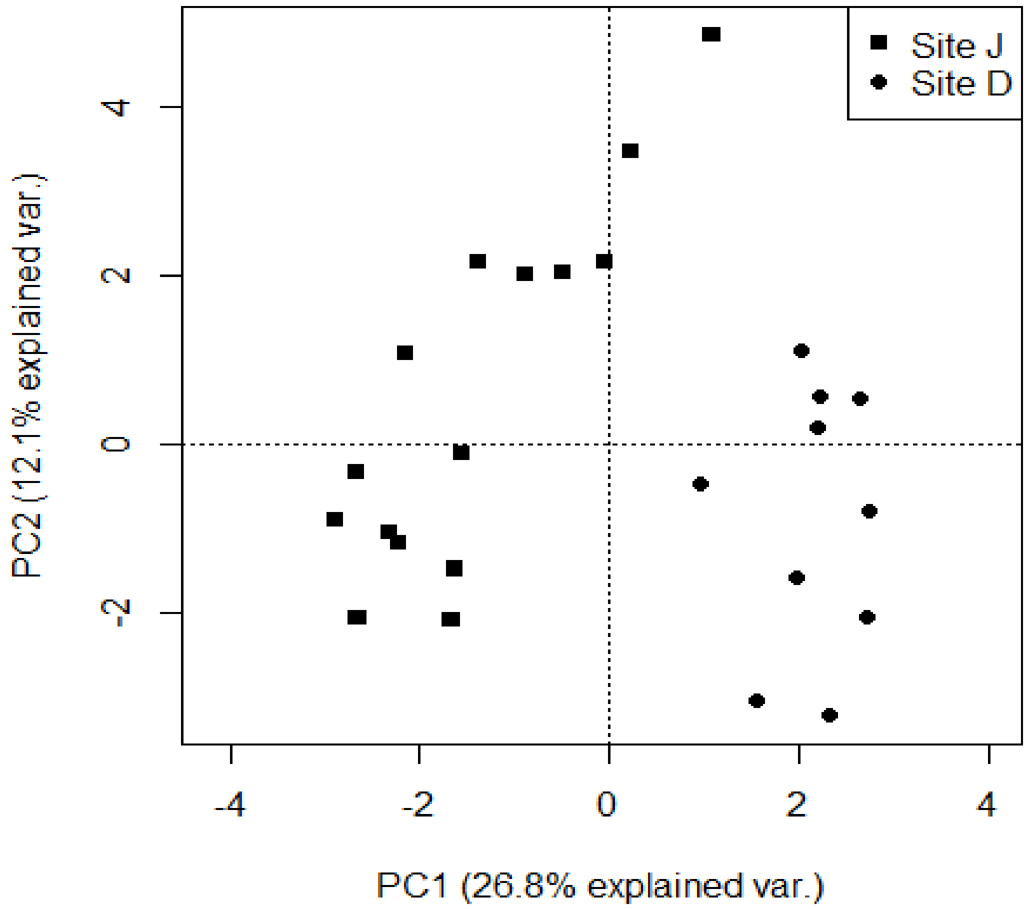

Figure 4.3: PCA ordination for comparison of pre-grazing vegetation compositions at sites D and J.

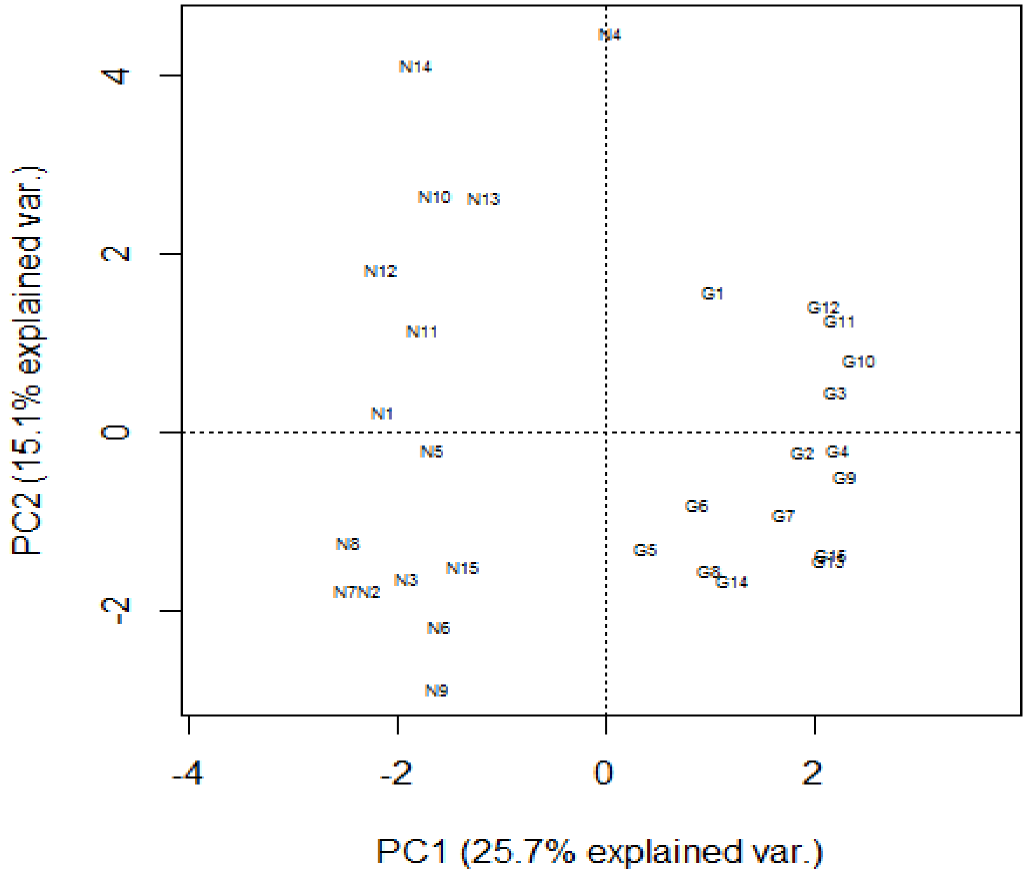

Figure 4.4: PCA ordination of 15 ungrazed (N) and 15 grazed (G) 1X1m plots at site J.

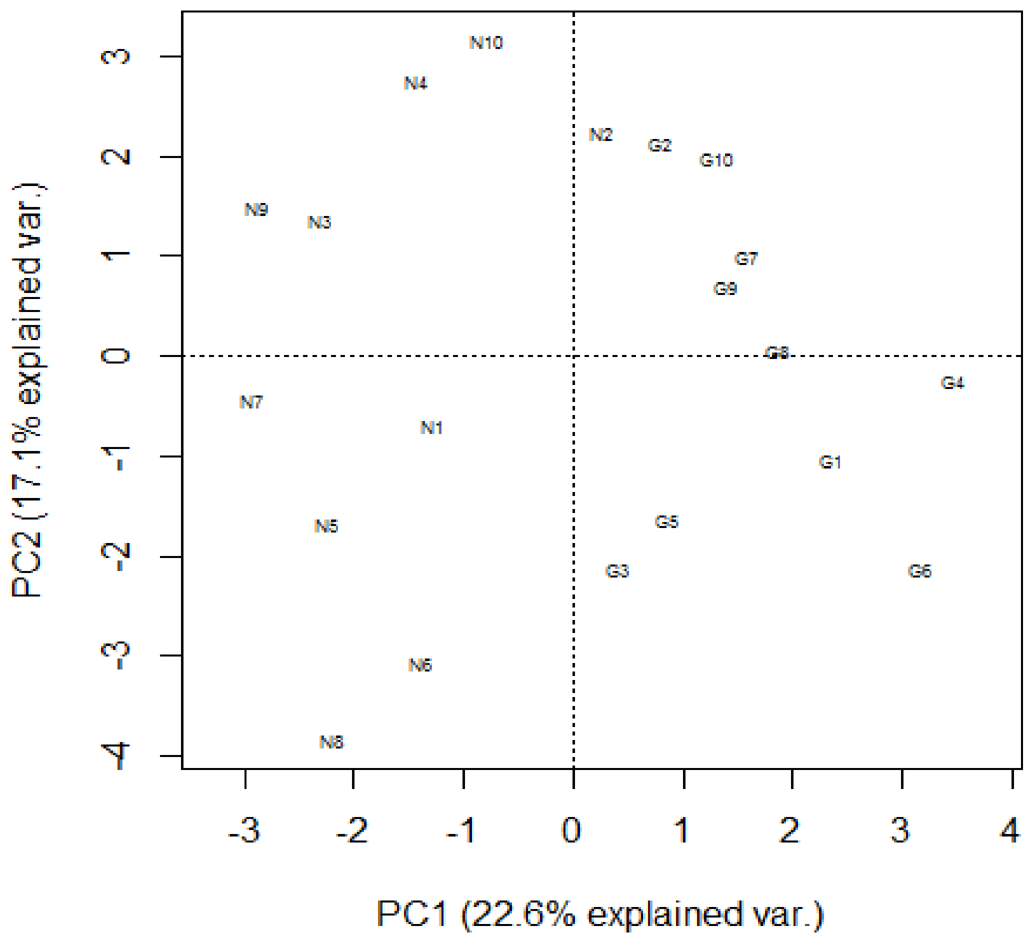

Figure 4.5: PCA ordination of 10 ungrazed (N) and 10 grazed (G) 1X1m plots at site D.

Chapter 5: Final Discussion and Conclusions

This study contributes to our general knowledge of alvar ecosystems and provides context for how they compare to other similar communities. Alvars contain a mixture of floral elements and high biodiversity that is affected by specific environmental conditions (shallow soil over limestone) and frequent disturbances (drought, flooding and so forth).

This thesis includes a quantitative classification of alvar vegetation in Manitoba using the abundance of all species. The eight vegetation communities described are a patchy continuum resulting from irregular environmental conditions including varying topography (moisture availability) and soil depth. The communities described were consistent across multiple statistical methods indicating that their classification is robust. As in alvars globally, this mosaic of communities contributes to the diverse flora of alvar ecosystems in Manitoba. The affinities of these species are a mixture of boreal, prairie, generalist and introduced species. This study did show that there is a distinct separation in vegetation composition between wooded alvars (dominated by trees and shrubs) and graminoid dominated alvars. However, in contrast to previous studies of alvars in North America, alvar shrubland and savanna communities did not have quantifiably different floristic compositions. This may differ from the alvars in the Great Lake region since alvar savannas (10-25% tree cover) are not extensive in Manitoba and alvar woodlands (26-60% tree cover) were not considered in this study. Defining these communities ensures that conservation efforts can preserve the biodiversity of alvars.

This study showed that environmental conditions on alvars in Manitoba determine what vegetation types establish. Changes in environmental conditions contribute to the patchy nature of alvar ecosystems through both large-scale variability such as topography, and small-scale variations including microhabitats (e.g. cracks in the limestone). Soil depth, rock cover and moisture availability were revealed as being of the utmost importance in affecting vegetation composition on alvars.

Alvars experience frequent disturbances such as flooding, drought, frost heaving, fire and grazing. Although many of these naturally maintain the openness of the ecosystem, cattle grazing on Manitoba alvars can have drastic effects on vegetation through changing diversity, composition and structure of alvar communities. Long-term grazing is causing a significant replacement of native species with introduced species. Further study is needed to determine the full influence cattle grazing has on alvar ecosystems and if this disturbance is altering the environmental conditions as well as the vegetation. An adaptive management plan for grazing activities is necessary for the conservation of Manitoba alvars.

Since all known alvars in Canada have been surveyed, further work on alvars can compare alvar vegetation across the country. This nation-wide comparison could improve upon the existing classifications of alvar vegetation by creating a single classification system with consistent terminology for communities. Conversely, it might be found that the alvar vegetation is distinct geographically and each region holds unique alvar communities. Study of alvars is vital to their conservation since it gives insight into the network of ecological factors that affect vegetation within these ecosystems.

Appendix 1: Definitions of alvars and similar ecosystems from literature.

REFERENCE	ECOSYSTEM	LOCATION	DEFINITION
Linnaeus (1745)	Alvar	Oland, SW	*“Now one could see the nature and peculiarities of the alvar-land which occupies most of Oland; it is a low table land, all dry, bare and sterile; the bedrock is a red limestone which is partly covered in*
Witte (1906) translated by Sjören (1988)	Comparison of alvars to European heath vegetation	Oland, SW	*“(Witte 1906, p. 17). ... the 'alvar' vegetation is a steppe vegetation conditioned by edaphic factors in a more or less insular climate and which has several features in common with the southeast European steppe vegetation and also some similarities with the mountain vegetation in the far north, but no or at least a highly insignificant similarity with true heath vegetation.”*
Harper (1926)	Cedar Glades	Tennessee, USA	*"A typical cedar clage is usually on a large flat area of limestone with very little soil"*
Krucera and Martin (1957)	Cedar Glades	Missouri, USA	*"The vegetation of the 'glades' is predominantly a grass cover with a scattering of cedar, Juniperus virginiana, and scrubby hardwoods. Soils are shalow, overlying resistant beds of limestone. Horizontal outcroppiings of rock occur at regular intervals on slopes."*
Beschel (1965)	Alvar	Ontario, CAN	*“Vegetation types dominated by forbs and grass-like plants are highly diverse. They cover most of the shallow limestone plains which are partly flooded in spring and very dry during most of the summer and correspond to the Swedish alvars.”*
Catling et al. (1975), Catling and Brownell (1995)	Alvar	Ontario, CAN	*“Alvars are naturally open areas of thin soil over essentially flat limestone or marble rock with trees absent or at least not forming a continuous canopy.”*
Nelson and Ladd (1981)	Cedar Glades	Missouri, USA	*"...the term 'glade' refers to essentially treeless rocky barrens generally occuring on south and west-facing slopes of otherwise forested ridges. Glades occur on a wide variety of substrate types, including limestones, cherts, basic intrusives volcanic rocks, dolomites, sandstones and shales. Glades are characterized by a very thin soil over and harsh, often widely fluctuating environmental conditions."*

Appendix 1: Definitions of alvars and similar ecosystems from literature (Continued)

REFERENCE	**ECOSYSTEM**	**LOCATION**	**DEFINITION**
Baskin and Baskin (1985)	Cedar Glades	Kentucky, USA	*"Cedar glades are treeless or almost treeless areas where limestone or dolomite bedrock is at or near the surface. They may or may not be surrounded by trees."*
Reschke (1990)	Sandstone Barrens	New York State, USA	*"Sandstone pavement barrens: an open canopy woodland that occurs on very shallow soils over snadstone bedrock; this community is best developed where the bedrock is nearly level, thus forming a pavement."*
Reschke (1990)	Limestone Woodland	New York State, USA	*"Limestone woodland: a woodland that occurs on shallow soils over limestone bedrock, and usually includes numerous rock outcrops. The tree canopy may be open or closed."*
Belcher et al. (1991)	Alvar	Ontario, CAN	*"Alvars are areas with a distinctive dry grassland vegetation growing in thin soil over limestone..."*
Belcher (1992)	Alvar	Ontario, CAN	*"Alvars are naturally treeless areas of herbaceous and shrubby vegetation in thin soil over limestone rock..."*
Heikins et al. (1994)	Shale and Chert Barrens	Illinois, USA	*"Barrens in southern Illinois are natural forest openings on rocky, shallow soils with xeric trees, shrubs, forbs and graminoid species including herbaceous species typical of prairie communities."* *"Shale is a fine-textured sedimentary rock that undergoes rapid erosion whereas chert (sometimes called flint) is a microcrystalline siliceous rock that is brittle and shatters with heat. Both shale and chert are commonly associated with limestone."*

Appendix 1: Definitions of alvars and similar ecosystems from literature (Continued)

REFERENCE	ECOSYSTEM	LOCATION	DEFINITION
Alvar Working Group (1995) as part of the International Alvar Conservation Initiative	Alvar	Ontario, CAN and Michigan, USA	*"Alvars are natural communities of humid and sub-humid climates, centered around areas of glaciated horizontal limestone/dolomite bedrock pavement with a discontinuous this soil mantle. These communities are characterized by distinctive flora and fauna with less than 60% tree cover, that is maintained by associated geologic, hydrologic and other landscape processes. Alvar communities occur in an ecological matrix with similar bedrock and hydrologically influenced communities"*
Catling and Brownell (1995)	Alvar	Ontario, CAN	*"Inherent in the use of the term "alvar" by botanists is the recognition of a distinctive vegetation in terms of both species and associations, prominence of periodic drought, slope and exposure in controlling zonations and vegetation cover of natural vegetation cover suggesting open habitat prior to human influence."*
Gilman (1995)	Alvar	New York State, USA	*"Alvar landscapes occur north of the glacial bounary where horizontal bedded limestone/dolomites are covered with thin, discontinuous soils."*
Schaefer (1996)	Alvar	Ontario, CA	*"Alvars are open areas of shallow or sporadic soil cover over flat limestone or dolostone bedrock. Although they are level, alvars potentially have rocky, infertile soils and alvar habitat has little commercial value (often being referred to as barren of wasteland sites)..."*

Appendix 1: Definitions of alvars and similar ecosystems from literature (Continued)

REFERENCE	ECOSYSTEM	LOCATION	DEFINITION
Reschke et al. (1999)	Midwest wet-mesic dolomite prairie	Illinois, USA	*"This grassland community occurs on shallow, temporarily flooded or frequently saturated soils overlying dolomite bedrock. It is only known from northeastern Illinois. This grassland has a dense cover of herbaceous vegetation, while woody species are virtually absent."* *"Although this grassland has a soil moisture regime very similar to alvar grasslands, the soils are generally deeper and this community seems to be dependent upon frequent fires. The combination of the fire regime and the relative abundance of many characteristic prairie species are the main reasons this community is considered a prairie instead of an alvar."*
Reschke et al. (1999)	Alvar	Great Lakes Alvars, CAN and USA	*"Alvar ecosystems are grassland, savannah and sparsely vegetated rock barrens that develop on flat limestone or dolostone bedrock where soils are very shallow."* *"While various alvar communities can look quite different, they all share several key characteristics:* *• they occur on flat limestone of dolostone bedrock where soils are thin or absent;* *• they are natural open landscapes, with tree cover absent or severely restricted;* *• they are all subject to seasonal drought, and some types to seasonal flooding;* *• they have a distinctive set of plant species and characteristic vegetation associations; and* *• they contain many species that are rare elsewhere in the Great Lakes basin and some species endemic to the basin, including plants, terrestrial molluscs, and invertebrates."*

