2017

Community Development of Terrestrial and Semi-Terrestrial Invertebrates Along Environmental Gradients in a Reclaimed Watershed

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COMMUNITY DEVELOPMENT OF TERRESTRIAL AND SEMI-TERRESTRIAL INVERTEBRATES ALONG ENVIRONMENTAL GRADIENTS IN A RECLAIMED WATERSHED

by

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A Thesis
Submitted to the Faculty of Graduate Studies
Through the Department of Biological Sciences
In Partial Fulfilment of the Requirements for
The Degree of Master of Science at the
University of Windsor

Windsor, Ontario, Canada

2017

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Abstract

The diversity-stability hypothesis suggests that diverse communities are resilient to change. Wetlands are especially diverse and are an area of concern in the Boreal Zone of northern Alberta, Canada, as they are affected by surface mining for oil sands. This thesis describes terrestrial and semi-terrestrial invertebrate community composition within the Sandhill Fen Watershed, the first-ever landform constructed on a foundation of oil sands tailings, in the post-mining landscape. Soil attributes and plant community composition were associated with spatial variation in invertebrate abundance, richness and composition at low-elevation (peat dominated) and upland (forest soil dominated) locations within Sandhill Fen, and in 8 reference fens. Peat-dominated sites in Sandhill Fen were typically wet, saline, and slightly acidic and supported a typical herbaceous wetland plant community. The invertebrates found in this habitat were those commonly associated with wetland plant communities and were similar in composition to invertebrates in *Carex*-dominated ('rich') reference fens. The Litter-Fermentation-Humic (LFH) soil dominated upland sites were drier, less saline, had a meadow plant community, and an invertebrate assemblage that was more variable than the peat community and distinct from the fauna of reference fens. Sandhill fen invertebrate abundance was equivalent to that of reference fens. Family richness in Sandhill Fen exceeded that of reference fen sites, likely reflecting associations with the greater plant diversity of low-elevation plus upland sites combined. Sandhill Fen soils were more saline than reference fen soils, but the plant community and invertebrate community of low-elevation peat sites fell within the range of variation observed in rich reference fens. Within Sandhill Fen, plant community assemblages are consistently associated with soil attributes (moisture, salinity). Invertebrate community assemblages are directly correlated with plant assemblages and indirectly with soil attributes. The present diversity of this community and its components indicates a stable, developing ecosystem mirroring some natural conditions.

For my family and friends.

Thank you for everything you do.

Acknowledgements

First of all, I would like to thank Dr. Jan Ciborowski for all of his guidance during this degree, whether it be through his passion for his work, statistical advice, or thoughtful suggestions. I would also like to thank him for first introducing me to the wonderful world of fieldwork. As someone who was not sure about what I was going to do after my Undergraduate degree, the opportunity to explore a new and different avenue of work is one that I will always appreciate. I would like to thank my committee, Dr. Oliver Love, Dr. Joel Gagnon, and Carla Wytrykush. Thank you for all your help and encouragement throughout this adventure. Your insights were extremely beneficial to all my work.

To the Ciborowski lab, I cannot express enough thanks for all of your advice and encouragement over the last few years. This lab contains an amazing group of people that are always there to support you, teach you, and laugh with you. To Li Wang, Michelle Dobrin, Jesse Gardner-Costa, and Lyndon Barr, thank you for your guidance. To my past and present labmates, Jasmine St. Pierre, Danielle Gunsch, Alyssa Frazao, and Chantal Dings-Avery, I can't thank you enough for being supportive and letting me talk and complain when I needed to. I want to give special thanks to Chantal for always letting me vent and helping me through the ups and downs of this degree and of life. I could not imagine doing this without you.

Next, to those who have helped me out in the field and made those long, stressful, and unproductive days worthwhile and fun: H. Bagnall, H. Wiseman, C. Dings-Avery, M. Hazell, K. Lukianchuk, C. Kelly, A. Despenic, D. Vanmensal, R. Boutette, and H. Mayorado. Without the adventures and amazing time in the field, I am not sure I would

have come to love fieldwork as much as I do. You made the Fort Mac summers ones that I will never forget.

Third, to those I have met over the years. To those at Syncrude: Carla, Lori, Jess, John, Mike, and Mohammed. Thank you for your constant teachings and enthusiasm for the work you do. To the students and other researchers: there are too many of you to list, but I thank each and every one of you. The knowledge and passion for your work shows in all you do.