Appendix 1: Definitions of alvars and similar ecosystems from literature (Continued)

REFERENCE	ECOSYSTEM	LOCATION	DEFINITION
Partel et al. (1999)	Alvar	Estonia	*“Alvars are calcareous grassland areas with thin soil (generally <20cm) on Ordovician or Silurian limestone material or monolithic limestone rock.”*
Dengler and Löbel (2006)	Alvar	Oland, SW	*"...almost level areas with superficial Ordovician or Silurian limestone that are only sparsely covered by vegetation, are largely restricted to the Baltic islands of Sweden (Öland, Gotland) and to Estonia, and reach their greatest extent in southern Öland."*
Eriksson and Rosén (2008)	Alvar	Oland, SW	*"Briefly, the alvar and calcareous flatrocks can be characterised by openness (reinforced by grazing), flatness, limestone bedrock,exposure to winds causing dryness in summer and impact by low temperatures and frost induced soil movements in winter. A main characteristic is a verythinsoil layer (0-30 cm)."*
Catling (2009)	Alvar	Northwest Territories,	*“They differ from limestone tundra in occurring within forested landscapes.”*
Murphy and Fernandez (2009)	Limestone Pavement	Ireland	*“Limestone pavements are areas of calcareous rock that were exposed by the scouring action of ice sheets as they moved across the landscape during the last glaciations”*
Cayouette et al. (2010)	Alvar	Quebec, CAN	*"...it has been customary to designate under the name of alvar a natural habitat opened in mid limestone, relatively flat, on rocky outcrop and ground thin, patchy vegetation , consisting mainly of shrubs, herbaceous plants and mosses and or the growth of trees is almost completely inhibited. These circles are usually flooded in the spring and suffer severe droughts in summer. "*

Appendix 1: Definitions of alvars and similar ecosystems from literature (Continued)

REFERENCE	**ECOSYSTEM**	**LOCATION**	**DEFINITION**
Willis (2011)	Limestone Pavement and Alvar	United Kingdom	*"Limestone pavements are "A partially or wholly exposed area of limestone, fissured by natural erosion into a pattern of clints and grikes, with a distinctive and unique plant community which characterises the microclimates of the grikes."* *"Alvars are similar to limestone pavements with thin soils over limestone or marble rock and sparse vegetation cover of shrubs and herbs, with trees absent or at least not forming a continuous canopy."*
Manitoba Alvar Initiative (2012)	Alvar	Manitoba, CAN	*"A globally uncommon habitat characterized by a thin or absent layer of soil over a limestone or dolomite bedrock pavement."*
Limestone Barrens Species at Risk Recovery Team (2014)	Limestone Barrens	Newfoundland, CAN	*"The limestone barrens of the Island of Newfoundland, divided into a southern and northern region, are founded upon a mixture of exposed calcareous bedrock outcrops, thin layers of frost-shattered calcareous gravel, and shallow calcareous soils with sparse, frost-disturbed vegetation."*
Hanel (2016) Pers. Comm.	Limestone Barrens	Newfoundland, CAN	*"The limestone barrens vary from being quite flat to having hills and cliffs. We don't usually call it a limestone barren if it has any vegetation much taller than your ankles. Some of it is covered with a thin heath layer, interspersed with grasses and forbs. Species that are normally trees or tall shrubs, like common juniper and black spruce can be found growing horizontally. Limestone barrens sites can vary in their moisture regime, but Newfoundland has a moister climate in all seasons than Manitoba."* *""Limestone tundra" may be a better word for it, because the lack of trees is generally climatic rather than edaphic as for the alvars."*

Appendix 2: Alvar vegetation communities of the Great Lakes region (Canada and United States) as described by Reschke *et al.* (1999).

GROUP	CHARACTERISTICS	COMMUNITY	CHARACTERISTICS	DOMINANT SPECIES
Open Alvar Grasslands and Pavements	few trees (<10% cover) and low shrub cover (<25%); Graminoids and forb dominated or with large ammounts of bare rock and non-vascular species.	Tuffed hairgrass wet alvar grassland	<10% tree cover; <10% shrub cover; dominated by graminoids; often wet; soils <10cm	*Deschampsia cespitosa, Carex crawei, Sporobolus heterolepis, Eleocharis compressa, Packera paupercula, Bryum pseudo-triquetrum, Abietinella abietinum, Tortella tortuosa* and *Drepanocladus* spp.
		Little bluestem alvar grassland	<10% tree cover; <25% shrub cover over 0.5m tall; up to 50% shrub cover of creeping shrubs; dominated by graminoids; soils usually <20cm deep with 6cm average	*Sporobolus heterolepis Schizachyrium scoparium, Juniperus horizontalis, Carex scirpoidea, Packera paupercula* and *Carex crawei*
		Annual alvar pavement-grassland	<10% tree cover; <25% shrub cover; dominated by patches of grasses and herbs or patches of moss;soils <10cm	*Sporobolus neglectus, Sporobolus vaginiflorus, Panicum philadelphicum, Poa compressa, Olgioneuron album, Danthonia spicata, Packera paupercula, Trichostema brachiatum, Carex crawei* and *Panicum flaxicaule*
		Alvar non-vascular pavement	<10% tree cover; <10% shrub cover; usually <15% cover of herbs; dominated by exposed bedrock; soils <2cm under moss layer	*Tortella tortuosa, Syntrichia ruralis, Cladonia poccilum, Saxifraga virginiensis, Penstemon hirsutus, Potentilla norvegica, Minuartia michauxii* var. *michuxii, Houstonia longifolia, Placynthium nigrum* and *Dermatocarpon miniatum*
		Poverty grass dry alvar grassland	<10% tree cover; <25% shrub cover; gramoinds dominant; shallow well drained soils usually <10cm	*Danthonia spicata, Poa compressa, Schizachtrium scoparium* and a mix of non-vascular species

Appendix 2: Alvar vegetation communities of the Great Lakes region (Canada and United States) as described by Reschke *et al.* (1999). (Continued)

GROUP	CHARACTERISTICS	COMMUNITY	CHARACTERISTICS	DOMINANT SPECIES
Shrublands	<10% tree cover; at least 25% shrub cover; graminoid and forb cover is variable.	Creeping juniper-shrubby cinqufoil alvar pavement	dwarf shrubs at least 25% of ground cover; <10% tall shrub cover; less than 50% herbaceous cover; soils <10cm	*Juniperus horizontalis, Pentaphylloides floribunda, Carex richardsonii, Carex scirpoidea, Schizachyrium scoparium, Pinus banksiana, Thuja occidentalis, Danthonia spicata, Olgioneuron album, Packera paupercula* and *Hymenoxys herbacea*
		Scrub conifer/ dwarf lake iris alvar shrubland	<10% tree cover; >25% shrub cover; >50% cover of herbs (graminoids and forbs); soils 20-30cm deep	*Iris lacustris, Carex eburnea, Picea glaua, Thuja occidentalis,Larix laricina, Abies balsamea, Juniperus horizontals, Prunus virginiana, Shepherdia canadensis, Cornus sericea, Rhamnus alnifolia, Carex richardsonii, Arctostaphylos uva-ursi* and *Danthonia spicata*
		Juniper alvar shrubland	<10% tree cover; >25% shrub cover which is predominantely short or dwarf species; variable cover of herbs, soils <30cm	*Juniperus virginiana, Thuja occidentalis, Quercus marcocarpa, Juniperus communis, Cornus foemina* ssp. *racemosa, Rhus aromatica, Prunus virginiana, Viburnum rafinesquianum, Danthonia spicata, Olgioneuron album* and *Carex umbellata*

Appendix 2: Alvar vegetation communities of the Great Lakes region (Canada and United States) as described by Reschke *et al.* (1999) (Continued).

GROUP	CHARACTERISTICS	COMMUNITY	CHARACTERISTICS	DOMINANT SPECIES
Savannas and Woodlands	savannas have 10-25% tree cover, woodlands have 25-60% tree cover; shrub, herb, moss and rock cover is variable.	Shagbark hickory/ prickly ash alvar savanna	10-25% tree cover; 2-55% shrub cover; variable herb cover; soils 10-20cm deep	*Carya ovata, Zanthoxylem americanum, Cornus foemina ssp. racemosa, Rhamnus cathartica, Prunus virginiana and Symphoricarpus albus, Danthonia spicata, Hieracium piloselloides, Panicum philadelphicum, Carex pensylvanica Poa compressa, Solidago nemoralis, Trichostema brachiatum* and *Geranium bicknellii*
		Chinquapin oak/ nodding onion alvar savanna	10-25% tree cover; 2-55% shrub cover; variable herb cover; soils usually 10 cm deep	*Quercus muehlenbergii, Juniperus virginiana, Cornus drummondii, Viburnum rafinesquianum, Rhus aromatica, Zanthoxylem americanum, Rhus typhina, Symphoricarpos albus, Poa compressa, Allium cernuum, Carex molesta, Packer paupercula, Panicum flexicaule* and *Trichostema brachiatum*
		White cedar - jack pine/ shrubby cinqufoil alvar savanna	10-25% tree cover; variable shrub cove; variable herb cover; soils <30cm deep.	*Thuja occidentalis, Pinus banksiana, Larix laricina, Pentaphylloides floribunda, Juniperus horizontalis, Schizachyrium scoparium, Sporobolus heterolepis, Carex scirpoidea, Carex richardsonii, Carex eburnea* and *Calamintha arkansana*
		Mixed conifer/ common juniper alvar woodland	25-60% tree cover; variable shrub cover; variable herb cover; soils <30cm deep.	*Picea glauca, Thuja occidentalis, Pinus banksiana, Abies balsamea, Pinus strobus, Juniperus communis, Juniperus horizontalis, Shepherdia canadensis, Arctostaphylos uva-ursi, Trichostema brachiatum, Carex crawei, Packera paupercula, Carex eburnea, Carex richardsonii, Sporobolus vaginiflorus, Tortella* spp. and *Schistidium* spp.
		Red cedar/ early buttercup alvar woodland	25-60% tree cover; variable shrub cover; variable herb cover; patches of exposed bedrock; soils <20cm deep.	*Poa compressa, Ranunculus fascicularis, Sporobolus vaginiflorus, Panicum philadelphicum, Panicum flexile, Ogioneuron album* and *Tortella* sp.

Appendix 3: Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Asteraceae	Common Yarrow	*Achillea millefolium* L.	Acmi	Forb	Perennial	Introduced	Introduced
Poaceae	Richardson's Needlegrass	*Achnatherum richardsonii* (Link) Barkworth	Acri	Graminoid	Perennial	Native	Prairie
Aceraceae	Mountain Maple	*Acer spicatum* Lam	Acsp	Tree	Perennial	Native	Boreal
Lamiaceae	Blue Giant Hyssop	*Agastache foeniculum* (Pursh.) Kuntze	Agfo	Forb	Perennial	Native	Prairie
Asteraceae	Pale Agoseris	*Agoseris glauca* (Pursh) Raf.	Aggl	Forb	Perennial	Native	Prairie
Poaceae	Rough Bentgrass	*Agrostis scabra* Willd.	Agsc	Graminoid	Perennial	Native	Prairie
Poaceae	Creeping Bentgrass	*Agrostis stolonifera* L.	Agst	Graminoid	Perennial	Introduced	Introduced
Poaceae	Shortawn Foxtail	*Alopecurus aequalis* Sobol.	Alae	Graminoid	Perennial	Native	Prairie
Liliaceae	Autumn Onion	*Allium stellatum* Fraser ex Ker Gawl.	Alst	Forb	Perennial	Native	Prairie
Liliaceae	Textile Onion	*Allium textile* A. Nelson & J.F. Macbr.	Alte	Forb	Perennial	Native	Prairie
Rosaceae	Saskatoon serviceberry	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.	Amal	Shrub	Perennial	Native	Generalist
Asteraceae	Annual Ragweed	*Ambrosia artemisiifolia* L. var. *elatior* (L.) Descourtils	Amar	Forb	Annual	Native	Prairie
Rosaceae	Low Serviceberry	*Amelanchier humilis* Wiegand	Amhu	Shrub	Perennial	Native	Prairie
Ranunculaceae	Canadian Anemone	*Anemone canadensis* L.	Anca	Forb	Perennial	Native	Prairie
Ranunculaceae	Candle Anemone	*Anemone cylindrica* A. Gray	Ancy	Forb	Perennial	Native	Prairie
Poaceae	Big Bluestem	*Andropogon gerardii* Vitman	Ange	Graminoid	Perennial	Native	Prairie
Asteraceae	Western Pearly Everlasting	*Anaphalis margaritacea* (L.) Benth.	Anma	Forb	Perennial	Native	Generalist
Asteraceae	Littleleaf Pussytoes	*Antennaria microphylla* Rydb.	Anmi	Forb	Perennial	Native	Prairie
Ranunculaceae	Pacific Anemone	*Anemone multifida* Poir.	Anmu	Forb	Perennial	Native	Prairie
Asteraceae	Howell's Pussytoes	*Antennaria howellii* Greene ssp. *neodioica* (Greene) Bayer	Anne	Forb	Perennial	Native	Boreal
Primulaceae	Pygmyflower Rockjasmine	*Androsace septentrionalis* L.	Anse	Forb	Perennial	Native	Prairie
Fabaceae	Common Kidneyvetch	*Anthyllis vulneraria* L.	Anvu	Forb	Perennial	Introduced	Introduced
Apocynaceae	Dogbane	*Apocynum androsaemifolium* L.	Apan	Forb	Perennial	Native	Boreal
Asteraceae	Absinthe	*Artemisia absinthium* L.	Arab	Forb	Perennial	Introduced	Introduced

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Asteraceae	Biennial Sagewort	*Artemisia biennis* Willd.	Arbi	Forb	Annual	Introduced	Introduced
Asteraceae	Field Sagewort	*Artemisia campestris* L. ssp. caudata (Michx.) H.M. Hall & Clem.	Arca	Forb	Perennial	Native	Prairie
Brassicaceae	Spreading Rockcress	*Arabis divaricarpa* A. Nelson	Ardi	Forb	Perennial	Native	Prairie
Asteraceae	Prairie Sagewort	*Artemisia frigida* Willd.	Arfr	Forb	Perennial	Native	Prairie
Brassicaceae	Tower Rockcress	*Arabis glabra* (L.) Bernh.	Argl	Forb	All	Native	Prairie
Brassicaceae	Hairy Rockcress	*Arabis hirsuta* (L.) Scop.	Arhi	Forb	All	Both	Prairie
Asteraceae	White Sagebrush	*Artemisia ludoviciana* Nutt.	Arlu	Forb	Perennial	Native	Prairie
Araliaceae	Wild Sarsaparilla	*Aralia nudicaulis* L.	Arnu	Forb	Perennial	Native	Generalist
Caryophyllaceae	Thymeleaf Sandwort	*Arenaria serpyllifolia* L.	Arse	Forb	Annual	Introduced	Introduced
Ericaceae	Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.	Aruu	Shrub	Perennial	Native	Boreal
Fabaceae	Purple Milkvetch	*Astragalus agrestis* Douglas ex G. Don	Asag	Forb	Perennial	Native	Prairie
Fabaceae	Canadian Milkvetch	*Astragalus canadensis* L.	Asca	Forb	Perennial	Native	Generalist
Fabaceae	Prairie Milkvetch	*Astragalus laxmanii* Jacq. var *robustior* (Hook.) Barneby & S.L. Welsh	Asla	Forb	Perennial	Native	Prairie
Asclepiadaceae	Oval-leaf Milkweed	*Asclepias ovalifolia* Decne.	Asov	Forb	Perennial	Native	Prairie
Poaceae	Spikeoat	*Avenula hookeri* (Scribn.) Holub	Avho	Graminoid	Perennial	Native	Prairie
Betulaceae	Dwarf Birch	*Betula glandulosa* Michx.	Begl	Shrub	Perennial	Native	Boreal
Poaceae	American Sloughgrass	*Beckmannia syzigachne* (Steud.) Fernald	Besy	Graminoid	Annual	Native	Prairie
Ophioglossaceae	Rattlesnake Fern	*Botrychium virginianum* (L.) Sw.	Bovi	Forb	Perennial	Native	Boreal
Poaceae	Smooth Brome	*Bromus inermis* Leyss.	Brin	Graminoid	Perennial	Both	Prairie
Poaceae	Porter Brome	*Bromus porteri* (J.M. Coult.) Nash	Brpo	Graminoid	Perennial	Native	Prairie
Cyperaceae	Golden Sedge	*Carex aurea* Nutt.	Caau	Graminoid	Perennial	Native	Boreal
Cyperaceae	Bebb's Sedge	*Carex bebbii* Olney ex Fernald	Cabe	Graminoid	Perennial	Native	Boreal
Cyperaceae	Shortbeak Sedge	*Carex brevior* (Dewey) Mack.	Cabr	Graminoid	Perennial	Native	Boreal
Brassicaceae	Shepherd's Purse	*Capsella bursa-pastoris* (L.) Medik.	Cabu	Forb	Annual	Introduced	Introduced