Finally, to my support system. To my parents and sister, thank you for dealing with my love for something eccentric and supporting my choices. To D.Y, and C.L, thank you for your constant support, your input, and for being there.

This research was funded by grants provided to Dr. Jan Ciborowski from Syncrude Canada Ltd and the Natural Sciences and Engineering Research Council of Canada (NSERC). I gratefully acknowledge the receipt of a bursary from Syncrude Canada Ltd., and additional graduate/research assistantships from the University of Windsor.

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Chapter One: General Introduction

The development and expansion of surface mining for oil sands in the Wood Buffalo boreal region of northeastern Alberta has been a topic of economic and environmental importance for the past 50 years. Because of the further need for oil sands mining, companies continue to increase the expanse of their projects, which has resulted in significant peatland loss in the region (Rooney et al., 2012). Habitat disturbance caused by the mining process necessitates reclamation in the disturbed areas. There has been past success in reclamation of terrestrial upland habitats, as seen in Gateway Hill and South Bison Hills (both Syncrude Canada Ltd.) (MacDonald et al., 2012). However, given the extent of peatlands in this region's landscape, there has been a shift in focus from upland reclamation practices to wetland and fen reclamation practices (Price et al., 2012). As a condition of continuing the operation of their mines, Syncrude Canada Ltd. was tasked in the construction and study of the Sandhill Fen Watershed, which is the first watershed built in the region and the first construction of a reclaimed wetland on soft tailings (Wytrykush et al., 2012). Design of the watershed began in 2007 (Syncrude, 2008), with construction occurring in 2010 (BGC Engineering, 2010) and culminating in 2012.

A key measure of reclamation success is the demonstration that biota colonize the landscape and form functional assemblages with equivalent capability to that of the pre-mining condition. Studies have been conducted on the recolonized land focusing on small mammals (Rodriguez-Estival & Smits, 2016), large mammals (Belovsky, 1981) and waterfowl (OSWWG, 2007), which are visible and desirable elements of the boreal landscape. There is also an ongoing need for research in reclaimed areas with respect to the colonization of aquatic and semi-aquatic invertebrates. Invertebrates are an essential

component at the base of the food web as they are primary consumers of plants and detritus and serve as food for other organisms (Kovalenko et al., 2013). Aquatic invertebrates are frequently used to document the quality of water and wetlands in which they live, making them important bioindicators (Hodkinson & Jackson, 2005; Sharma & Rawat, 2009). Research on the semi-terrestrial and terrestrial fauna of natural peatlands has been particularly lacking (Danks & Rosenberg, 1987).

The focus of this project was to survey the terrestrial and semi-terrestrial invertebrates in the Sandhill Fen and similar local reference wetlands. Objectives included the following:

1) Documenting the composition and distribution of terrestrial and semi-terrestrial invertebrates of the Sandhill Fen Watershed to provide a baseline inventory against which to assess current ecological condition relative to reference systems and to future assessments;
2) Determining whether and how the relative abundance of invertebrates varies among the differing ecozones of the Sandhill Fen?
3) Determining how invertebrate community composition compares to older fens or similar wetland areas with respect to invertebrate diversity, and feeding guilds.

Project Summary and Objectives

My research investigated the differences in the moisture and nutrient properties between two topsoil types in a reclaimed wetland, and the associated distribution of terrestrial and semi-terrestrial invertebrate community composition. The project is a case

study of Syncrude Canada's reclaimed Sandhill Fen Watershed, which is the first of its kind to be created in the post-mining landscape of the Athabasca Oil Sands deposit located near Fort McMurray, AB (Wytrykush et al., 2012). The main goal of this project is to assess the invertebrate richness, abundance and community composition of the watershed, and to determine the relative influences of environmental variables on the invertebrate community composition. This project assesses the spatial organization of microhabitats across gradients within the watershed. Finally, invertebrate biodiversity of the Sandhill Fen is compared to that of natural fens in the region.

Habitat Choice

Explaining an organism's choice of habitat is one of the most important concepts in ecology, having been studied in organisms as diverse as birds and small mammals (MacArthur & MacArthur, 1961), fishes (Savino & Stein, 1988; Ehlinger, 1990), and large mammals (Belovsky, 1981). The process of habitat choice by invertebrates as a group has been studied extensively (Andow, 1991; Goodman, 1975; Brose, 2003a; Brose, 2003b), and various hypotheses have been proposed to explain the relationship between invertebrates and the habitat in which they are found, focusing mainly on the role of the plant community.

Root (1972) conducted an experiment that assessed the invertebrate communities on plants that were part of a large monoculture and those of a small monoculture nearby to a polyculture. He found that the large-monoculture community supported a large population of herbivorous *Phyllotreta* beetles because the food source was so abundant. In contrast, the monocultures planted near the polycultures supported fewer of these insects, but also had greater abundance of beetles, predators and parasites. Root concluded that

because there was a lower concentration of the food source in the smaller monocultures, *Phyllotreta* abundance was controlled by the food and predators from neighbouring plants. This led him to develop the "Resource Concentration Hypothesis", which states that invertebrates searching for a food source are more likely to find that source in an area with high densities of the food plant. Andow (1991) conducted a rigorous comparison of multiple hypotheses that attempted to explain the habitat relationship between plants and invertebrates. In his review, Andow highlighted the "Diversity-Stability Hypothesis", which applies to ecological communities as a whole. The Diversity-Stability hypothesis attempts to explain how communities function as a whole, and how species diversity promotes a stable community through multiple interactions between organisms and trophic levels (Goodman, 1975). However, there is still debate about whether this hypothesis is credible because of ambiguous experimental results (McCann, 2000). Third, in order to better understand what aspects of the plant community are most important in fostering insect community diversity, Haddad et al. (2001) tested whether the structure of the plant community or the species richness of the community was more important (Haddad et al., 2001). Their study showed that both increased plant functional group richness and plant species richness resulted in higher invertebrate species abundance.

Most researchers conclude that plant-invertebrate relationships continue to be poorly understood and that further study is needed. Patterns can be seen, but understanding their underlying causes is what is driving further research. In particular, specific habitats should be studied and contrasted to better understand what drives the relationship between the invertebrates and the plants.

Wetland Structure and Function

Wetlands are among the most productive ecosystems in the world in terms of carbon sequestration, with those found in the boreal landscape constituting approximately one-third of the terrestrial stored carbon on Earth (IPCC, 2007). They are transitional zones between terrestrial and aquatic ecosystems in terms of their spatial arrangement, hydrology regime, and ecosystem processes (Mitsch and Gosselink, 2015). The Canadian Wetland Classification System (CWCS) defines a wetland as being "…land that is saturated with water long enough to promote wetland or aquatic processes…and various kinds of biological activity that are adapted to a wet environment" (Tarnocai et al., 1988). Zoltai and Vitt (1995) expanded on the CWCS definition and created a classification of wetlands based on several attributes including abiotic characteristics (hydrology, water chemistry, minerology) and biotic characteristics (vegetation and soil). Five broad classes of wetlands were identified: Shallow Open Water, Marshes, Swamps, Bogs, and Fens. Peatlands (bogs and fens) in particular, are especially important to the carbon sequestration process and encompass the majority of wetland habitats in the Boreal region of North America (Warner and Asada, 2006).

Peatland Formation

Peatlands, which cover approximately 23% of the boreal landscape, first began to develop in the Boreal Zone 8000 years BP, after the retreat of glaciers from the last ice age (Koropchak et al., 2012). Previous research and plant macrofossil collection from natural fens in the Boreal Zone suggested three possible peatland formation hypotheses (Koropchak et al., 2012):

1) Peatlands were formed from what were originally terrestrial ecosystems that filled in waterbodies
2) Peatlands were formed in habitats containing mineral soil dominated by *Carex*-like plant community
3) Peatlands were formed in areas of moist soil that underwent paludification

Core samples taken from the fens provided records of plant development patterns and soil composition that suggested the most likely method of peatland formation in the boreal region of northern Alberta was through paludification of mineral soils (Koropchak et al., 2012).

Paludification is the process of peatland development by which bog wetlands begin to cover terrestrial habitats that have a mineral soil base, which typically occurs in times of climate change or habitat reconstruction (Glazer, 1987; Lavoie et al., 2004). Along with paludification, two primary processes are needed for the development of peatlands: positive water balance and peat production (Mitsch & Gosselink, 2015). A positive water balance occurs when precipitation exceeds a wetland's evapotranspiration, resulting in moisture accumulation in the ecosystem. The balance between water gains and losses in the system partially determines whether a water table occurs at or near the surface of the soil. Saturated soil is anoxic, and this limits rates of vegetative decomposition. Persistent anoxic conditions result in the gradual accumulation and sequestration of particulate carbon (detritus) in the system, which ultimately transforms into peat, contributing to hydrological stability to the ecosystem.