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Cyperaceae	Buxbaum's sedge	*Carex buxbaumii* Wahlenb.	Cabux	Graminoid	Perennial	Native	Boreal
Scrophulariaceae	Scarlet Indian Paintbrush	*Castilleja coccinea* (L.) Spreng.	Caco	Forb	Annual	Native	Prairie
Cyperaceae	Crawe's Sedge	*Carex crawei* Dewey	Cacr	Graminoid	Perennial	Native	Boreal
Cyperaceae	Needleleaf Sedge	*Carex duriuscula* C.A. Mey.	Cadu	Graminoid	Perennial	Native	Prairie
Cyperaceae	Bristleleaf Sedge	*Carex eburnea* Boott	Caeb	Graminoid	Perennial	Native	Boreal
Cyperaceae	Limestone Meadow Sedge	*Carex granularis* Muhl. ex Willd.	Cagr	Graminoid	Perennial	Native	Boreal
Cyperaceae	Hooker's Sedge	*Carex hookeriana* Dewey	Caho	Graminoid	Perennial	Native	Prairie
Cyperaceae	Sun Sedge	*Carex inops* L.H. Bailey ssp. *heliophila* (Mack.) Crins	Cain	Graminoid	Perennial	Native	Boreal
Cyperaceae	Medium Sedge	*Carex spp.*	CaME	Graminoid	Perennial	Native	---
Scrophulariaceae	Giant Red Inidian Paintbrush	*Castilleja minita* Douglas ex Hook.	Cami	Forb	Perennial	Native	Boreal
Cyperaceae	Obtuse Sedge	*Carex obtusata* Lilj.	Caob	Graminoid	Perennial	Native	Prairie
Brassicaceae	Sand Bittercress	*Cardamine parviflora* L.	Capa	Forb	Annual	Native	Boreal
Cyperaceae	Woolly Sedge	*Carex pellita* Muhl. ex Willd.	Capel	Graminoid	Perennial	Native	Prairie
Cyperaceae	Pennsylvania Sedge	*Carex pensylvanica* Lam.	Capen	Graminoid	Perennial	Native	Prairie
Cyperaceae	Clustered Field Sedge	*Carex praegracilis* W. Boott.	Caprae	Graminoid	Perennial	Native	Prairie
Cyperaceae	Meadow Sedge	*Carex praticola* Rydb.	Caprat	Graminoid	Perennial	Native	Boreal
Cyperaceae	Necklace Sedge	*Carex projecta* Mack.	Capro	Graminoid	Perennial	Native	Boreal
Cyperaceae	Richardson's Sedge	*Carex richardsonii* R. Br.	Cari	Graminoid	Perennial	Native	Boreal
Campanulaceae	Bluebell Bellflower	*Campanula rotundifolia* L.	Caro	Forb	Perennial	Native	Generalist
Cyperaceae	Northern Single Spike Sedge	*Carex scirpoidea* Michx.	Casc	Graminoid	Perennial	Native	Generalist
Cyperaceae	Dryspike Sedge	*Carex siccata* Dewey	Casi	Graminoid	Perennial	Native	Boreal
Cyperaceae	Small Sedge	*Carex* spp.	CaSM	Graminoid	Perennial	Native	---
Poaceae	Northern Reedgrass	*Calamagrostis stricta* (Timm) Koeler subsp. inexpansa (A. Gray) C.W. Greene	Cast	Graminoid	Perennial	Native	Generalist
Cyperaceae	Quill Sedge	*Carex tenera* Dewey	Cate	Graminoid	Perennial	Native	Boreal

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	**Common Name**	***Latin Name***	**Code**	**Life Form**	**Growth Type**	**Status**	**Affinity**
Cyperaceae	Rigid Sedge	*Carex tetanica* Schkuhr	Catet	Graminoid	Perennial	Native	Generalist
Cyperaceae	Shaved Sedge	*Carex tonsa* (Fernald) E.P. Bicknell	Caton	Graminoid	Perennial	Native	Boreal
Cyperaceae	Torrey's Sedge	*Carex torreyi* Tuck.	Cator	Graminoid	Perennial	Native	Prairie
Cyperaceae	Whitescale Sedge	*Carex xerantica* L.H. Bailey	Caxe	Graminoid	Perennial	Native	Boreal
Caryophyllaceae	Field Chickweed	*Cerastium arvense* L.	Cear	Forb	Perennial	Both	Prairie
Chenopodiaceae	Lambsquarters	*Chenopodium album* L.	Chal	Forb	Annual	Both	Prairie
Onagraceae	Fireweed	*Chamerion angustifolium* (L.) Holub ssp. *angustifolium*	Chan	Forb	Perennial	Native	Prairie
Asteraceae	Canada Thistle	*Cirsium arvense* (L.) Scop.	Ciar	Forb	Perennial	Introduced	Introduced
Asteraceae	Dwarf Thistle	*Cirsium drummondii* Torr. & A. Gray	Cidr	Forb	Perennial	Native	Prairie
Asteraceae	Flodman's thistle	*Cirsium flodmanii* (Rydb.) Arthur	Cifl	Forb	Perennial	Native	Prairie
Betulaceae	Beaked Hazelnut	*Corylus cornuta* Marsh	Coam	Shrub	Perennial	Native	Boreal
Santalaceae	Bastard Toadflax	*Comandra umbellata* (L.) Nutt.	Coum	Forb	Perennial	Native	Prairie
Rosaceae	Fireberry Hawthorn	*Crataegus chrysocarpa* Ashe.	Crch	Shrub	Perennial	Native	Generalist
Asteraceae	Fiddleleaf Hawksbeard	*Crepis runcinata* (James) Torr. & A. Gray	Crru	Forb	Perennial	Native	Prairie
Asteraceae	Narrowleaf Hawksbeard	*Crepis tectorum* L.	Crte	Forb	Annual	Introduced	Introduced
Dryopteridaceae	Brittle Bladderfern	*Cystopteris fragilis* (L.) Bernh.	Cyfr	Forb	Perennial	Native	Generalist
Orchidaceae	Lesser Yellow Lady Slipper	*Cypripedium parviflorum* Salisb.	Cypa	Forb	Perennial	Native	Boreal
Fabaceae	White Prairie Clover	*Dalea candida* Michx. ex Willd.	Daca	Forb	Perennial	Native	Prairie
Rosaceae	Shrubby Cinqufoil	*Dasiphora fruticosa* (L.) Rydb. ssp *floribunda*	Dafr	Shrub	Perennial	Native	Prairie
Fabaceae	Purple Prairie Clover	*Dalea purpurea* Vent.	Dapu	Forb	Perennial	Native	Prairie
Poaceae	Poverty Oatgrass	*Danthonia spicata* (L.) P. Beauv. ex Roem. & Schult.	Dasp	Graminoid	Perennial	Native	Generalist
Orchidaceae	Longbract Frog Orchid	*Dactylorhiza viridis* (L.) R.M. Bateman, A.M. Pridgeon & M.W. Chase	Davi	Forb	Perennial	Native	Generalist
Poaceae	Tufted Hairgrass	*Deschampsia cespitosa* (L.) P. Beauv.	Dece	Graminoid	Perennial	Native	Prairie
Brassicaceae	Herb Sophia	*Descurainia sophia* (L.) Webb ex Prantl	Deso	Forb	Annual	Introduced	Introduced

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	**Common Name**	***Latin Name***	**Code**	**Life Form**	**Growth Type**	**Status**	**Affinity**
Poaceae	Slender Rosette Grass	*Dicanthelium xanthophysum* (A. Gray) Freckmann	Dixa	Graminoid	Perennial	Native	Boreal
Lamiaceae	Moldavian Dragonhead	*Dracocephalum moldavica* L.	Drmo	Forb	Perennial	Introduced	Introduced
Brassicaceae	Woodland Draba	*Draba nemorosa* L.	Drne	Forb	Annual	Native	Prairie
Cyperaceae	Flatstem Spikerush	*Eleocharis compressa* Sull.	Elco	Graminoid	Perennial	Native	Generalist
Cyperaceae	Elliptic Spikerush	*Eleocharis elliptica* Kunth	Elel	Graminoid	Perennial	Native	Boreal
Cyperaceae	Common Spikerush	*Eleocharis palustris* (L.) Roem. & Schult.	Elpa	Graminoid	Perennial	Native	Generalist
Poaceae	Slender Wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners ssp. s*ubsecundus* (Link) Á. Löve & D. Löve	Eltrs	Graminoid	Perennial	Native	Boreal
Poaceae	Slender Wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners subsp. *trachycaulus*	Eltrt	Graminoid	Perennial	Native	Prairie
Onagraceae	Fringed Willowherb	*Epilobium ciliatum* Raf. ssp. *ciliatum*	Epci	Forb	Perennial	Native	Generalist
Onagraceae	Bog Willowherb	*Epilobium leptophyllum* Raf.	Eple	Forb	Perennial	Native	Generalist
Asteraceae	Rough Fleabane	*Erigeron asper* Nutt.	Eras	Forb	Perennial	Native	Prairie
Brassicaceae	Wormseed Wallflower	*Erysimum cheiranthoides* L.	Erch	Forb	Annual	Introduced	Introduced
Asteraceae	Swamp Boreal Daisy	*Erigeron elatus* (Hook.) Greene	Erel	Forb	Perennial	Native	Prairie
Asteraceae	Streamside Fleabane	*Erigeron glabellus* Nutt.	Ergl	Forb	Perennial	Native	Boreal
Asteraceae	Philadelphia Fleabane	*Erigeron philaldephicus* L.	Erph	Forb	Both	Native	Generalist
Asteraceae	Prairie Fleabane	*Erigeron strigosus* Muhl. ex Willd.	Erst	Forb	Both	Native	Prairie
Brassicaceae	Western Wallflower	*Erysimum asperum* Nutt. DC.	Eryas	Forb	Perennial	Native	Prairie
Asteraceae	Flat-top Goldentop	*Euthamia graminifolia* (L.) Nutt. var. *graminifolia*	Eugr	Forb	Perennial	Native	Prairie
Poaceae	Plains Rough Fescue	*Festuca hallii* (Vasey) Piper	Feha	Graminoid	Perennial	Native	Prairie
Poaceae	Red Fescue	*Festuca rubra* L.	Feru	Graminoid	Perennial	Introduced	Introduced
Poaceae	Rocky Mountain Fescue	*Festuca saximontana* Rydb.	Fesa	Graminoid	Perennial	Native	Prairie
Rosaceae	Virginia Strawberry	*Fragaria virginiana* Duchesne	Frvi	Forb	Perennial	Native	Prairie
Asteraceae	Blanketflower	*Gaillardia aristata* Pursh.	Gaar	Forb	Perennial	Native	Prairie
Rubiaceae	Northern Bedstraw	*Galium boreale* L.	Gabo	Forb	Perennial	Native	Generalist

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Family	**Common Name**	***Latin Name***	**Code**	**Life Form**	**Growth Type**	**Status**	**Affinity**
Rosaceae	Yellow Avens	*Geum aleppicum* Jacq.	Geal	Forb	Perennial	Native	Prairie
Gentianaceae	Autumn Dwarf Gentian	*Gentianella amarella* (L.) Börner	Geam	Forb	Annual	Native	Generalist
Geraniaceae	Bicknell's Cranesbill	*Geranium bicknellii* Britton	Gebi	Forb	Annual	Native	Boreal
Geraniaceae	Carolina Geranium	*Geranium carolinianum* L.	Geca	Forb	Annual	Native	Prairie
Gentianaceae	Greater Fringed Gentian	*Gentianopsis crinita* (Froel.) Ma	Gecr	Forb	Annual	Native	Boreal
Rosaceae	Prairie Smoke	*Geum triflorum* Pursh.	Getr	Forb	Perennial	Native	Prairie
Scrophulariaceae	Golden Hedgehyssop	*Gratiola aurea* Pursh.	Grau	Forb	Perennial	Native	Prairie
Asteraceae	Curlycup Gumweed	*Grindelia squarrosa* (Pursh) Dunal	Grsq	Forb	Both	Native	Prairie
Boraginaceae	American Stickseed	*Hackelia deflexa* (Wahlenb.) Opiz var. *americana* (A. Gray) Fernald & I.M. Johnst.	Haam	Forb	All	Native	Prairie
Gentianaceae	American Spurred Gentian	*Halenia deflexa* (Sm.) Griseb.	Halde	Forb	Annual	Native	Boreal
Fabaceae	Alpine Sweetvetch	*Hedysarum alpinum* L.	Heal	Forb	Perennial	Native	Prairie
Lamiaceae	Rough False Pennyroyal	*Hedeoma hispida* Pursh.	Hehi	Forb	Annual	Native	Prairie
Asteraceae	Nuttall's Sunflower	*Helianthus nuttallii* Torr. & A. Gray	Henu	Forb	Perennial	Native	Prairie
Saxifragaceae	Richardson's Alumroot	*Heuchera richardsonii* R. Br.	Heri	Forb	Perennial	Native	Prairie
Poaceae	Porcupinegrass	*Hesperostipa spartea* (Trin.) Barkworth	Hesp	Graminoid	Perennial	Native	Prairie
Asteraceae	Narrowleaf Hawkweed	*Hieracium umbellatum* L.	Hium	Forb	Perennial	Native	Boreal
Poaceae	Foxtail Barley	*Hordeum jubatum* L.	Hoju	Graminoid	Perennial	Introduced	Introduced
Rubiaceae	Longleaf Summer Bluet	*Houstonia longifolia* Gaertn.	Holo	Forb	Perennial	Native	Generalist
Juncaceae	Mountain Rush	*Juncus balticus* Willd.	Juba	Graminoid	Perennial	Native	Generalist
Cupressaceae	Common Juniper	*Juniperus communis* L.	Juco	Shrub	Perennial	Native	Boreal
Juncaceae	Dudley's Rush	*Juncus dudleyi* Wiegand	Judu	Graminoid	Perennial	Native	Generalist
Cupressaceae	Creeping Juniper	*Juniperus horizontalis* Moench	Juho	Shrub	Perennial	Native	Boreal
Juncaceae	Longstyle Rush	*Juncus longistylis* Torr.	Julo	Graminoid	Perennial	Native	Generalist

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Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Juncaceae	Knotted Rush	*Juncus nodosus* L.	Juno	Graminoid	Perennial	Native	Generalist
Juncaceae	Poverty Rush	*Juncus tenuis* Willd.	Jute	Graminoid	Perennial	Native	Generalist
Poaceae	Prairie Junegrass	*Koeleria macrantha* (Ledeb.) Schult.	Koma	Graminoid	Perennial	Native	Prairie
Fabaceae	Cream Pea	*Lathyrus ochroleucus* Hook.	Laoc	Forb	Perennial	Native	Generalist
Fabaceae	Veiny Pea	*Lathyrus venosus* Muhl. ex Willd.	Lave	Forb	Perennial	Native	Boreal
Brassicaceae	Common Pepperweed	*Lepidium densiflorum* Schrad.	Lede	Forb	Annual	Introduced	Introduced
Asteraceae	Oxeye Daisy	*Leucanthemum vulgare* Lam.	Levu	Forb	Perennial	Introduced	Introduced
Caprifoliaceae	Twinflower	*Linnaea borealis* L.	Libo	Forb	Perennial	Native	Boreal
Boraginaceae	Hoary Puccoon	*Lithospermum canescens* (Michx.) Lehm.	Lica	Forb	Perennial	Native	Prairie
Linaceae	Blue Flax	*Linum lewisii* Pursh.	Lile	Forb	Perennial	Native	Prairie
Asteraceae	Rocky Mountain Blazing Star	*Liatris ligulistylis* (A. Nelson) K. Schum.	Lili	Forb	Perennial	Native	Prairie
Liliaceae	Wood Lily	*Lilium philadelphicum* L.	Liph	Forb	Perennial	Native	Generalist
Fabaceae	Bird's Foot Trefoil	*Lotus corniculatus* L.	Loco	Forb	Perennial	Introduced	Introduced
Caprifoliaceae	Honeysuckle	*Lonicera dioica* L.	Lodi	Shrub	Perennial	Native	Generalist
Juncaceae	Common Woodrush	*Luzula multiflora* (Ehrh.) Lej.	Lumu	Graminoid	Perennial	Native	Generalist
Primulaceae	Fringed Loosestrife	*Lysimachia ciliata* L.	Lyci	Forb	Perennial	Native	Generalist
Liliaceae	Canada Mayflower	*Maianthemum canadense* Desf.	Maca	Forb	Perennial	Native	Boreal
Liliaceae	Stary False Solomons Seal	*Maianthemum stellatum* (L.) Link	Mast	Forb	Perennial	Native	Boreal
Fabaceae	Sweet White Clover	*Melilotus albus* (L.) Lam.	Meal	Forb	Both	Introduced	Introduced
Lamiaceae	Wild Mint	*Mentha arvensis* L. var. *villosa* (Benth.) S.R. Stweart	Mear	Forb	Perennial	Native	Generalist
Scrophulariaceae	Narrowleaf Cowwheat	*Melampyrum lineare* Desr.	Meli	Forb	Annual	Native	Boreal
Fabaceae	Black Medick	*Medicago lupulina* L.	Melu	Forb	Both	Introduced	Introduced
Fabaceae	Sweet Yellow Clover	*Melilotus officinalis* (L.) Lam.	Meof	Forb	Both	Introduced	Introduced
Caryophyllaceae	Rock Stichwort	*Minuartia dawsonensis* (Britton) House	Mida	Forb	Perennial	Native	Boreal

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Lamiaceae	Wild Bergamot	*Monarda fistulosa* L.	Mofi	Forb	Perennial	Native	Prairie
Poaceae	Field Muhly	*Muhlenbergia cuspidata* (Torr. ex Hook.) Rydb.	Mucu	Graminoid	Perennial	Native	Prairie
Poaceae	Spiked Muhly	*Muhlenbergia glomerata* (Willd.) Trin.	Mugl	Graminoid	Perennial	Native	Boreal
Poaceae	Marsh Muhly	*Muhlenbergia racemosa* (Michx.) Britton, Sterns & Poggenb.	Mura	Graminoid	Perennial	Native	Prairie
Poaceae	Mat Muhly	*Muhlenbergia richardsonis* (Trin.) Rydb.	Muri	Graminoid	Perennial	Native	Generalist
Ranunculaceae	Mousetail	*Myosurus minimus* L.	Mymi	Forb	Perennial	Native	Prairie
Onagraceae	Common Evening Primrose	*Oenothera biennis* L.	Oebi	Forb	Biennial	Native	Prairie
Asteraceae	Prairie Goldenrod	*Oligoneuron album* (Nutt.) G.L. Nesom	Olal	Forb	Perennial	Native	Boreal
Asteraceae	Stiff Goldenrod	*Oligoneuron rigidum* (L.) Small	Olri	Forb	Perennial	Native	Prairie
Poaceae	Roughleaf Ryegrass	*Oryzopsis asperifolia* Michx.	Oras	Graminoid	Perennial	Native	Boreal
Scrophulariaceae	Yellow Owl's-clover	*Orthocarpus luteus* Nutt.	Orlu	Forb	Annual	Native	Prairie
Poaceae	Littleseed Ricegrass	*Oryzopsis micrantha* (Trin. & Rupr.) Romasch., P.M. Peterson & R.J. Soreng	Ormi	Graminoid	Perennial	Native	Prairie
Poaceae	Mountain Riccegrass	*Piptatheropsis pungens* (Torr.) Romasch., P.M. Peterson & R.J. Soreng	Orpu	Graminoid	Perennial	Native	Boreal
Pyrolaceae	Sitebells Wintergreen	*Orthilia secunda* (L.) House	Orse	Forb	Perennial	Native	Generalist
Fabaceae	Showy Locoweed	*Oxytropis splendens* Douglas ex Hook.	Oxsp	Graminoid	Perennial	Native	Boreal
Asteraceae	Wooly Grounsel	*Packera cana* (Hook.) W.A. Weber & Á. Löve	Pacan	Forb	Perennial	Native	Prairie
Poaceae	Witchgrass	*Panicum capillare* L.	Pacap	Graminoid	Annual	Native	Generalist
Asteraceae	Balsam Groundsel	*Packera paupercula* (Michx.) Á. Löve & D. Löve	Papau	Forb	Perennial	Native	Prairie
Scrophulariaceae	Canadian Lousewort	*Pedicularis canadensis* L.	Peca	Forb	Perennial	Native	Boreal
Fabaceae	Indian Breadroot	*Pediomelum esculentum* (Pursh.) Rydb.	Pees	Forb	Perennial	Native	Prairie
Pteridaceae	Gastonyi's Cliffbrake	*Pellaea gastonyi* Windham	Pega	Forb	Perennial	Native	Generalist
Pteridaceae	Western Dwarf Cliffbrake	*Pellaea glabella* Mett. ex Kuhn ssp *occidentalis* (E.E. Nelson) Windham	Pegl	Forb	Perennial	Native	Boreal
Scrophulariaceae	Lilac Penstemon	*Penstemon gracilis* Nutt.	Pegr	Forb	Perennial	Native	Prairie
Scrophulariaceae	Waxleaf Penstemon	*Penstemon nitidus* Douglas ex Benth.	Peni	Forb	Perennial	Native	Prairie