Fen Characteristics

Fen peatlands are considered to be transitional wetlands between marshes and bogs, and as such have intermediate abiotic and biotic characteristics (Mitsch & Gosselink, 2015). Water sources of fens consist primarily of groundwater and precipitation, resulting in a higher nutrient input than bogs, which derive almost all of their water from precipitation (Vitt, 1990). The mobile characteristics of the ground and surface water within a fen allows for higher nutrient input opposed to the lower nutrient concentration found in bog peatlands (Mitsch & Gosselink, 2015). The soil chemistry of fens is often influenced by the soil minerology, which in turns affects the pH and can lead one to classify a fen as ombrotrophic (acidic, low nutrients) or mesotrophic (more basic, moderate nutrients) (Zoltai & Vitt, 1995). In addition to pH, salinity is a key gradient in fen classification as it influences the floral community present in fens (Parida, 2004; Purdy et al., 2005).

One of the more straightforward means of classifying wetlands is by its vegetation (Slack et al., 1980; Vitt et al., 1995). Slack et al. (1980) surveyed fens in western Alberta, summarizing water chemistry attributes and plant composition to create an inventory of wetland vegetative communities and the abiotic conditions under which they are found. Subsequent studies have augmented the knowledge of these community patterns in peatlands (Warner & Asada, 2006; Zoltai & Vitt, 1995; Trites & Bayley, 2009; Vitt et al., 1995; National Wetlands Working Group (NWWG), 1997). Drier fens support shrubby plants, *Betula, Salix,* and *Larix* spp., and black spruce *Picea mariana*. Fens with the water table at the surface are characterized by graminoid vegetation (sedges) and bryophytes (mosses). Sites with low concentrations of dissolved minerals are commonly found to

support *Sphagnum* mosses. Fens rich in minerals tend to be dominated by sedges and brown mosses, as well as shrubs if they can be supported (NWWG, 1997).

Invertebrates

The vegetative community of boreal fens and other wetlands supports a variety of aquatic and semi-terrestrial peatland invertebrates (Danks & Rosenberg, 1987). However, research on the association between the vegetation and invertebrates of these plant communities in unclear. Andow (1991) attempted to explain plant-invertebrate interactions using multiple hypotheses concerning agricultural uses, monocultures, and polycultures. Brose (2003b) and Schaffers et al. (2008) independently compared top-down and bottom-up controls, respectively, in the context of plant-invertebrate interactions and found that no one hypothesis was able to explain all attributes of the relationship. Williams (2014) studied the differences between the invertebrate community composition in fens and the wet meadow zone of NE Alberta marshes and found that on average, marshes support a higher species diversity than fens. In general, relatively little research has focused on the attributes of the ecosystem as a whole that may influence the composition of the invertebrate community.

The diversity of soil-dwelling invertebrates and their relationships to additional soil attributes has been studied in grasslands (Yeates, 1997; Coupe et al., 2009), aquatic habitats (Cespedes et al., 2013), terrestrial forests (Kappes et al., 2008), and wetlands (Batzer, 1996; Heino, 2000). Davis et al. (2006) explored the relationship between invertebrates and abiotic soil factors, namely soil moisture, elevation, and nutrients. Over multiple sampling seasons, the authors showed that the most important abiotic factors influencing invertebrate presence are soil moisture content and soil nutrients (N, P, K, and organic matter). Higher

moisture content was associated with lower elevations and Tipulidae (crane flies), Staphylinidae (rove beetles) and Acari (mites). The lower elevations were also associated with higher nutrient and organic soil content.

Oil Sands Mining in Northern Alberta

One of the most prevalent ecological issues in the Boreal region of Alberta is the mining of oil sand deposits and the resulting ecological disturbance. Alberta is home to three major oil sand deposits that cover approximately 14 million ha of boreal forest, with 29% of this land being peatland (Wielder et al., 2012). Approximately half of this land has the potential to be disturbed through oil sand open pit mining (Wielder et al., 2012). Open pit mining involves the removal of all surface vegetation and overburden soil material to a depth of up to 100 m, in order to expose the oil sand deposit below (BGC Engineering, 2010). These near-surface oil sand deposits account for the majority of oil production and have the largest long-term impact on boreal ecosystems through environmental alteration (Johnson & Miyanishi, 2008). Consequently, the companies are required as a condition of their mining permits to restore 'self-sustaining, locally common boreal forest' (Johnson & Miyanishi, 2008; Government of Alberta (EPEA), 2014).

Most previous reclamation projects in the Athatbasca Oil Sands Region have focused on restoring upland boreal landscapes (Johnson & Miyanishi, 2008; BGC Engineering, 2010; Pinno & Hawkes, 2015). MacDonald et al. (2012) advocated for the accelerated establishment of closed canopy trees in reclaimed boreal forest, facilitating carbon input into base soils. This in turn, provides nutrients that stimulate natural vegetation growth. Recently, reclamation projects have used a "LFH" soil base in order to maximize the growth rate of plants through revegetation processes (Naeth et al., 2013).

"LFH" refers to the three top horizons present in the soil. The top layer of LFH soil, 'Litter', comprises of fresh organic material, with little to no evidence of plant material decomposition. The middle layer, 'Fermented', contains organic material that is moderately decomposed, with the origin of the material still discernable. Finally, the deepest layer, 'Humus', is dominated by well-decomposed organic matter, which provides the majority of nutrients in the soil. The organic constituents include material at various stages of decomposition, plant roots, and seed propagules.

Although upland boreal landscapes have been successfully established in the Athabasca Oil Sands Region (AOSR), concern still arises with respect to the immense carbon loss caused by the destruction of wetlands and peatlands associated with land clearing for open pit mining practices (Johnson & Miyanishi, 2008; OSWWG, 2000; Rooney et al., 2012). As new landforms have become available for reclamation (such as the landscape provided by refilled in-pits), the focus of reclamation strategies and research has shifted from development of forested areas to creating wetlands, which constitute the dominant landform type in the AOSR (NWWG, 1997). Several full-scale wetlands and contributing watersheds have recently been constructed, monitored and researched in an attempt to understand the applications and processes needed to re-establish productive and self-sustaining wetlands (Daly et al., 2012; Wytrykush et al., 2012; Borkenhagen & Cooper, 2015). More recently, an emphasis on the feasibility of creating fen watersheds has been included for consideration in mine closure plans (BGC Engineering, 2010; Price, 2010). Sandhill Fen, located outside of Fort McMurray, AB (Figure 1.1), is one such watershed, and is the focal study site of this project.

Project Introduction

The Sandhill Fen Watershed is constructed on top of what was once Syncrude Canada's East In-Pit Mine, which was active from 1977 to 1999 (Wytrykush et al., 2012). The watershed was constructed on top of approximately 35 m of consolidated tailings and tailings sand layers (both by-products of the extraction process), covered by approximately 10-m of tailings sand cap, and is approximately 1000 m by 500 m in area (Syncrude, 2008; Figure 1.1). Sloped hummocks (hills) were constructed to promote the flow of water from higher elevations towards the central basin. The entire wetland area and some hummocks were covered with clay-till overburden material to provide a mineral soil base, with LFH soil covering hummocks and upland sites and peat placed to provide organic soil for wetland initiation in a central basin (Wytrykush et al., 2012). Peat used in this construction was salvaged during the mining process from wetlands, dried and stockpiled for use in construction purposes. Stockpiled peat differs from peat found in natural peatlands in that water drains from the organic matter, allowing the material to dry and be harvested for later use. Natural peat, found in peatlands, forms from organic material in a water-saturated environment that has accumulated over a long period of time (Government of Alberta, 2016). Fresh water used to initially provide water for the establishment of the wetland basin was supplied by pipeline from a near-by lake (Mildred Lake) and stored in an adjacent pond where it is available to be released via a porous dam into the wetland itself as needed. This creates a possible moisture gradient, with soil moisture content increasing east to west along the wetland, and increasing from high elevations to low elevations down the hummocks. An underdrain system was designed to control the water

table level in the wetland as necessary to minimize upwelling of saline tailings sand groundwater into the peat layer. .