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Family	**Common Name**	***Latin Name***	**Code**	**Life Form**	**Growth Type**	**Status**	**Affinity**
Poaceae	Reed Canarygrass	*Phalaris arundinacea* L.	Phar	Graminoid	Perennial	Native	Generalist
Polemoniaceae	Spiny Phlox	*Phlox hoodii* Richardson	Phho	Forb	Perennial	Native	Prairie
Poaceae	Timothy	*Phleum pratense* L.	Phpr	Graminoid	Perennial	Introduced	Introduced
Pinaceae	Jack Pine	*Pinus banksiana* Lamb.	Piba	Tree	Perennial	Native	Boreal
Pinaceae	White Spruce	*Picea glauca* (Moench) Voss	Pigl	Tree	Perennial	Native	Boreal
Poaceae	Alpine Bluegrass	*Poa alpina* L.	Poal	Graminoid	Perennial	Both	Boreal
Rosaceae	Silverweed Cinquefoil	*Potentilla anserina* (L.) Rydb.	Poans	Forb	Perennial	Native	Generalist
Rosaceae	Silver Cinquefoil	*Potentilla argentea* L.	Poarge	Forb	Perennial	Introduced	Introduced
Rosaceae	Tall Cinquefoil	*Potentilla arguta* Pursh.	Poargu	Forb	Perennial	Native	Prairie
Polygonaceae	Prostrate Knotweed	*Polygonum aviculare* L.	Poav	Forb	Perennial	Introduced	Introduced
Salicaceae	Balsam Poplar	*Populus balsamifera* L.	Poba	Tree	Perennial	Native	Generalist
Rosaceae	Tansy Cinqufoil	*Potentilla bipinnatifida* Douglas ex Hook.	Pobi	Forb	Perennial	Native	Prairie
Poaceae	Canada Bluegrass	*Poa compressa* L.	Pocom	Graminoid	Perennial	Introduced	Introduced
Polygonaceae	Black Bindweed	*Polygonum convolvulus* L.	Pocon	Forb	Annual	Introduced	Introduced
Polygonaceae	Douglas' Knotweed	*Polygonum douglasii* Greene	Podo	Forb	Annual	Native	Prairie
Rosaceae	Slender Cinquefoil	*Potentilla gracilis* Douglas ex Hook.	Pogr	Forb	Perennial	Native	Prairie
Rosaceae	Norwegian Cinquefoil	*Potentilla norvegica* L.	Pono	Forb	Perennial	Both	Generalist
Portulacaceae	Little Hogweed	*Portulaca oleracea* L.	Pool	Forb	Annual	Introduced	Introduced
Rosaceae	Pennsylvania cinquefoil	*Potentilla pensylvanica* L.	Pope	Forb	Perennial	Native	Generalist
Poaceae	Kentucky Bluegrass	*Poa pratensis* L.	Popr	Graminoid	Perennial	Both	Generalist
Polygalaceae	Seneca snakeroot	*Polygala senega* L.	Pose	Forb	Perennial	Native	Prairie
Salicaceae	Trembling Aspen	*Populus tremuloides* Michx.	Potr	Tree	Perennial	Native	Boreal
Asteraceae	White Rattlesnakeroot	*Prenanthes alba* L.	Pral	Forb	Perennial	Both	Generalist
Liliaceae	Drops-of-Gold	*Prosartes hookeri* Torr.	Prho	Forb	Perennial	Native	Generalist

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Rosaceae	Pin Cherry	*Prunus pensylvanica* L. f.	Prpe	Shrub	Perennial	Native	Generalist
Asteraceae	Purple Rattlesnakeroot	*Prenanthes racemosa* Michx.	Prra	Forb	Perennial	Native	Generalist
Rosaceae	Sand Cherry	*Prunus susquehanae* hort. ex Willd.	Prsu	Shrub	Perennial	Native	Boreal
Rosaceae	Chokecherry	*Prunus virginiana* L.	Prvi	Shrub	Perennial	Native	Generalist
Lamiaceae	Common Selfheal	*Prunella vulgaris* L.	Prvu	Forb	Perennial	Introduced	Introduced
Ranunculaceae	Eastern Pasqueflower	*Pulsatilla patens* (L.) Mill. ssp. *patens* (L.) Mill.	Pupa	Forb	Perennial	Native	Prairie
Pyrolaceae	Sidebells Wintergreen	*Orthilia secunda* (L.) House	Pyse	Forb	Perennial	Native	Generalist
Fagaceae	Bur Oak	*Quercus macrocarpa* Michx.	Quma	Tree	Perennial	Native	Prairie
Ranunculaceae	Tall Buttercup	*Ranunculus acris* L.	Raac	Forb	Perennial	Introduced	Introduced
Ranunculaceae	Early Buttercup	*Ranunculus fascicularis* Muhl. ex Bigelow	Rafa	Forb	Perennial	Native	Boreal
Ranunculaceae	Labrador buttercup	*Ranunculus rhomboideus* Goldie	Rarh	Forb	Perennial	Native	Prairie
Rhamnaceae	Buckthorn	*Rhamnus alnifolia* L'Hér.	Rhal	Shrub	Perennial	Native	Boreal
Anacardiaceae	Smooth Sumac	*Rhus glabra* L.	Rhgl	Shrub	Perennial	Native	Boreal
Grossulariaceae	Hairystem Gooseberry	*Ribes hirtellum* Michx.	Rihi	Shrub	Perennial	Native	Boreal
Grossulariaceae	Canadian Gooseberry	*Ribes oxyacanthoides* L.	Riox	Shrub	Perennial	Native	Boreal
Rosaceae	Prickly Rose	*Rosa acicularis* Lindl.	Roac	Shrub	Perennial	Native	Generalist
Rosaceae	Smooth Rose	*Rosa blanda* Aiton	Robl	Shrub	Perennial	Native	Generalist
Polygonaceae	Western Dock	*Rumex aquaticus L. var. fenestratus* (Greene) Dorn	Ruaq	Forb	Perennial	Native	Generalist
Asteraceae	Black-eyed Susan	*Rudbeckia hirta* L. *var. pulcherrima* Farw.	Ruhi	Forb	Perennial	Native	Prairie
Rosaceae	Grayleaf Blackberry	*Rubus idaeus* L. ssp. *strigosus* (Michx.) Focke	Ruid	Shrub	Perennial	Native	Generalist
Rosaceae	Dwarf Red Blackberry	*Rubus pubescens* Raf.	Rupu	Shrub	Perennial	Native	Boreal
Salicaceae	Bebb Willow	*Salix bebbiana* Sarg.	Sabe	Shrub	Perennial	Native	Generalist
Salicaceae	Sageleaf Willow	*Salix candida* Flueggé ex Willd.	Saca	Shrub	Perennial	Native	Generalist
Salicaceae	Prairie Willow	*Salix humilis* Marsahll	Sahu	Shrub	Perennial	Native	Boreal

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	Common Name	*Latin Name*	Code	Life Form	Growth Type	Status	Affinity
Apiaceae	Maryland sanicle	*Sanicula marilandica* L.	Sama	Forb	Perennial	Native	Prairie
Salicaceae	Meadow Willow	*Salix pediolaris* Sm.	Sape	Shrub	Perennial	Native	Generalist
Poaceae	False Melic	*Schizachne purpurascens* (Torr.) Swallen	Scpu	Graminoid	Perennial	Native	Prairie
Selaginellaceae	Lesser Spikemoss	*Selaginella densa* Rydb.	Sede	Forb	Perennial	Native	Prairie
Elaeagnaceae	Buffaloberry	*Shepherdia canadensis* (L.) Nutt.	Shca	Shrub	Perennial	Native	Boreal
Caryophyllaceae	Sleepy Silene	*Silene antirrhina* L.	Sian	Forb	Annual	Native	Boreal
Iridaceae	Strict Blue-eyed Grass	*Sisyrinchium montanum* Greene	Simo	Forb	Perennial	Native	Prairie
Smilacaceae	Smothe Carrionflower	*Smilax herbacea* L.	Smhe	Forb	Perennial	Native	Prairie
Asteraceae	Field Sowthistle	*Sonchus arvensis* L.	Soar	Forb	Perennial	Introduced	Introduced
Asteraceae	Canada Goldenrod	*Solidago canadensis* L. var. *canadensis*	Soca	Forb	Perennial	Native	Prairie
Asteraceae	Hairy Goldenrod	*Solidago hispida* Muhl. ex Willd.	Sohi	Forb	Perennial	Native	Boreal
Asteraceae	Early Goldenrod	*Solidago juncea* Aiton	Soju	Forb	Perennial	Native	Boreal
Asteraceae	Missouri Goldenrod	*Solidago missouriensis* Nutt.	Somi	Forb	Perennial	Native	Prairie
Asteraceae	Gray Goldenrod	*Solidago nemoralis* Aiton	Sone	Forb	Perennial	Native	Prairie
Asteraceae	Mt Albert Goldenrod	*Solidago simplex* Kunth ssp. *simplex*	Sosi	Forb	Perennial	Native	Boreal
Rosaceae	White Meadow-sweet	*Spiraea alba* Du Roi	Spal	Shrub	Perennial	Native	Boreal
Poaceae	Prairie Dropseed	*Sporobolous heterolepis* (A. Gray) A. Gray	Sphe	Graminoid	Perennial	Native	Prairie
Orchidaceae	Hooded Lady's Tresses	*Spiranthes romanzoffiana* Cham.	Spro	Forb	Perennial	Native	Boreal
Caryophyllaceae	Longleaf Starwort	*Stellaria longifolia* Muhl. ex Willd.	Stlo	Forb	Perennial	Native	Boreal
Caprifoliaceae	Snowberry	*Symphoricarpos albus* (L.) S.F. Blake	Syal	Forb	Perennial	Native	Generalist
Asteraceae	Lindley's aster	*Symphyotrichum ciliolatum* (Lindl.) Á. Löve & D. Löve	Syci	Forb	Perennial	Native	Boreal
Asteraceae	White Heath Aster	*Symphyotrichum ericoides* (L.) G.L. Nesom var. *ericoides*	Syer	Forb	Perennial	Native	Prairie
Asteraceae	Smooth Blue Aster	*Symphyotrichum laeve* (L.) Á. Löve & D. Löve	Sylae	Forb	Perennial	Native	Prairie

Appendix 3 (Continued): Vascular plant species list from 103 plots across twenty alvar sites in Manitoba showing codes, life form, growth type, status and affinity as considered for this study. Voucher specimens in the University of Manitoba Herbarium (WIN). Species in alphapetical order by code.

Family	**Common Name**	***Latin Name***	**Code**	**Life Form**	**Growth Type**	**Status**	**Affinity**
Asteraceae	White Panicle Aster	*Symphyotrichum lanceolatum* (Willd.) G.L. Nesom	Sylan	Forb	Perennial	Native	Generalist
Caprifoliaceae	Snowberry	*Symphoricarpos occidentalis* Hook.	Syoc	Forb	Perennial	Native	Prairie
Asteraceae	Common Dandilion	*Taraxacum officinale* F.H. Wigg.	Taof	Forb	Perennial	Both	Generalist
Brassicaceae	Field Pennycress	*Thlaspi arvense* L.	Thar	Forb	Perennial	Introduced	Introduced
Ranunculaceae	Veiny Meadowrue	*Thalictrum venulosum* Trel.	Thve	Forb	Annual	Native	Boreal
Anacardiaceae	Eastern Poision Ivy	*Toxicodendron radicans* (L.) Kuntze var *rybergii*	Tora	Forb	Perennial	Native	Boreal
Asteraceae	Yellow Salsify	*Tragopogon dubius* Scop.	Trdu	Forb	Annual	Introduced	Introduced
Fabaceae	Red Clover	*Trifolium pratense* L.	Trpr	Forb	Perennial	Introduced	Introduced
Fabaceae	White Clover	*Trifolium repens* L.	Trre	Forb	Perennial	Introduced	Introduced
Typhaceae	Broadleaf Cattail	*Typha latifolia* L.	Tyla	Forb	Perennial	Native	Generalist
Scrophulariaceae	Neckweed	*Veronica peregrina* L.	Vepe	Forb	Annual	Native	Generalist
Violaceae	Hookspur Violet	*Viola adunca* Sm.	Viad	Forb	Perennial	Native	Generalist
Fabaceae	American Vetch	*Vicia americana* Muhl. ex Willd.	Viam	Forb	Perennial	Native	Prairie
Fabaceae	American Vetch	*Vicia americana var. angustifolia* Muhl. ex Willd.	Vian	Forb	Perennial	Native	Prairie
Caprifoliaceae	Downy Arrowwood	*Viburnum rafinesquianum* Schult.	Vira	Shrub	Perennial	Native	Prairie
Violaceae	Common Blue Violet	*Viola sororia* Willd.	Viso	Forb	Both	Native	Prairie
Apiaceae	Meadow Zizia	*Zizia aptera* (A. Gray) Fernald	Ziap	Forb	Perennial	Native	Prairie
Liliaceae	Mountain Deathcamas	*Zigadenus elegans* Pursh	Ziel	Forb	Perennial	Native	Prairie

Appendix 4: Detailed descriptions of eight alvar vegetation types in the Interlake region of Manitoba

Species conservation ranks (S-ranks) for Manitoba were proviced by Chris Friesen, Manitoba Conservation Data Centre.

Occurance areas are rough estimates using GoogleEarthPro and should not be considered exact values due to the patchy nature of alvar ecosystems and the fact these communities occur as a continuum within this.

TYPE I

General Name: WET GRAMINOID MEADOW

Association: ***Deschampsia cespitosa- Carex pellita- Juncus balticus***

Occurrences

This open graminoid community occurs in small patches at seven sites (B, C, D, E, F, G, H and K). Significant continuous cover large enough for plots was only found at sites C (12.5km^2), H (~4.2km^2) and K (~3.3km^2). Individual patches of wet graminoid meadows occupy areas of approximately 0.5- 1 km^2 or smaller. This is the least representative habitat with less than 10% site cover where it occurs.

A. Physiognomy and General Description:

Wet graminoid meadow alvars occur in small patches where the topography is lower than the surrounding area. These are the wettest part of the alvar and experiences extensive flooding in spring and after heavy rain. This type had the highest cover of bryophytes (23.97%) compared to other alvar types. A thick bryophyte layer including; *Campylium stellatum, Drepanocladus sordidus, Drepanocladus polygamus* and *Ptychostomum pseudotriquetrum*, occurs over the thin soil and could assist in retaining moisture for longer periods of time. Graminoids are dominant in all three grassland types; however, a gradient from dry grassland to wet graminoid meadow is often visually apparent on the landscape with taller species of *Carex* and *Juncus* compared to the shorter graminoids found in drier areas. This type also has the highest proportion of cover due to graminoids (82.60%) and the least due to perennials (6.05%). Affinity of this type is predominantly boreal with also a high proportion of generalist wetland species. This is a very open community with no trees and little cover by shrubs (2% mean cover). When present, shrubs are predominately *Salix bebbiana, Salix pediolaris*, *Spiraea alba* and *Dasiphora fruiticosa*. Forbs are uncommon but wet loving species such as *Mentha arvense*, *Rumex aquaticus* and *Symphyotrichum lanceolatum* occur here while absent or uncommon in other alvar communities. Lichens are uncommon (less than 1%) and restricted to erratic boulders of granite or limestone. Wet graminoid meadow alvars are often surrounded by other open alvar habitats or on the edge of the alvar by aspen woodlands.

B. Mean Species Richness and Diversity:

Type I has the lowest richness and diversity values of all other alvar communities in Manitoba. Shannon H per plot is 1.55. Effective Richness per plot is 4.9 with a mean species richness of 20 per plot.

C. Dominant and Frequent Species:

1. Woody Plants:

No woody plants were dominant or occurred in high frequency.

2. Annuals:

No annuals were dominant or occurred in high frequency.

3. Graminoids:

Species	**Mean Cover (%)**	**Frequency (%)**
Deschampsia caespitosa	31	100
Eleocharis compressa	10.34	100
Carex pellita	14.6	60
Carex praegracilis	9.16	60
Juncus balticus	8.65	80
Carex tennera	1.39	80
Juncus dudleyi	0.73	80

4. Herbaceous Perennials:

Species	**Mean Cover (%)**	**Frequency (%)**
Rumex aquaticus var. *fenestratus*	0.85	80
Mentha arvensis var. *villosa*	1.23	40

5. Cryptogams

Moss cover is very high and a mixture of *Campylium stellatum, Drepanocladus sordidus, Drepanocladus polygamus* and *Ptychostomum pseudotriquetrum*. Lichen cover is very low and comprised of granite erratic species, such as from the genera *Xanthoparmelia*, *Xanthoria*, and *Phaeophysia.*

D. Indicator Species:

Graminoids: *Deschampsia cespitosa, Carex tenera, Juncus balticus, Carex praegracilis, Carex pellita, Carex brevior, Hordeum jubatum, Agrostis stolonifera, Carex bebbii.*

Perennials: *Rumex occidentalis, Symphyotrichum lanceolatum, Typha latifolia, Mentha arvensis, Epilobium leptophyllum.*

Shrubs: *Salix pediolaris.*

E. Environmental Characteristics:

Type I has moderate soil depth (fourth shallowest, mean = 49.10 mm) under a thick moss layer and is the wettest alvar community. This type has very little bare soil (third lowest of all types, 0.9%) and low bare rock cover (1.93% cover, second lowest of all types).