In collaboration with 5 other universities, the University of Windsor has been an integral part of designing and monitoring the reclamation efforts of the Sandhill Fen Watershed (BCG Envineering Inc. 2010), especially with respect to documenting the aquatic invertebrate colonization and early community development. My research addresses the accrual and establishment of terrestrial and semi-terrestrial invertebrates within the Sandhill Fen Watershed with respect to the dominant environmental gradients likely to determine community composition.

My thesis poses three main questions:

1) What environmental variables influence the terrestrial and semi-terrestrial invertebrate community composition of the Sandhill Fen watershed?
2) Can variation in invertebrate community composition be detected along gradients of the Sandhill Fen watershed?
3) How do invertebrate communities in the constructed fen compare to communities in reference fens in the area?

The first chapter of this thesis focuses on the major soil-associated environmental variables and their variation with the Sandhill Fen Watershed. The variables studied are soil chemistry, soil nutrients, soil type, and vegetation, which are important factors in assessing the condition of productivity of a restored landscape for invertebrate development (Davis et al., 2006).

Soil chemistry measurements focused on the soil moisture content, soil salinity, and soil pH, which are important determinants of plant growth and productivity. Soil moisture content regulates both plant establishment and growth (Slack et al., 1980; Bridge and Johnson, 2000) and invertebrate colonization (Davis et al., 2006). Sites with high moisture content (hygric to hydric soils (Ducks Unlimited, 2001)) support flora whose roots can cope with anoxia, such as *Carex sp.,* and semi-terrestrial invertebrates. The salinity of the soil is important in plant growth and productivity as it greatly influences the plant community (Parida, 2004). Purdy et al. (2005) researched the effect of soil salinity in natural and reclaimed wetlands in the oil sands region. They found that there was a large salinity range among the wetlands studied, and that plant species distributions were highly correlated with soil salinity. Soil nutrients (nitrogen, phosphorus, and potassium) are important in nutrient cycling and commonly used to assess soil condition because of their ability to limit or enhance plant growth (Verhoeven et al., 1994). Additionally, soil nutrients regulate the composition of microflora and fauna. As mentioned above, the predominant soil types used in construction of the Sandhill Fen were an "LFH-mix" in upland areas, and peat in the lower-elevation (wetland) portion of the watershed, typical of a natural, Boreal wetland watershed. The environmental variables of sites with both soil types were measured. Finally, the plant community in a specific location influences the resident invertebrates, as they are dependent upon vegetation for food and refugia.

The second chapter of my thesis identifies the invertebrate assemblages and their distribution within the watershed. Groupings of invertebrates across the fen were assessed and compared to the measured environmental gradients. Root's study (1972) and Andow's review (1991) highlighted the effects of high plant species richness on the invertebrate

species richness. Support for these hypotheses would see such a pattern occurring in the Sandhill Fen Watershed, where areas with high plant species richness would correspond with high invertebrate species richness. Additionally, Davis et al. (2006) and Sanderson et al. (1995) suggested that moisture content and salinity soil patterns would correlate with the presence of specific invertebrate taxa, which was also explored in this chapter.

The third data chapter of my thesis describes variation in soil-associated environmental variables and invertebrate community composition among naturally occurring fens in the Fort McMurray area, which can serve as a reference condition against which to evaluate the biota of the Sandhill Fen Watershed. I compared the invertebrate communities, environmental variables, and plant communities of Sandhill Fen Watershed to those of the reference fens to determine the degree to which Sandhill Fen components mimic natural analogues.

My final chapter summarizes and integrates my findings, outlines the study limitations and proposes future research questions. Taken together, the data gathered document key invertebrate species associations, illustrate how assemblages are distributed along environmental gradients in a newly developed watershed and how the invertebrate assemblages of the Sandhill Fen watershed compare to those found in natural areas with similar vegetative and soil influences. This project is significant and unique in providing a coordinated inventory of aquatic, semiaquatic and terrestrial peatland invertebrates and an evaluation of their association with key environmental covariates early in the succession of a constructed landscape.

Figure 1.1: Google Earth image of Sandhill Fen Watershed. Site measures approximately 17hectares. Red bar measures approximately 50 m.