With the second highest nitrogen level in soils and highest phosphorus levels in soils (NO3-N = 97.18 mg/kg and PO4-P = 29.00 mg/kg), Type I also has the second highest EC values (this is also reflected in high N and P values). The pH is neutral (like all other types).

F. Disturbance

This community experienced moderate level of cattle grazing intensity (third highest of all types). These low areas might be used for water rather than consuption. There was little consumption observed in this vegetation type. No browsing by deer was observed although the evidence of scat might be removed faster due to the wet nature of this type.

G. Introduced Species

There is a low proportion of introduced species in terms of cover and richness and the majority of introduced cover is due to graminoids:

Species	**Mean Cover (%)**	**Frequency (%)**
Poa pratensis	1.12	80
Poa compressa	2.54	60
Agrostis stolonifera	0.19	60

H. Unique/Rare Species (S-ranks of S1 to S3S4)

Eleocharis compressa (10.34% cover, freq = 100%) is the only rare species documented from this type.

TYPE II

General Name: MOIST GRAMINOID MEADOW

Association: *Poa compressa- Deschampsia cespitosa- Dasiphora fruiticosa*

Occurrences

The moist graminoid meadow alvar community type was documented quantitatively at 7 sites (B, C, E, F, H, J and K). An estimate of average cover area is 2-10 km^2 per site occurring in multiple patches rather than one large expanse. This community can occupy 10-40% of sites where it occurs.

A. Physiognomy and General Description:

Like wet graminoid meadow alvar, the moist graminoid meadow alvar community is an open community (no tree cover), occurring in patches on the alvar topography and is not usually a dominant community at any site. This type has a high affinity to prairie, generalist and introduced species with a low cover of boreal species. Moist graminoid meadow has the second highest graminoid cover (59.23%) and the highest proportion of cover by introduced graminoids (20%).

Compared to wet graminoid meadow, *Poa compressa, Juncus dudleyii* and *Eleocharis compressa* become more common with decreasing cover of tall sedges such as *Carex pellita* and *Carex tennera*. Herbaceous forb cover is moderate (mean =17.60% cover) but with a variety of species that are more abundant in drier grasslands. In descending order, the most abundant (cover) fobs are *Geum triflorum*, *Potentilla gracilis, Antennaria howellii, Galium boreale* and *Allium stellatum*. Shrub cover ranged from 0-51% with an average of 14%. When shrubs occurred in high abundance it was due to *Dasiphora fruiticosa* (12.62% mean cover, freq=100%). Other shrubs included *Salix bebbiana, Salix pediolaris*, *Spiraea alba, Rosa ascicularis* and *Juniperus horizontalis*. Byrophyte (9.75%) and lichen (3.76%) cover are moderate compared to other vegetation types in Manitoba.

Further separation of the cluster analysis divides this type based on amount of shrub cover. *Dasiphora fruiticosa* (12.62% mean cover, freq=100%) has a mean cover of 1.47% in sub-type 1 but a mean cover of 19.59% in sub-type 2. *Poa pratensis* and *Poa compressa* are more common in sub-type 1 (23.65% and 14.62% cover respectively) than in sub-type 2 (1.27% and 2.29% cover respectively). Sub-type 2 has higher native graminoid cover by *Deschampsia cespitosa* and *Sporobolus heterolepis.*

B. Mean Species Richness and Diversity:

The mean values diversity (per plot) of this community type are the second lowest of any alvar vegetation type in Manitoba. Mean Shannon diversity index per plot is 2.03, effective richness per plot is 8.2 and mean species richness per plot is 39. Floristically this types diversity is lower than the majority of other vegetation types, at the per plot level.

C. Dominant and Frequent Species:

1. Woody Plants:

Dasiphora fruiticosa (12.62% mean cover, freq=100%) has a mean cover of 19.59% in sub-type 2 but a cover of 1.47% in sub-type 1.

Rosa ascicularis has a mean cover of 0.28% and a frequency of 62%.

2. Annuals:

Lepidium densiflorum (0.35% cover, freq=38%) is more frequent in sub-type12 (80% frequency) than sub-type 2.

3. Graminoids:

Species	**Mean Cover (%)**	**Frequency (%)**
Koeleria macrantha	3.23	92
Poa compressa	7.23	85
Eleocharis compressa	11.91	85
Poa pratensis	9.9	77
Deschampsia caespitosa	8.53	77
Danthonia spicata	3.02	77
Juncus dudleyi	1.21	77
Carex crawei	2.18	54
*Sporobolus heterolepis**	4.19	15

**Sporobolus heterolepis* occurred infrequently (possibly due to grazing effects) but in amounts of up to 50% cover.

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Campanula rotundifolia	0.16	100
Antennaria howellii ssp. *neodioica*	1.37	100
Galium boreale	1.21	92
Erigeron asper	0.52	92
Geum triforum	3.52	85
Sisyrinchium montanum	0.09	85
Symphyotrichum laeve	0.54	62
Allium stellatum	0.63	62
Potentilla gracilis	2.76	54

5. Cryptogams

Species	Mean Cover (%)	Frequency (%)
Ditrichum flexicaule	46.25	69
Bryum spp.	11.03	62
Syntrichia ruralis	14.65	54

Dominant lichens are *Cladonia* spp., *Xanthoparmelia* spp. and *Peltigera* spp.

D. Indicator Species:

Graminoids: *Eleocharis compressa, Poa compressa, Juncus dudleyi, Poa alpina, Koeleria macrantha.*

Perennials: *Allium stellatum, Prunella vulgaris, Potentilla gracilis, Potentilla bipinnatifida, Veronica peregrina, Ranunculus rhomboideus, Packera paupercula*.

Indicator Species for sub-type 1: *Poa pratensis, Poa compressa, Poa alpina, Veronica peregrina, Ranunculus rhomboideus, Dasiphora fruticosa.*

Indicator Species for Sub-type 2: *Deschampsia cespitosa, Antennaria howellii* ssp. *neodioica, Allium stellatum, Oligoneuron album, Packera paupercula, Sisyrinchium montanum, Symphyotrichum laeve.*

E. Environmental Characteristics:

Moist graminoid meadows had the highest cover of bare earth (4.81% cover), moderate rock cover (4.72%) and moderate soil depths (second deepest, mean=51-50mm). This type is moderately wet as it occurs in lower depressions on the alvar.

There were average amounts of nitrogen and phosphorus in soils (NO3-N = 56.90 mg/kg and PO4-P = 11.75mg/kg when averages across all plots are 72.59 mg/kg and 12.50 mg/kg respectively) leading to moderate EC values. This type has a neutral pH (like all other types).

F. Disturbance

Type II experienced moderate cattle grazing intensity (fourth highest of all types) with higher levels observed in the sub-type 1 than in sub-type 2, which has led to increased disturbance and presence of introduced species. This type had low levels of browsing by deer (tied with Type I for lowest in all types).

G. Introduced Species

Highest proportion of introduced species (21.31% cover), which is mostly graminoid cover dominated by *Poa pratensis* 9.90% cover, freq= 77%) and *Poa compressa* (7.23% cover, freq=85%). Additional species are frequent at low cover:

Species	Mean Cover (%)	Frequency (%)
Achillea millefolium	1.3	92
Cerastium arvense	0.15	85
Taraxacum officinale	0.37	77
Poa alpina	0.74	62
Phleum pratense	0.24	54

TYPE III

General Name: DRY GRASSLAND

Associaton: *Poa pratensis- Geum triflorum- Achillea millefolium- Festuca saximontana*

Occurrences

Dry grassland was quantitatively recorded at sites C, D, E, G, H, I, M, N and O. It was a dominant alvar community in the Interlake region. Some sites were dominated by this alvar type with it covering the majority of site area while other sites dry grassland was less than or equally dominant as alvar shrubland. This community type occupies between 20-80% of sites where it occurs.

A. Physiognomy and General Description:

Dry alvar grassland occurs in open areas (third lowest tree cover, mean =0.02%) higher on the topography. It is often associated with patches of moist graminoid meadow alvar or alvar shrubland that occur within its large expanse. The vegetation cover is dominated by prairie species with more boreal cover than other graminoid types (Figure 3.6). Compared to Types I and II, forbs and shrubs become more prominent in this grassland community (Figure 3.4). This type has the highest cover by native perennials (33.33% cover) and woody plants (19% cover) of any graminoid alvar community in Manitoba (Table 3.2). Graminoid cover is the third highest of all types (mean=38.07% cover). Dominant cover is by *Poa pratensis, Danthonia spicata, Sporobolus heterolepis, Koeleria macrantha* and *Festuca hallii. Sporobolus heterolepis* and *Festuca hallii* increase in occurrence in less grazed areas. Dominant forb cover is *Geum triflorum, Antennaria howellii* ssp*. neodioica, Galium boreale*, *Comandra umbellata* and a mix of *Erigeron* species. *Arctostaphylos uva-ursi* and *Dasiphora fruiticosa* are the dominant shrubs although, *Arctostaphylos uva-ursi* (8.28% mean cover but up to 62% in a single plot, freq=36%) often has a patchy distribution with high cover in certain areas, while *Dasiphora fruiticosa* (3.27% cover, freq=82%) has lower cover more frequently. Lichen (8.02%) and bryophyte (4.24%) cover are moderate.

Sub-types within Type III do not differ in composition of life forms but rather in species composition. Sub-type 1 is a predominately *Poa- Geum triflorum* grassland while sub-type 2 is more diverse and *Festuca* grasses are more characteristic. Sub-type 1 only occurs at the alvar on Sylvan Community Pasture and might be a result of heavier grazing activities.

B. Mean Species Richness and Diversity:

This type had average species diversity and richness values (Shannon H = 2.19; Effective Richness = 9.6; Mean species richness = 24) at the per plot level.

C. Dominant and Frequent Species:

1. Woody Plants:

Species	Mean Cover (%)	Frequency (%)
Arctostaphylos uva-ursi	8.28	36
Dasiphora fruticosa	3.27	82

2. Annuals:

Species	Mean Cover (%)	Frequency (%)
Orthocaprus luteus	0.9	50
Arenaria serpyllifolia	0.55	45

3. Graminoids:

Species	Mean Cover (%)	Frequency (%)
Poa pratensis	9.72	100
Danthonia spicata	9.12	95
Koeleria macrantha	2.2	95
Festuca saximontana	0.95	86
Agrostis scabra	0.27	82
Elymus trachycaulus subsp. *subsecundus*	0.95	77
Festuca hallii	2.79	59
Juncus dudleyi	0.41	55
Sporobolus heterolepis	2.64	14

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Geum triforum	16.35	95
Galium boreale	0.84	91
Campanula rotundifolia	0.15	91
Antennaria howellii ssp. *neodioica*	2.7	86
Allium stellatum	0.17	77
Sisyrinchium montanum	0.1	73
Erigeron asper	0.27	73
Erigeron glabellus	0.33	64
Symphyotrichum laeve	0.83	59

5. Cryptogams

Cryptogam cover is somewhat low with 4.24% cover by mosses including *Syntrichia ruralis* (17.25% cover, 45% frequency), *Abietinella abietina* (6.21% cover, 55% frequency) and *Ditrichum flexicaule* (9.83% cover, 45% frequency). Lichen cover is also quite low (8.02% cover) and largely *Cladonia* spp. and *Peltigera* spp.

D. Indicator Species:

Graminoids: *Agrostis scabra, Elymus trachycaulus subsp. subsecundus, Festuca saximontana, Koeleria macrantha, Festuca hallii, Poa pratensis, Poa alpina, Danthonia spicata*

Perennials: *Geum triflorum, Achillea millefolium, Arenaria serpyllifolia, Trifolium pratense, Medicago lupulina, Sisyrinchium montanum, Symphyotrichum ericoides var. ericoides, Antennaria howellii* ssp. *neodioica*

Indicator Species for sub-type 1: *Poa pratensis, Achillea millefolium, Cerastium arvense, Elymus trachycaulus* subsp. *subsecundus*, *Geum triflorum, Potentilla bipinnatifida, Solidago nemoralis*

Indicator Species for Sub-type 2*:* *Festuca hallii, Festuca saximontana, Antennaria howellii* ssp. *neodioica, Comandra umbellata, Galium boreale, Symphyotrichum laeve*

E. Environmental Characteristics:

This grassland community has moderate soil depths (55.68mm), moderate rock cover (third highest, 5.64% cover), moderate bare soil cover (2.53%) and moderate soil moisture (but is driest of the graminoid alvars).

Moderate levels of nitrogen and phosphorus in soils (NO3-N = 73.26 mg/kg and PO4-P = 12.30mg/kg) are shown in moderate EC values (0.53 mS/cm). As with all types, this community had a neutral pH.

F. Disturbance

This type experienced the highest grazing intensity of all graminoid dominated alvar communities. This could be due to increased presence of edible grasses for cattle or biased results from slower rates of patty decomposition in drier areas. This type includes a sub-type only found on the Sylvan Community Pasture that is managed for livestock grazing. Only low levels of browsing by deer were observed.

G. Introduced Species

Introduced cover is dominated by graminoids and is highest in sub-type 1 which is found in Sylvan Community Pasture.

Species	Mean Cover (%)	Frequency (%)
Poa pratensis	9.72	100
Poa compressa	0.56	55
Cerastium arvense	0.24	91
Achillea millefolium	1.5	95
Phleum pratense	0.09	59
Medicago lupulina	0.29	77

H. Unique/Rare Species (S-ranks of S1 to S3S4)

This is one of the only types where *Pellaea gastonyi* (0.07% cover, freq =9%) occurred, although it was plots with limestone features that are not characteristic of this type. This type contains the largest amount of *Festuca hallii* (2.79% cover, freq=59%) and relatively high amounts of *Sporobolus heterolepis* (2.64% mean cover but up to 34% in one plot, freq=14%). Rare species with moderate frequencies include *Carex crawei* (0.55% cover, freq =23%), *Eleocharis compressa* (0.36, freq=23%), *Avenula hookeri* (0.06% cover, freq = 14%), *Bromus porteri* (0.02% cover, freq = 23%) and *Erigeron strigosus* (0.17% cover, freq = 41%). *Carex xerantica* and *Muhlenbergia richardsonis* also occurred in this community although with low percent cover and frequency (% cover < 0.01, freq <20%). These species were both not restricted to this community type and occurred in at least half of the types at low frequencies.

TYPE IV

General Name: ROCKY DWARF SHRUBLAND

Association: ***Juniperus horizontalis- Dasiphora fruiticosa- Solidago simplex- Solidago nemoralis***

Occurrences

Rocky alvar shrubland was quantitatively documented at sites K, L, M and N, which are all part of the Fisher alvar. Smaller patches may occur on sites C and D. This community often occurs in patches or strips of higher topography and thinner soils and can be seen in small amounts at other sites. It can occur in patches surrounded by other alvar habitat types with deeper soils or occupy larger areas that grade into edge habitats. The largest expanses are at the southern end of the Fisher alvar at sites M and N. This community type occupies between 5-40% of sites where it occurs.

A. Physiognomy and General Description:

Affinity of the vegetation cover in rocky dwarf shrubland is predominantly boreal (>50%) with a strong prairie influence (35%) but little generalist or introduced species. Despite having no tree cover, this type has the highest over of woody perennials. Dominant ground cover is shrubs (57%) growing in the soil filled cracks and bryophytes over the thin soil or rock. Dominant shrub cover is *Juniperus horizontalis* and *Dasiphora fruiticosa*. Forb cover is low (8.91%) but diverse with no one species becoming noticeably more common than others. Graminoid cover is the lowest of all types (14.15%) with low lying grasses and sedges such as *Danthonia spicata* and small *Carex* species being the dominant graminoids. Moss cover in this type is high (9.07%) and comprised of *Tortula ruralis, Tortella tortuosa, Tortella fragilis, Thuidium abietinum, Ditrichum flexicaule* and *Grimmea* spp. Lichen cover is high (22.04%) with the crustose lichens covering the exposed limestone rock. Macro-lichen cover included species in the genera *Cladonia* (mostly in form of squamules), *Umbilicaria, Xanthoparmelia* and *Peltigera*.

B. Mean Species Richness and Diversity:

This type had low-moderate mean diversity and richness values per plot (Shannon diversity index = 1.67; Effective Richness = 5.8; Mean species richness = 45).

C. Dominant and Frequent Species:

1. Woody Plants:

Species	**Mean Cover (%)**	**Frequency (%)**
Dasiphora fruticosa	18.73	100
Juniperus horizontalis	33.54	78
Arctostaphylos uva-ursi	1.88	56

2. Annuals:

Thalictum venulosum: 78% frequency, but low cover (0.08%).

3. Graminoids:

Species	**Mean Cover (%)**	**Frequency (%)**
Danthonia spicata	4.68	100
Poa compressa	1.49	100
Koeleria macrantha	0.78	100
Carex scirpoidea	0.81	89
Festuca saximontana	0.14	78
Festuca hallii	0.18	56
Elymus trachycaulus subsp. *subsecundus*	0.17	56

4. Herbaceous Perennials:

Species	**Mean Cover (%)**	**Frequency (%)**
Oligoneuron album	1.3	100
Solidago nemoralis	1.08	100
Campanula rotundifolia	0.19	100
Galium boreale	0.18	100
Geum triforum	0.75	89
Erigeron asper	0.49	89
Antennaria howellii ssp. *neodioica*	0.31	89
Sisyrinchium montanum	0.02	89
Viola adunca	0.18	78
Symphyotrichum laeve	0.32	67
Allium stellatum	0.19	67

5. Cryptogams

Species	Mean Cover (%)	Frequency (%)
Tortella spp. (*T. fragilis* and *T. tortuosa*)	4.34	100
Ditrichum flexicaule	1.93	100
Syntrichia ruralis	0.79	78
Abietinella abietina	1.11	78

Dominant species of macro-lichens were in the genera: *Cladonia*, *Umbilicaria, Xanthoparmelia* and *Peltigera*. Crustose lichens that were unidentified are dominant on the exposed rock.

D. Indicator Species:

Graminoids: *Elymus trachycaulus subsp. trachycaulus, Carex scirpoidea, Muhlenbergia racemosa.*

Perennials: *Artemisia campestris ssp. caudate, Solidago simplex ssp. simplex, Minuartia dawsonensis, Solidago nemoralis, Anthyllis vulneraria, Cirsium arvense, Arabis hirsuta, Artemisia absinthium, Epilobium ciliatum ssp. ciliatum*

Shrubs: *Juniperus horizontalis*, *Dasiphora fruticosa* ssp. *floribunda*

Moss: *Tortella* sp.

Lichens: foliose lichens (*Peltigera* sp.)

E. Environmental Characteristics:

Rocky alvar shrubland occurs on rocky areas that experience extreme drought conditions in the summertime. This community is the driest with the shallowest soil (mean= 19.90mm) and highest cover of exposed limestone bedrock (14.08%). Cover by bare soil was moderately high (second highest of all types, 2.75%).

Rocky dwarf shrubland has the highest nitrogen and phosphorus in soils (NO3-N = 152.26 mg/kg and PO4-P = 13.72mg/kg, with means being 72.59 mg/kg and 12.50 mg/kg, respectively). Type IV had the highest EC values (this is also reflective of high N and P values) and a neutral pH (like all other types).

F. Disturbance

Rocky alvar shrubland occurred in areas with low grazing (third lowest) and browsing intensity, potentially due to a lack of desirable food.

G. Introduced Species

This type had the lowest proportion of cover due to introduced species (Figure 3.6) but a high proportion of species richness (Figure 3.5). This vegetation type was the only type in Manitoba to have approximately equal proportions of introduced graminoids and introduced forbs.

Species	Mean Cover (%)	Frequency (%)
Poa compressa	1.49	100
Achillea millefolium	0.45	100
Cerastium arvense	0.34	100
Arabis hirstuta	0.05	100
Lepidium deniflorum	0.08	78

H. Unique/Rare Species (S-ranks of S1 to S3S4)

Erigeron strigosus (0.33% cover, freq = 67%), *Solidago simplex* (0.47% cover, freq=67%), *Festuca hallii* (0.18% cover, freq = 56%) and *Houstonia longifolia* (0.03% cover, freq= 44%) occurred fairly frequently at low cover. *Carex crawei* (0.23% cover, freq=33%), *Eleocharis compressa* (0.14% cover, freq=33%) and *Sporobolus heterolepis* (1.80% cover, freq=33%) occurred with low frequency and cover. *Pedicularis canadensis, Muhlenbergia racemosa* and *Muhlenbergia richardsonis* also occurred in this community although with low percent cover and frequency (% cover < 0.01, freq <20%).

TYPE V

General Name: BUR OAK- JACK PINE - LOW SHRUB

Association: ***Arctostaphylos uva-ursi – Juniperus communis- Pinus banskiana- Quercus macrocarpa***

Occurrences

This type was documented at sites C, D, E, H, I, J, M, N and O. This community occurs along exposed limestone ridges or rocky pavement with cracks large enough for tree development. It also includes areas with limestone tabletops (flat limestone features that stand over limestone pavement as if parts of a previously standing limestone ridge). Type V represents approximately 10-25% of site area where it occurs.

A. Physiognomy and General Description:

Vegetation cover is predominantly boreal (>50%), with prairie vegetation occupying over a quarter. The cover of generalists and introduced species is low in this community. This community is dominated by woody vegetation and has even amounts of graminoid and perennial cover. This alvar community had the second highest tree cover (mean= 11.83% cover, range of 0-32%) with a combination of species including *Quercus macrocarpa, Pinus banksiana* and *Picea glauca* with the occasional *Populus tremuloides*. Shrub cover (mean= 48.15% cover) is dominated by *Arctostaphyos uva-ursi, Juniperus horizontalis, Dasiphora fruiticosa* and *Juniperus communis.* Forb cover (12.73% cover) is moderate but diverse with many species occurring in each plot. Forb species include: *Oligoneuron album, Monarda fistulosa, Symphyotrichum laeve, Antennaria howellii* ssp*. neodioica* and *Geum triflorum* being of the highest cover. Graminoid cover is variable from <5%- <50% (mean is second lowest of all types, 21.97% cover). Dominant graminoids are *Danthonia spicata, Carex richardsonii, Festuca hallii* and *Carex crawei*.

The moderately high moss cover (mean = 6.59% cover) is dominated by *Thiudium abietinum* and *Tortella* spp. (including *T. tortuosa* and *T. fragilis*). Lichen cover (second highest, mean =17.75% cover) is moderately high with moderate cover by all lichen forms (crustose, foliose and fruticose). Since this community contains a wide variety of substrates for attachment (bare rock, soil, wood), lichen diversity is high. Dominant lichen taxa included *Cladonia* and *Cladina* species. *Flavopunctelia, Parmelia, Physia* and *Candelaria* lichens were frequently found growing on oak bark.

Further branching in the cluster analysis separated Type V into two distinct sub-types. In sub-type 1 dominant tree cover is a combination of *Pinus banksiana, Quercus macrocarpa* and *Picea glauca*. Tree cover in sub-type 2 is predominately *Quercus macrocarpa*. *Arctostaphylos uva-ursi* is more common in sub-type 1 (mean of 29% compared to 11%). *Juniperus horizontalis* is more abundant in sub-type 2 (mean of 17% compared to 9%). *Oligoneuron album*, *Symphyotrichum laeve* and *Solidago nemoralis* are the dominant forbs in sub-type 1. *Geum triflorum* is much more common in sub-type 2 (mean 7% compared to 1%). *Antennaria howellii* ssp*. neodioica* also increased in cover in sub-type 2 (mean 2% compared to 0.5%). *Carex richardsonii* in sub-type 1 is replaced by *Carex crawei* and *Carex inops* as dominant graminoids in sub-type 2.

B. Mean Species Richness and Diversity:

Type V has high mean Shannon H per plot (mean= 2.43), effective Richness per plot (mean= 11.9) and mean species richness per plot (mean= 55). These values are the second highest of all types, indicating that this type is more floristically diverse at the plot level compared to other alvar vegetation communities in Manitoba.

C. Dominant and Frequent Species:

1. Woody Plants:

Species	Mean Cover (%)	Frequency (%)
Arctostaphylos uva-ursi	17.87	100
Juniperus horizontalis	13.84	100
Juniperus communis	3.77	95
Dasiphora fruticosa	8.14	90
Quercus marcocarpa	6.52	71
*Pinus banksiana**	3.63	29

**Pinus banksiana* is present in 75% of sub-type 1 (mean cover = 9.52%) but completely absent in sub-type 2.

2. Annuals:

Species	Mean Cover (%)	Frequency (%)
Arenaria serpyllifolia	0.41	48

Arenaria serpyllifolia characteristic of sub-type 1 (freq=80%) but infrequent in sub-type .

3. Graminoids:

Species	Mean Cover (%)	Frequency (%)
Danthonia spicata	6.91	95
Festuca saximontana	0.35	90
Elymus trachycaulus subsp. *subsecundus*	0.11	90
Koeleria macrantha	0.69	86
Poa pratensis	3.25	81
Festuca hallii	1.24	52
Carex richardsonii	2.36	29

Carex richardsonii (2.36% cover, freq =29%), occurred in patches and when present could have a high cover: 20%.

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Galium boreale	0.85	100
Campanula rotundifolia	0.23	100
Viola adunca	0.24	95
Monarda fistulosa	0.77	95
Antennaria howellii ssp. *neodioica*	1.53	95
Solidago nemoralis	0.83	90
Geum triforum	5.86	81
Symphyotrichum laeve	0.98	81
Erigeron glabellus	1.04	81
Heuchera richardsonii	0.19	81
Oligoneuron album	1.23	76

5. Cryptogams

Species	Mean Cover (%)	Frequency (%)
Tortella spp. (*T. fragilis* and *T. tortuosa*)	2.31	95
Syntrichia ruralis	0.75	81
Abietinella abietina	1.99	71
Ditrichum flexicaule	0.68	71

Lichen cover includes *Cladina, Cladonia, Peltigera, Parmelia, Physia* and *Umbilicaria* spp.

D. Indicator Species:

Graminoids: *Carex richardsonii, Muhlenbergia glomerata, Piptatheropsis pungens*

Perennials: *Heuchera richardsonii, Apocynum androsaemifolium, Anemone cylindrica, Cerastium arvense, Pulsatilla patens* ssp. *patens*

Shrubs: *Juniperus communis, Symphoricarpos albus, Arctostaphylos uva-ursi.*

Trees: *Quercus macrocarpa*

Mosses: *Tortella* spp.

Lichens: crustose lichens, fruticose lichens

Indicator Species separating sub-type 1: *Arenaria serpyllifolia, Poa pratensis, Medicago lupulina, Lithospermum canescens, Solidago hispida, Arctostaphylos uva-ursi, Pinus banksiana*

Indicator Species separating sub-type 2: *Thuidium* sp., *Tortula ruralis, Ditrichum flexicaule, Juniperus horizontalis, Juniperus communis*

E. Environmental Characteristics:

This type has thinner soils than most types (second thinnest, mean = 36.05 mm) and is moderately dry. Type V has the second highest cover of bare rock (8.85%) and a moderate level of bare soil cover (1.74%).

With average nitrogen content in soils and Phosphorus content in the soils (NO3-N = 94.17 mg/kg, PO4-P = 10.44mg/kg), this type has moderate EC values (EC=0.57 mS/cm). As with all other types, the pH of Type V is neutral.

F. Disturbance

As shown in Table 3.3, this type experiences a moderate level of cattle grazing intensity (4th highest of all types) and moderate levels of browsing by deer (2nd highest of all types).

G. Introduced Species

Type V has a low proportion of introduced species (5.57% cover), which is a mixture of both graminoids and forbs.

Species	Mean Cover (%)	Frequency (%)
Poa pratensis	3.25	81
Poa compressa	1.15	57
Cerastium arvense	0.32	95
Achillea millefolium	0.42	81
Arabis hirstuta	0.04	86
*Arenaria serpyllifolia**	0.41	48

**Arenaria serpyllifolia* (0.41% cover, freq = 48%) is more common in sub-type 1 (freq=80%).

H. Unique/Rare Species (S-ranks of S1 to S3S4)

This vegetation type contains limestone ridges and tabletops that the ferns *Pellaea glabella* ssp. *occidentalis* (cover< 0.01%, freq= 5%) and *Pellaea gastonyii* (0.03% cover, freq = 10%) occur on. *Botrychium virginianum* also occurred in this community type but was infrequent and not documented by any plots.

In addition to both *Festuca hallii* (1.24% cover, freq = 52%) and *Bromus porteri* (0.13% cover, freq = 52%) occurring frequently in low cover, this community type also has a diverse list of rare species that occur in low abundance and frequencies:

Carex crawei (1.34% cover, freq =38%).
Erigeron strigosus (0.03% cover, freq = 29%).
Avenula hookeri (0.07% cover, freq = 24%).
Sporobolus heterolepis (0.05% cover, freq= 24%)
Eleocharis compressa (0.06% cover, freq = 14%).

Carex inops (0.55% cover, freq= 5%).
Selaginella densa (0.64% cover, freq = 14%) occurs in infrequent patches that can be quite large.
Houstonia longifolia, Solidago simplex ssp. simplex, Carex tetanica, *Carex xerantica* and *Muhlenbergia richardsonis* also occurred in this community although with very low percent cover and frequency (% cover < 0.01, freq <20%).

TYPE VI

General Name: BUR OAK – TALL SHRUB

Association: *Quercus macrocarpa- Amelanchier alnifolia- Prunus virginiana*

Occurrences

The bur oak-tall shrub alvar community was quantitatively recorded at sites G, H, P, R, S and T. This community can occur in patches within the alvar or as an edge habitat. Other habitats form a gradient into this community type where it occurs. This community represents 5-25% of site area where it occurs.

A. Physiognomy and General Description:

This community has roughly similar amounts of cover by prairie, boreal, generalist and introduced species although prairie influence does become slightly higher in this type (Figure 3.6). Vegetation cover is dominated by woody vegetation (Figure 3.4). Tree cover (0-25% with mean cover of 14.23%) is almost completely by *Quercus macrocarpa* with infrequent *Picea glauca* and *Populus tremuloides*. Shrub cover (20-70%) is very high with dominant species being *Arctostaphylos uva-ursi, Dasiphora fruiticosa, Corylus Americana, Amelanchier alnifolia, Prunus virginiana, Juniperus horizontalis* and *Betula glandulosa.* Herbaceous perennial cover is moderate (24.62%). Common species include: *Artemisia ludoviciana, Erigeron glabellus, Fragaria virginiana, Galium boreale, Geum triflorum, Olgioneuron rigidum, Monarda fistulosa, Symphyotrichum ciliolatum, Hieracium umbellatum* and *Comandra umbellata.* Graminoid cover is relatively high (between 5-40%, mean=34.75%) and dominated by *Poa pratensis*, *Danthonia spicata, Festuca hallii, Andropogon gerardii* and small *Carex* spp. Moss (<1%) and lichen (2%) cover is low.

B. Mean Species Richness and Diversity:

The richness and diversity values of this type are the highest of all types (i.e. floristically most diverse type, at per plot level). Shannon H (per plot) is 2.55. Effective Richness per plot is 13.1 and mean species richness per plot is 60 species.

C. Dominant and Frequent Species:

1. Woody Plants:

Species	Mean Cover (%)	Frequency (%)
Amelanchier alnifloia	4.3	100
Arctostaphylos uva-ursi	12.86	90
Prunus virginiana	7.8	90
Quercus marcocarpa	13	80
Dasiphora fruticosa	7.80	80
Corylus cornuta	3.5	50

2. Annuals:

Thalictum venulosum: 70% frequency, but low cover (0.4%).

3. Graminoids:

Species	Mean Cover (%)	Frequency (%)
Poa pratensis	15.3	100
Elymus trachycaulus subsp. *subsecundus*	0.38	100
Koeleria macrantha	0.35	100
Danthonia spicata	11.17	80
Carex spp.	1.40	80
Bromus porteri	0.19	80
Festuca saximontana	0.13	70

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Galium boreale	1.10	100
Campanula rotundifolia	0.31	100
Monarda fistulosa	1.70	100
Sanicula marlandica	0.12	70
Lysimachia ciliata	0.26	60
Geum triforum	3.00	80
Symphyotrichum ciliolatum	1.58	90
Erigeron glabellus	1.30	80
Hieracium umbellatum	0.62	80
Oligoneuron rigidum	2.24	70

5. Cryptogams

Cryptogam cover is quite low with >1% cover by mosses. Bryophyte cover when present is primarily pleurocarps such as *Brachythecium* spp., which occurred in every plot. Lichen cover is also quite low (2.05% cover) and largely *Peltigera* spp. and *Cladonia* spp.

D. Indicator Species:

Graminoids: *Schizachne purpurascens, Poa pratensis, Oryzopsis asperifolia*.

Perennials: *Lysimachia ciliata, Sanicula marilandica, Hieracium umbellatum, Symphyotrichum ciliolatum, Artemisia ludoviciana, Monarda fistulosa, Thalictrum venulosum, Maianthemum canadense, Anemone cylindrica, Fragaria virginiana, Lithospermum canescens, Cirsium drummondii, Maianthemum stellatum*, *Zizia aptera, Polygala senega*.

Shrubs: *Prunus virginiana, Amelanchier alnifolia, Corylus americana, Symphoricarpos albus*.

Trees: *Quercus marcocarpa*.

E. Environmental Characteristics:

The bur oak-tall shrub alvar community has relatively deep soils (second deepest, mean=74.5mm), moderate rock cover (4th highest of all types) and moderately moist soils. Very little bare soil (lowest of all types, 0.5%) is present in this community.

Type VI has very nitrogen and phosphorus-poor soils (NO3-N = 19.37 mg/kg and PO4-P = 8.15mg/kg when averages across all plots are 72.59 mg/kg and 12.50 mg/kg respectively).

The lowest EC values seen in this type are also reflected in low N and P values. Like all other types, pH is neutral.

F. Disturbance

This type experienced high level of cattle grazing intensity (second highest of all types) and medium levels of browsing by deer (fourth highest).

G. Introduced Species

The bur oak-tall shrub alvar community has a high proportion of introduced species (18.57% cover), which is mostly graminoid (15.88% cover) dominated by *Poa pratensis* (mean cover 15.3%, 100% frequency) and a mixture of introduced forbs (2.63% cover) that occur frequently at lower cover:

Species	Mean Cover (%)	Frequency (%)
Cerastium arvense	0.23	100
Achillea millefolium	0.91	100
Taraxacum officinale	0.29	80
Medicago lupulina	0.20	70

H. Unique/Rare Species (S-ranks of S1 to S3S4)

Achnatherum richardsonii (0.75% cover, freq =10%), although infrequent, was only found in this alvar community. *Bromus porteri* (0.19% cover, freq = 80%), *Avenula hookeri* (0.08% cover, freq = 60%), *Festuca hallii* (0.51% cover, freq = 20%) and *Erigeron strigosus* (0.28% cover, freq = 40%) occur in this type with low cover. *Carex xerantica* and *Muhlenbergia richardsonis* also occurred in this community although with low percent cover and frequency (% cover < 0.01, freq <20%). These species were both not restricted to this community type and occurred in at least half of the types at low frequencies.

TYPE VII

General Name: PRAIRIE-JACK PINE- LOW SHRUB

Association: Punis banksiana- Arctostaphylos uva-ursi – Dasiphra fruiticosa- Olgioneuron rigidum

Occurrences

Low prairie alvar shrubland/savanna is present at sites A, B, P, Q and T. This alvar type occurs as edge habitat of alvar sites or as shrubland associated with jack pine savannas. It occurs mostly in the most northern alvar region but also in lesser grazed regions to the south. This community may be restricted to burnt areas that have been disturbed by fire. It occupies 10-15% of alvar sites where it occurs.

A. Physiognomy and General Description:

Vegetation cover in this type is dominated by prairie species (~50%) with boreal having less influence (~30%) than types 4 and 5. There is little cover by introduced or generalist species.