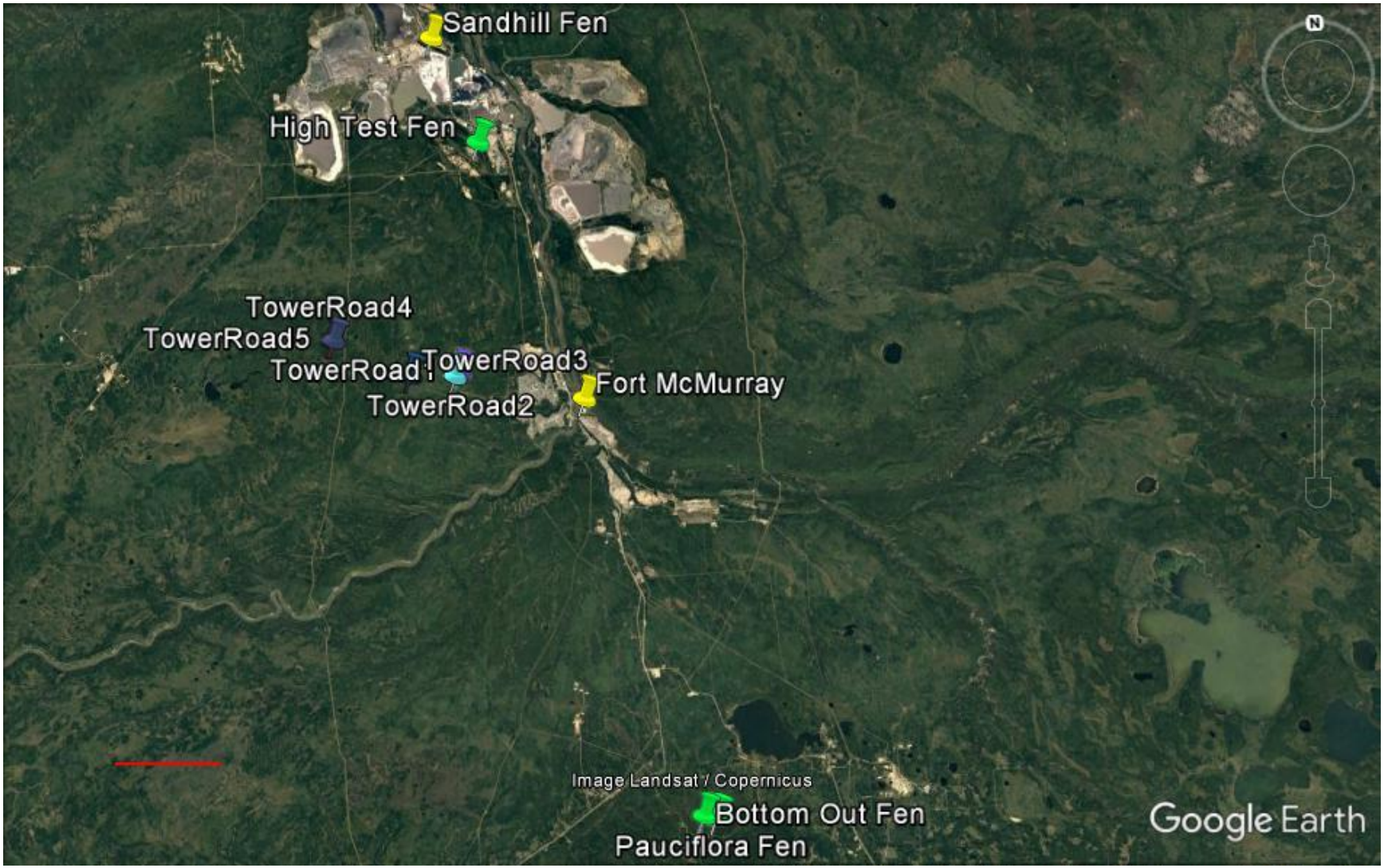

Figure 1.2: Google Earth image of reference sites, Sandhill Fen, and Fort McMurray. Red bar at bottom left represents approximately 10km.

Chapter 2 – Spatial patterns of key hydrological and soil chemistry factors within Sandhill Fen Watershed

Introduction

Hydrology and hydrogeology are perhaps the most important drivers in the creation and establishment of wetlands, influencing landscape features and modifying the physiochemical properties of the soil and water (Mitsch & Gosselink, 2015). To facilitate the assessment and research of wetlands, the Canadian Wetland Classification System (1997) was developed to categorize wetlands based on the characteristics of hydrology, soil and water chemistry, and biota (Zoltai & Vitt, 1995).