Woody vegetation is dominant with approximately equal amounts of native graminoid and native perennial cover. Tree cover is variable (0-25%) but with a low mean (3.09% cover).
Tree cover is dominated by *Pinus banskiana,* with other species (*Populus tremuloides, Quercus macrocarpa* and *Picea glauca*) occurring occasionally*.* Shrub cover is dominated by *Arctostaphylos uva-ursi* and *Dasiphora fruiticosa* with moderate cover by *Juniperus horizontalis* and *Rosa acicularis*. The variable (2-75%, mean=36.01% cover) graminoid cover is dominated by *Deschampsia cespitosa, Carex praegracilis, Danthonia spicata, Sporobolous heterolepis, Andropogon gerardii, Hesperostipa spartea, Festuca hallii, Bromus porteri* and *Festuca saximontana.* Forb cover is the highest of all communities (33.96%). Forb species are diverse and dominant species include: *Agoseris glauca, Geum triflorum, Antennaria howellii* ssp*. neodioica, Erigeron glabellus, Galium boreale, Fragaria virginiana, Maianthemum stellatum, Monarda fistulosa, Olgioneuron album Olgioneuron rigidum, Lathyrus venous, Symphyotrichum ciliolatum, Symphyotrichym laeve* and *Potentilla arguta*. Lichen (1.40%) and moss (3.50%) cover is low.

B. Mean Species Richness and Diversity:

This community has moderate mean richness and diversity values. Mean Shannon H (per plot) is 2.27. Mean effective Richness per plot is 9.9 and mean species richness per plot is 49.

C. Dominant and Frequent Species:

1. Woody Plants:

Species	**Mean Cover (%)**	**Frequency (%)**
Dasiphora fruticosa	15.50	93
Rosa ascicularis	1.14	93
Amelanchier alnifloia	0.91	93
Arctostaphylos uva-ursi	27.12	86
*Pinus banksiana**	2.86	15

*high cover where *Pinus banksiana* occurs (17-23%).

2. Annuals:

Thalictum venulosum: 64% frequency, but low cover (0.15%).

3. Graminoids:

Species	Mean Cover (%)	Frequency (%)
Koeleria macrantha	0.38	100
Elymus trachycaulus subsp. *subsecundus*	0.40	93
Poa pratensis	5.67	86
Agrostis scabra	0.54	86
Bromus porteri	0.54	86
Danthonia spicata	1.12	71

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Geum triforum	6.38	100
Symphyotrichum laeve	5.40	100
Oligoneuron rigidum	4.99	100
Vicia americana	0.24	100
Campanula rotundifolia	0.20	100
Antennaria howellii ssp. neodioica	1.29	93
Galium boreale	0.56	93
Lithospermum canescens	0.32	93
Erigeron glabellus	1.52	86

5. Cryptogams

Cryptogam cover is relatively low with approximately 4% cover by mosses that when present are primarily *Brachythecium* spp., *Bryum* spp., *Abietinella abietina* and *Tortella* spp. (*T. fragilis* and *T. tortuosa*). Lichen cover is also quite low (1.40% cover) and largely *Cladonia* spp. and *Peltigera* spp.

D. Indicator Species:

Graminoids: *Bromus porteri, Hesperostipa spartea, Phleum pratense, Agrostis scabra, Elymus trachycaulus subsp. subsecundus*

Shrubs: *Rosa acicularis, Arctostaphylos uva-ursi, Dasiphora fruticosa ssp floribunda*

Perennials: *Oligoneuron rigidum, Agoseris glauca, Symphyotrichum leave, Gaillardia aristata, Potentilla arguta, Liatris ligulistylis, Vicia americana, Erigeron glabellus, Oligoneuron album, Fragaria virginiana, Lithospermum canescens, Hieracium umbellatum, Sisyrinchium montanum, Solidago missouriensis, Erigeron philaldephicus.*

E. Environmental Characteristics:

Type VII has the deepest soils of all types (mean=81.13mm) with low cover of bare soil (lowest of all types, 0.44%) and bare rock (0.30%) (Table 3.3). The moisture availability is moderate.

This type has low nitrogen and high phosphorus in soils (NO3-N = 24.16 mg/kg and PO4-P = 14.49mg/kg), the second lowest EC values (EC=0.38) and a neutral pH (like all other types).

F. Disturbance

Type VII experienced low levels of cattle grazing (second lowest of all types) and included some sites that were completed ungrazed (A and B). Moderate levels of browsing by deer (third highest) were observed.

G. Introduced Species

This vegetation type has a high proportion of cover by introduced species (9% cover) dominated by *Poa pratensis* (mean cover 5.67%, 86% frequency) and *Phleum pretense* (mean cover 4.51%, freq=57%), and little cover by introduced forbs.

Species	Mean Cover (%)	Frequency (%)
Achillea millefolium	0.42	100
Taraxacum officinale	0.08	50
Cerastium arvense	0.08	36

H. Unique/Rare Species (S-ranks of S1 to S3S4)

Festuca hallii (3.06% cover, freq = 43%).
Bromus porteri (0.54% cover, freq = 86%).
Avenula hookeri (0.3% cover, freq = 14%).
Erigeron strigosus (0.12% cover, freq = 50%).
Oxytropis splendens (0.15% cover, freq = 21%).
Pediomelum esculentum (0.01% cover, freq = 7%).
Sporobolus heterolepis (5.18% cover, freq = 14%).

TYPE VIII

General Name: SPRUCE SAVANNA- BLUESTEM GRASSLAND

Association: *Picea glauca- Acrtostaphylos uva-ursi -Andropogon gerardii-Hespersostipa spartea*

Occurrences

Spruce savannas and bluestem grasslands were restricted to the ungrazed southern portion of the alvar sites. This was restricted to the southern alvar areas including sites R and S. This alvar type represented 20-50% of the site. Site R has the largest expanse of this habitat (~7 km^2) including areas of the bluestem grassland sub-type.

A. Physiognomy and General Description:

The cover of boreal (52%) and prairie (45%) vegetation is almost equal, with extremely low cover of species with generalist or introduced affinities. This vegetation type has the most obvious prairie elements due to the presence of typical prairie graminoids (including *Andropogon gerardii)*. Cover is dominated by woody vegetation including low lying dwarf shrubs and spruce trees. Tree cover is variable (0-26%) with a mean of 9.16% cover. Tree cover is predominately *Picea glauca* (mean cover = 7.36%, freq=44%). There is a mixture of shrubs (45% cover) including Arctostaphylos *uva-ursi* (mean cover=16.72%, in all plots)*, Dasiphora fruticosa* (mean cover=6.13%, in all plots), *Juniperus horizontalis* (mean cover=14.74%, freq=89)and *Betula glandulosa* (mean cover=5.17%, freq=78%). Native perennial cover is the lowest (10.45%) of any alvar types, with graminoid cover of the highest values of any wooded alvar community (Types IV-VIII). Graminoid coveris predominantely *Andropogon gerardii* and ranged from <10% to >85% (mean= 32.37%), leading to a separation between spruce savanna/shrubland and bluestem grassland sub-types within Type VIII. This vegetation type had moderate lichen (11.71%) and bryophyte (4.63%) cover.

Bluestem alvar grassland sub-type (sub-type 1):

Bluestem alvar grassland is most similar in vegetation composition to spruce savannas also occurring in the southern alvar region; however the bluestem alvar grassland sub-type has >85% graminoid cover, low shrub cover (<20%) and almost no tree cover (>1%) suggesting it’s distinction from spruce savanna alvars. Dominant shrubs include: *Arctostaphylos uva-ursi, Juniperus horizontalis, Dasiphora fruiticosa* and *Betula glandulosa*, although they do not have high cover values as in spruce savanna/shrubland alvar. Forb cover is lower than in spruce savanna/shrubland alvars with the dominant species being *Dalea candida, Oxytropis splendens, Cyprepedium parviflorum, Cirsium drummondii, Symphyotrichum laeve* and *Pediomelum esculentum*. *Cyprepedium parviflorum* was observed in this sub-type but not found in spruce savanna/shrubland alvars. *Cirsium drummondii* was also common in bluestem grasslands but not as frequent in spruce savanna/shrubland alvars. Lichen cover is low.

This community occurs intermixed with alvar shrublands (occurring in nearby regions shallower soils) and alvar savannas (areas with trees).

Spruce savanna/shrubland alvar sub-type (sub-type 2):

The spruce savanna/shrubland sub-type had <25% graminoid cover, >25% shrub cover and 1-26% tree cover (mean=12%). Dominant tree cover is *Picea glauca* and *Populus tremuloides*.

Dominant shrubs include: *Arctostaphylos uva-ursi, Juniperus horizontalis, Dasiphora fruiticosa* and *Betula glandulosa*. Forb cover is low but diverse. Dominant forbs include: *Dalea purpurea, Geum triflorum, Galium boreale, Solidago nemoralis, Oligoneuron rigidum* and *Solidago hispida*. *Solidago nemoralis, Antennaria howellii* ssp. *neodioica, Oligoneuron rigidum*, and *Dalea purpurea* are common in this sub-type but less so in bluestem grasslands. Lichen cover is moderate and higher than in bluestem grasslands.

B. Mean Species Richness and Diversity:

This vegetation type has moderate diversity values compared to other vegetation types in Manitoba. Mean Shannon H (per plot) is 2.04. Mean effective Richness per plot is 9.0. Mean species richness per plot is 53.

C. Dominant and Frequent Species:

1. Woody Plants:

Species	**Mean Cover (%)**	**Frequency (%)**
Arctostaphylos uva-ursi	16.72	100
Dasiphora fruticosa	6.13	100
Juniperus horizontalis	14.74	89
Betula glandulosa	5.17	78
Rosa ascicularis	0.21	78
Quercus macrocarpa	0.36	56
Picea glauca	7.36	44

2. Annuals:

No annuals were dominant or frequent in this habitat

3. Graminoids:

Species	**Mean Cover (%)**	**Frequency (%)**
Andropogon gerardii	28.78	100
Bromus porteri	0.06	100
Danthonia spicata	0.68	89
Festuca saximontana	0.44	78
Koeleria macrantha	0.06	56

4. Herbaceous Perennials:

Species	Mean Cover (%)	Frequency (%)
Symphyotrichum laeve	0.80	100
Galium boreale	0.58	100
Oligoneuron rigidum	0.55	100
Oligoneuron album	0.39	100
Solidago hispida	0.39	100
Comandra umbellata	0.39	100
Monarda fistulosa	0.35	100
Campanula rotundifolia	0.01	100
Geum triforum	0.62	89

5. Cryptogams

Species	Mean Cover (%)	Frequency (%)
Abietinella abietina	16.70	78
Syntrichia ruralis	6.96	78
Ditrichum flexicaule	9.96	33

Lichen cover is fairly high (11.71% cover) and largely *Cladonia* spp. and *Peltigera* spp.

D. Indicator Species:

Graminoids: *Andropogon gerardii.*

Perennials: *Dalea purpurea, Pediomelum esculentum, Dalea candida, Lilium philadelphicum, Solidago hispida, Rudbeckia hirta var. pulcherrima, Linum lewisii, Astragalus laxmanii var robustior, Heuchera richardsonii.*

Trees: *Populus tremuloides, Picea glauca.*

Shrubs: *Betula glandulosa, Shepherdia canadensis.*

Indicator Species for sub-type 1: *Rudbeckia hirta* var. *pulcherrima, Oxytropis splendens, Lilium philadelphicum, Hieracium umbellatum, Dalea candida, Cypripedium parviflorum, Cirsium drummondii, Apocynum androsaemifolium, Andropogon gerardii, Hesperostipa spartea*

Indicator Species for Sub-type 2: *Juniperus horizontalis, Populus tremuloides, Prunus susquehanae, Betula glandulosa, Arctostaphylos uva-ursi, Solidago nemoralis, Oligoneuron rigidum, Olgioneuron rigidum, Monarda fistulosa, Heuchera richardsonii, Gaillardia aristata, Geum triflorum, Galium boreale, Dalea purpurea, Pulsatilla patens* ssp. *patens, Tortula ruralis, Festuca saximontana, Danthonia spicata, Koeleria macrantha*

E. Environmental Characteristics:

The bluestem grassland and spruce savanna/shrubland community had shallow to moderate soil depths (second shallowest, mean = 41.86 mm), moderate rock cover (3rd lowest of all types), moderate amount of bare soil (1.50%) and a dry moisture regime (second driest type).

Type VIII had moderately high nitrogen and phosphorus in soils (NO3-N = 84.42 mg/kg and PO4-P = 10.22mg/kg), moderate EC values (EC= 0.49) and a neutral pH (like all other types).

F. Disturbance

This type experienced no grazing. High levels of browsing were observed, although this may have been grazed previously.

G. Introduced Species

Introduced species cover is low and infrequent. The most common species is *Achillea millefolium* (0.03% cover, freq = 78%).

H. Unique/Rare Species (S-ranks of S1 to S3S4)

Bromus porteri (0.06% cover, freq = 100%) was present in all plots at low cover.
Carex crawei (0.22% cover, freq = 44%).
Avenula hookeri (0.07% cover, freq = 33%).
Sporobolus heterolepis (0.42% cover, freq =33%)
Pediomelum esculentum (0.17% cover, freq = 44%).

Appendix 5: List of vascular and non-vascular plant species on the limestone cliffs at Marble Ridge in Manitoba including species found by Caners (2011).

NON-VASCULAR PLANTS

Family	Common	Latin Name
Amblystegiaceae	Goldenleaf Campylium Moss	*Campylium chrysophyllum* (Brid.) J. Lange
Amblystegiaceae	Hispid Campylium Moss	*Campylium hispidulum* (Brid.) Mitt.
Amblystegiaceae	Compact Conardia Moss	*Conardia compacta* (C. Müll.) Robins
Anomodontaceae	Snomodon Moss	*Anomodon minor* (Hedw.) Fürnr.
Anomodontaceae	Anomodon Moss	*Anomodon rostratus* (Hedw.) Schimp.
Anytoniaceae	Liverwort	*Mannia fragrans* (Balbis) Frye et Clark
Anytoniaceae	Liverwort	*Mannia sibirica* (K. Müll.) Frye et Clark
Aulacomniaceae	Aulacomnium Moss	*Aulacomnium palustre* (Hedw.) Schwaegr.
Brachytheciaceae	Brachythecium Moss	*Brachythecium collinum* (Schleich. ex C. Müll.)
Brachytheciaceae	Brachythecium Moss	*Brachythecium acuminatum* (Hedw.) Aust
Brachytheciaceae	Brachythecium Moss	*Brachythecium laetum* Schimp. in B.S.G
Brachytheciaceae	Brachythecium Moss	*Brachythecium salebrosum* (Web. & Mohr) Schimp
Brachytheciaceae	Brachythecium Moss	*Eurhynchium pulchellum* (Hedw.) Jenn.
Bryaceae	Dry Calcareous Bryum Moss	*Bryum caespiticium* Hedw.
Bryaceae	Common Green Bryum Moss	*Bryum pseudotriquetrum* (Hedw.) Gaertn. et al
Bryaceae	Pohlia Moss	*Pohlia cruda* (Hedw.) Lindb
Bryaceae	Ontario Rhodobryum Moss	*Rhodobryum ontariense* (Kindb.) Par. in Kindb.
Cleveaceae	Liverwort	*Athalamia hyalina* (Sommert.) Hatt
Ditrichaceae	Distichium Moss	*Distichium capillaceum* (Hedw.) Bruch & Schimp
Ditrichaceae	Bendy Ditrichum	*Ditrichum flexicaule* (Schwägr.) Hampe
Encalyptaceae	Candle Snuffer Moss	*Encalypta procera* Schwaegr
Encalyptaceae	Yellow Awm Candle Snuffer Moss	*Encalypta rhaptocarpa* Hedw.
Fissidentaceae	Bryoid Fissidens Moss	*Fissidens bryoides* Hedw.
Geocalycaceae	Liverwort	*Lophocolea minor* Nees
Grimmiaceae	Grimmia Dry Rock Moss	*Grimmia teretinervis* Limpr
Grimmiaceae	Schistidium Moss	*Schistidium frigidum* H. H. Blom
Grimmiaceae	Streamside Schistidium Moss	*Schistidium rivulare* var. *rivulare* (Brid.) Podp.
Hedwigiaceae	Ciliate Hedwigia Moss	*Hedwigia ciliata* (Hedw.) P. Beauv.
Hylocomiaceae	Splended Feather Moss	*Hylocomium splendens* (Hedw.) Schimp.
Hypnaceae	Vaucher's Hypnum Moss	*Hypnum vaucheri* Lesq.
Hypnaceae	Isopterygiopis Moss	*Isopterygiopsis pulchella* (Hedw.) Iwats
Hypnaceae	Jugermann's Platydictya Moss	*Platydictya jungermannioides* (Brid.) Crum
Hypnaceae	Pylaidiella Moss	*Pylaisiella polyantha* (Hedw.) Grout
Jubulaceae	Liverwort	*Frullania inflata* Gott.
Leskeaceae	Leskeella Moss	*Leskeella nervosa* (Brid.) Loeske
Leskeaceae	Pseudoleskeella Moss	*Pseudoleskeella tectorum* (Funck ex Brid.) Kindb.
Mniaceae	Ambiguous Calcareous Moss	*Mnium ambiguum* H. Müll.
Mniaceae	Thomson's Calcareous Moss	*Mnium thomsonii* Schimp
Mniaceae	Largetoorth Calcareous Moss	*Mnium spinulosum* Bruch & Schimp.
Mniaceae	Toothed Plagiomnium Moss	*Plagiomnium cuspidatum* (Hedw.) T. Kop

Appendix 5: List of vascular and non-vascular plant species on the limestone cliffs at Marble Ridge in Manitoba including species found by Caners (2011).

NON-VASCULAR PLANTS (CONTINUED)

Family	**Common**	**Latin Name**
Mniaceae	Intermediate Plagiomnium Moss	*Plagiomnium medium* (Bruch & Schimp. in B.S.G.) T. Kop.
Neckeraceae	Neckera Moss	*Neckera pennata* Hedw.
Orthotrichaceae	Orthotrichum Moss	*Orthotrichum anomalum* Hedw.
Orthotrichaceae	Obtuseleaf Aspen Moss	*Orthotrichum obtusifolium* Brid.
Plagiochilaceae	Liverwort	*Plagiochila porelloides* (Torrey ex Nees) Lindenb.
Pottiaceae	Convoluted Barbula Moss	*Barbula convoluta* Hedw.
Pottiaceae	Fragile Tortella Moss	*Tortella fragilis* (Hook. & Wilson) Limpr.
Pottiaceae	Tortured Tortella Moss	*Tortella tortuosa* (Hedw.) Limpr.
Pottiaceae	Mucronleaf Tortula Moss	*Tortula mucronofolia* Schwägr.
Pterigynandraceae	Myurella Moss	*Myurella julacea* (Schwägr.) Schimp.
Radulaceae	Liverwort	*Radula complanata* (L.) Dum.
Thuidiaceae	Abietinella Moss	*Abietinella abietina* (Hedw.) Fleisch.
Thuidiaceae	Thuidium Moss	*Thuidium recognitum* (Hedw.) Lindb.

VASCULAR PLANTS

Family	**Common**	**Latin Name**
Aceraceae	Mountain Maple	*Acer spicatum* Lam
Anacardiaceae	Eastern Poision Ivy	*Toxicodendron radicans var. rybergii* (L.) Kuntze
Apocynaceae	Dogbane	*Apocynum androsaemifolium* L.
Araliaceae	Wild Sarsaparilla	*Aralia nudicaulis L.*
Asteraceae	Field Sagewort	*Artemisia campestris* L. ssp. *caudata* (Michx.) H.M. Hall & Clem.
Asteraceae	Prairie Goldenrod	*Oligoneuron album* (Nutt.) G.L. Nesom
Asteraceae	Balsam Groundsel	*Packera paupercula* (Michx.) Á. Löve & D. Löve
Asteraceae	Hairy Goldenrod	*Solidago hispida* Muhl. ex Willd.
Asteraceae	Smooth Blue Aster	*Symphyotrichum laeve* (L.) Á. Löve & D. Löve
Asteraceae	Gray Goldenrod	*Solidago nemoralis* Aiton
Betulaceae	American Hazelnut	*Corylus americana* Walter
Boraginaceae	American Stickseed	*Hackelia deflexa* (Wahlenb.) Opiz var. *americana* (A. Gray) Fernald & I.M. Johnst.
Boraginaceae	Hoary Puccoon	*Lithospermum canescens* (Michx.) Lehm.
Brassicaceae	Tower Rockcress	*Arabis glabra* (L.) Bernh.
Brassicaceae	Hairy Rockcress	*Arabis hirsuta* (L.) Scop.
Campanulaceae	Bluebell Bellflower	*Campanula rotundifolia* L.
Caprifoliaceae	Twinflower	*Linnaea borealis* L.
Caprifoliaceae	Snowberry	*Symphoricarpos albus* (L.) S.F. Blake
Caprifoliaceae	Downy Arrowwood	*Viburnum rafinesquianum* Schult.
Caryophyllaceae	Field Chickweed	*Cerastium arvense* L.
Cornaceae	Red-osier Dogwood	*Cornus sericea* Jepson.

Appendix 5: List of vascular and non-vascular plant species on the limestone cliffs at Marble Ridge in Manitoba including species found by Caners (2011).

VASCULAR PLANTS (CONTINUED)

Family	**Common**	**Latin Name**
Cupressaceae	Common Juniper	*Juniperus communis* L.
Cyperaceae	Crawe's Sedge	*Carex crawei* Dewey
Cyperaceae	Bristleleaf Sedge	*Carex eburnea* Boott
Dryopteridaceae	Brittle Bladderfern	*Cystopteris fragilis* (L.) Bernh.
Elaeagnaceae	Buffaloberry	*Shepherdia canadensis* (L.) Nutt.
Ericaceae	Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Fagaceae	Bur Oak	*Quercus macrocarpa Michx.*
Grossulariaceae	Hairystem Gooseberry	*Ribes hirtellum* Michx.
Grossulariaceae	Canadian Gooseberry	*Ribes oxyacanthoides* L.
Liliaceae	Wood Lily	*Lilium philadelphicum* L.
Liliaceae	Canada Mayflower	*Maianthemum canadense* Desf.
Liliaceae	Drops-of-Gold	*Prosartes hookeri* Torr.
Onagraceae	Fireweed	*Chamerion angustifolium* (L.) Holub ssp. *angustifolium* (L.) Holub
Pinaceae	White Spruce	*Picea glauca* (Moench) Voss
Poaceae	Slender Wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners subsp. subsecundus (Link) Á. Löve & D. Löve
Poaceae	Slender Wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners *subsp. trachycaulus* (Link) Gould ex Shinners
Poaceae	Prairie Junegrass	*Koeleria macrantha* (Ledeb.) Schult.
Poaceae	Roughleaf Ryegrass	*Oryzopsis asperifolia* Michx.
Poaceae	Mountain Riccegrass	*Piptatheropsis pungens* (Torr.) Romasch., P.M. Peterson & R.J. Soreng
Poaceae	False Melic	*Schizachne purpurascens* (Torr.) Swallen
Pteridaceae	Western Dwarf Cliffbrake	*Pellaea glabella* Mett. ex Kuhn ssp *occidentalis* (E.E. Nelson) Windham
Pyrolaceae	Sidebells Wintergreen	*Orthilia secunda* (L.) House
Ranunculaceae	Canadian Anemone	*Anemone canadensis* L.
Ranunculaceae	Eastern Pasqueflower	*Pulsatilla patens* (L.) Mill. ssp. *patens* (L.) Mill.
Ranunculaceae	Veiny Meadowrue	*Thalictrum venulosum* Trel.
Rosaceae	Saskatoon serviceberry	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.
Rosaceae	Shrubby Cinqufoil	*Dasiphora fruticosa ssp floribunda* (L.) Rydb.
Rosaceae	Virginia Strawberry	*Fragaria virginiana* Duchesne
Rosaceae	Pennsylvania cinquefoil	*Potentilla pensylvanica* L.
Rosaceae	Pin Cherry	*Prunus pensylvanica* L.f
Rosaceae	Prickly Rose	*Rosa acicularis* Lindl.
Rosaceae	Grayleaf Blackberry	*Rubus idaeus* L. ssp. *strigosus* (Michx.) Focke
Rosaceae	Dwarf Red Blackberry	*Rubus pubescens* Raf.
Rubiaceae	Northern Bedstraw	*Galium boreale* L.
Salicaceae	Trembling Aspen	*Populus tremuloides* Michx.
Salicaceae	Bebb Willow	*Salix bebbiana* Sarg.
Saxifragaceae	Richardson's Alumroot	*Heuchera richardsonii* R. Br.
Violaceae	Hookspur Violet	*Viola adunca* Sm.

Appendix 6: Non-vascular plants of Manitoba alvars

Family	Common Name	Latin Name	Code
Amblystegiaceae	Creeping Feather Moss	*Amblystegium serpens* (Hedwig) Schimper	Amse
Amblystegiaceae	Golden Creeping Moss	*Campylium chrysophyllum* (Brid.) J. Lange	Cachr
Amblystegiaceae	Hispid Campylium Moss	*Campylium hispidulum* (Brid.) Mitt.	Cahi
Amblystegiaceae	Yellow Starry Fen Moss	*Campylium stellatum* (Hedw.) J. Lange & C. Jens	Caste
Amblystegiaceae	Compact Conardia Moss	*Conardia compacta* (C. Müll.) Robins	Cocom
Amblystegiaceae	Drepanocladus Moss	*Drepanocladus polygamus* (Schimper) Hedenas	Drpo
Amblystegiaceae	Drepanocladus Moss	*Drepanocladus sordidus* (Müller Hal.) Hedenas	Drso
Amblystegiaceae	Pladydictya Moss	*Platydictya confervoides* (Bridel) H. A. Crum	Plco
Amblystegiaceae	Pseudocalliergon Moss	*Pseudocalliergon turgescens* (T. Jensen) Loeske	Pstu
Anomodontaceae	Snomodon Moss	*Anomodon minor* (Hedw.) Fürnr.	Anmin
Anomodontaceae	Anomodon Moss	*Anomodon rostratus* (Hedw.) Schimp.	Anro
Anytoniaceae	Liverwort	*Mannia fragrans* (Balbis) Frye et Clark	Mafr
Anytoniaceae	Liverwort	*Mannia sibirica* (K. Müll.) Frye et Clark	Masi
Aulacomniaceae	Aulacomnium Moss	*Aulacomnium palustre* (Hedw.) Schwaegr.	Aupa
Brachytheciaceae	Brachythecium Moss	*Brachythecium collinum* (Schleich. ex C. Müll.)	Braca
Brachytheciaceae	Acuminate Brachythecium Moss	*Brachythecium acuminatum* (Hedw.) Austin	Braac
Brachytheciaceae	Field Ragged Moss	*Brachythecium campestre* (Müller Hal.) Schimper	BraSP
Brachytheciaceae	Brachythecium Moss	*Brachythecium laetum* Schimp. in B.S.G	Brala
Brachytheciaceae	Brachythecium Moss	*Brachythecium salebrosum* (Web. & Mohr) Schimp	BraSP
Brachytheciaceae	Brachythecium Moss	*Eurhynchium pulchellum* (Hedw.) Jenn.	Eupu
Bryaceae	Common Green Bryum Moss	*Bryum pseudotriquetrum* (Hedw.) Gaertn. et al	Bryps
Bryaceae	Dry Calcareous Bryum Moss	*Gemmabryum caespiticium* (Hedwig) J. R. Spence	Geca
Bryaceae	Pohlia Moss	*Pohlia cruda* (Hedw.) Lindb	Pocr
Bryaceae	Ptychostomum Moss	*Ptychostomum pseudotriquetrum* (Hedwig) Spence & Ramsay ex Holyoak & Pedersen	Ptps
Bryaceae	Ontario Rhodobryum Moss	*Rhodobryum ontariense* (Kindb.) Par. in Kindb.	Rhon

Appendix 6 (Continued): Non-vascular plants of Manitoba alvars

Family	Common Name	Latin Name	Code
Cleveaceae	Liverwort	*Athalamia hyalina* (Sommert.) Hatt	Athy
Dicranaceae	Dicranum Moss	*Dicranum polysetum* Sw.	Dipo
Ditrichaceae	Fire Moss	*Ceratodon purpureus* (Hedwig) Bridel	Cepu
Ditrichaceae	Distichium Moss	*Distichium capillaceum* (Hedw.) Bruch & Schimp	Dica
Ditrichaceae	Bendy Ditrichum	*Ditrichum flexicaule* (Schwägr.) Hampe	Difl
Encalyptaceae	Candle Snuffer Moss	*Encalypta procera* Schwaegr	Enpr
Encalyptaceae	Yellow Awm Candle Snuffer Moss	*Encalypta rhaptocarpa* Hedw.	Enrh
Entodontaceae	Red-stemmed Feather Moss	*Pleurozium schreberi* (Willdenow ex Bridel) Mitten	Plsc
Fissidentaceae	Bryoid Fissidens Moss	*Fissidens bryoides* Hedw.	Fibr
Fissidentaceae	Fissidens Moss	*Fissidens adianthoides* Hedwig	Fiad
Geocalycaceae	Liverwort	*Lophocolea minor* Nees	Lomi
Grimmiaceae	Grimmia Moss	*Grimmia longirostris* Hooker	Grlo
Grimmiaceae	Grimmia Dry Rock Moss	*Grimmia teretinervis* Limpr	Grte
Grimmiaceae	Schistidium Moss	*Schistidium frigidum* H. H. Blom	Scfr
Grimmiaceae	Streamside Schistidium Moss	*Schistidium rivulare var. rivulare* (Brid.) Podp.	GrSP
Hedwigiaceae	Ciliate Hedwigia Moss	*Hedwigia ciliata* (Hedw.) P. Beauv.	Heci
Hylocomiaceae	Splended Feather Moss	*Hylocomium splendens* (Hedw.) Schimp.	Hysp
Hypnaceae	Vaucher's Hypnum Moss	*Hypnum vaucheri* Lesq.	Hyva
Hypnaceae	Isopterygiopis Moss	*Isopterygiopsis pulchella* (Hedw.) Iwats	Ispu
Hypnaceae	Jugermann's Platydictya Moss	*Platydictya jungermannioides* (Brid.) Crum	Plju
Hypnaceae	Pylaidiella Moss	*Pylaisiella polyantha* (Hedw.) Grout	Pypo
Jubulaceae	Liverwort	*Frullania inflata* Gott.	Frin
Leskeaceae	Leskeella Moss	*Leskeella nervosa* (Brid.) Loeske	Lene
Leskeaceae	Pseudoleskeella Moss	*Pseudoleskeella tectorum* (Funck ex Brid.) Kindb.	Pste
Mniaceae	Ambiguous Calcareous Moss	*Mnium ambiguum* H. Müll.	Mnam
Mniaceae	Thomson's Calcareous Moss	*Mnium thomsonii* Schimp	Mnth
Mniaceae	Largetoorth Calcareous Moss	*Mnium spinulosum* Bruch & Schimp.	Mnsp
Mniaceae	Toothed Plagiomnium Moss	*Plagiomnium cuspidatum* (Hedw.) T. Kop	Plcu
Mniaceae	Intermediate Plagiomnium Moss	*Plagiomnium medium* (Bruch & Schimp.) T. Kop.	Plme
Neckeraceae	Neckera Moss	*Neckera pennata* Hedw.	Nepe
Orthotrichaceae	Orthotrichum Moss	*Orthotrichum anomalum* Hedw.	Oran
Orthotrichaceae	Obtuseleaf Aspen Moss	*Orthotrichum obtusifolium* Brid.	Orob

Appendix 6 (Continued): Non-vascular plants of Manitoba alvars

Family	Common Name	Latin Name	Code
Plagiochilaceae	Liverwort	*Plagiochila porelloides* (Torrey ex Nees) Lindenb.	Plpo
Polytrichaceae	Juniper Polytrichum Moss	*Polytrichum juniperinum* Hedw.	Poju
Pottiaceae	Convoluted Barbula Moss	*Barbula convoluta* Hedw.	BarSP
Pottiaceae	Red Beard Moss	*Bryoerythrophyllum recurvirostre* (Hedw.) Chen	Brre
Pottiaceae	Gymnostomum Moss	*Gymnostomum aeruginosum* Sm.	Gyae
Pottiaceae	Syntrichia Moss	*Syntrichia norvegica* F. Weber	Syno
Pottiaceae	Syntrichia Moss	*Syntrichia ruralis* (Hedwig) F. Weber & D. Mohr	Syru
Pottiaceae	Fragile Tortella Moss	*Tortella fragilis* (Hook. & Wilson) Limpr.	Tofr
Pottiaceae	Tortured Tortella Moss	*Tortella tortuosa* (Hedw.) Limpr.	Toto
Pottiaceae	Mucronleaf Tortula Moss	*Tortula mucronofolia* Schwägr.	Tomu
Pterigynandraceae	Myurella Moss	*Myurella julacea* (Schwägr.) Schimp.	Myju
Radulaceae	Liverwort	*Radula complanata* (L.) Dum.	Raco
Thuidiaceae	Abietinella Moss	*Abietinella abietina* (Hedw.) Fleisch.	Thab
Thuidiaceae	Thuidium Moss	*Thuidium recognitum* (Hedw.) Lindb.	Thre

Appendix 7: Preliminary list of lichens identified from alvars in the Interlake region of Manitoba.

Family	Species	Form	Substrate
Candelariaceae	*Candelaria concolor*	Foliose	Bark
Cladoniaceae	*Cladina rangiferina*	Fruticose	Ground
Cladoniaceae	*Cladina stellaris*	Fruticose	Ground
Cladoniaceae	*Cladonia botrytes*	Fruticose	Ground
Cladoniaceae	*Cladonia coniocraea*	Fruticose	Ground
Cladoniaceae	*Cladonia cristatella*	Fruticose	Dead Wood
Cladoniaceae	*Cladonia gracilis*	Fruticose	Ground
Cladoniaceae	*Cladonia multiformis*	Fruticose	Ground
Cladoniaceae	*Cladonia pocillum*	Fruticose	Ground
Cladoniaceae	*Cladonia uncialis*	Fruticose	Ground
Collemataceae	*Collema undulatum*	Foliose	Limestone Pavement
Lecanoraceae	*Lecidella stigmatea*	Crustose	Limestone Rock
Parmeliaceae	*Cetraria ericetorum*	Fruticose	Ground
Parmeliaceae	*Cetraria islandica*	Fruticose	Ground
Parmeliaceae	*Evernia mesomorpha*	Fruticose	Bark
Parmeliaceae	*Flavopunctelia soredica*	Foliose	Bark
Parmeliaceae	*Melanelia septentrionalis*	Foliose	Bark
Parmeliaceae	*Parmelia sulcata*	Foliose	Bark
Parmeliaceae	*Usnea glabrescens*	Fruticose	Bark
Parmeliaceae	*Usnea laapponica*	Fruticose	Bark
Parmeliaceae	*Vilpicida pinastri*	Foliose	Bark
Parmeliaceae	*Xanthoparmelia cumberlandii*	Foliose	Granite Eratics
Parmeliaceae	*Xanthoparmelia somlo ënsis*	Foliose	Granite Eratics
Peltigeraceae	*Peltigera rufescens*	Foliose	Ground
Physciaceae	*Phaeophyscia pusilloides*	Foliose	Bark
Physciaceae	*Phaeophyscia sciastra*	Foliose	Granite Eratics
Physciaceae	*Physcia adscedens*	Foliose	Bark
Physciaceae	*Physcia caesia*	Foliose	Rock
Physciaceae	*Physcia stellaris*	Foliose	Bark
Physciaceae	*Physcia tenella*	Foliose	Rock and Wood
Psoraceae	*Protoblastenia rupestris*	Crustose	Limestone Rock
Ramalinaceae	*Ramalina americana*	Fruticose	Bark
Ramalinaceae	*Ramalina dilacerta*	Fruticose	Bark
Teloschistaceae	*Caloplaca holocarpa*	Crustose	Limestone Rock
Teloschistaceae	*Teloschistaceae chysophthamalus*	Fruticose	Bark
Teloschistaceae	*Xanthoria elegans*	Foliose	Granite Eratics
Teloschistaceae	*Xanthoria hacciana*	Foliose	Bark
Teloschistaceae	*Xanthoria polycarpa*	Foliose	Rock and Wood
Umbilicariaceae	*Umbilicaria muehlenbergii*	Foliose	Rock
Verrucariaceae	*Dermatocarpon miniatum*	Foliose	Limestone Rock