Hydrology determines soil moisture, which influences decomposition processes within wetlands by creating aerobic (unsaturated soil) and anaerobic (saturated soil) habitats (Mitsch & Gosselink 2015). Most fen wetlands tend to be ecotones between a body of water, such as a lake or marsh, and drier upland areas, which often guide subsurface flow of water into the fen itself (CWCS 1997). The lateral flow of water into the fen from surrounding areas introduces additional water and nutrients, which may affect the physicochemical environment (Mitsch & Gosselink 2015). Because nutrients move with water, it is predicted that moisture gradients across a wetland will result in parallel nutrient and vegetation gradients, which will be discussed later in this thesis.

Along with soil moisture, gradients in salinity also exist. Zoltai & Vitt (1995) highlight how salinity constrains biotic communities of fen wetlands. Fens with highly saline water tend to support plants that are salt tolerant, like brown mosses and sedges (Parida, 2004; Zoltai & Vitt 1995), but those that are low in salinity, are typically characterized by the presence of *Sphagnum* mosses (Slack et al, 1980).

Nutrient gradients also exist and are important for creating different redox environments and for nutrient cycling (i.e. carbon, phosphorus and nitrogen; Zoltai & Vitt, 1995; Mitsch & Gosselink, 2015). Nitrogen is typically a limiting nutrient in wetlands because of its role in the oxidation of wetland organic material (Mitsch & Gosselink, 2015). Because water levels fluctuate within these wetlands, anaerobic (reducing) or aerobic (oxidizing) conditions can occur, which result in different soil nutrient composition and processes. Much like nitrogen, phosphorus is a limiting nutrient within a wetland because of its ability to bind with calcium, iron and aluminum (creating inorganic compounds), its binding with organic matter. Both the inorganic and organic forms are bioavailable to plants (Mitsch & Gosselink, 2015). Less research has focused on the prevalence and importance of potassium in wetland soil chemistry. Potassium is important in osmoregulation, enzyme activation and carbohydrate pathways in plants (Ericsson, 1993).

The distribution of soil moisture and chemistry (nutrients and salinity) creates a mosaic of unique microhabitats and resulting in heterogeneous distribution of floral and faunal communities (Mitsch & Gosselink, 2015). Although these factors have been studied extensively in natural wetlands, less is known about the interactions of moisture, nutrients and salinity gradients, and their independent and interactive effects within a constructed wetland or watershed. The construction of wetlands in the oil sands region of Alberta is focused on restoring a landscape to equivalent land capability relative to its condition prior to mining in the area (Government of Alberta, 2014). Although study wetlands have been created explicitly for research purposes in the oil sands post-mining landscape since the 1990s, most have been hydrologically isolated marsh-like ponds, designed to assess the residual toxicity of fine fluid tails (FFT) and other mining byproducts to support design of

end-pit lakes (Kovalenko et al. 2013). However, recent investigations have endeavoured to construct wetlands that are hydrologically stable with potential to develop into fens contained within a constructed watershed (Wytrykush et al., 2012). The Sandhill Fen Watershed is the first operational scale watershed constructed explicitly to support a wetland. It has been extensively studied since its creation in 2013.

This study summarizes and interprets baseline information on the water, soil and plant characteristics and their distribution in the Sandhill Fen watershed during the first 3 years since its creation. The objectives are to:

1) Identify the important environmental variables within the watershed and their gradients
2) Assess the effect of placed soil substrate on soil moisture content, soil pH, soil salinity and nutrients (N, K, P)
3) Assess the associations between the environmental variables and plant community composition within the watershed

The Sandhill Fen Watershed was designed to ultimately consist of a mesic-to-dry upland region expected to become forested, and a sub-hygric fen basin. Consequently, four types of soil were placed the watershed's mineral substrates, two of which were studied in this project –a forest topsoil (litter/fermentation/humic layers; LFH) on uplands zand peat excavated from a nearby fen in the low areas (BGC Engineering, 2010). The important factors that I assessed were soil moisture content, soil salinity (measured as electrical conductance (EC)), soil pH, and nutrients nitrogen, potassium, and phosphorus. The fen basin, which consists of a clay layer overlain by wetland surface soil (peat) will have higher moisture content (due to its ability to hold water) than the LFH placed in upland

areas, as per design. It is predicted that peat substrate would have higher moisture content than LFH both because of its location and because of its ability to hold water. Peat areas will also contain relatively low concentrations of all nutrients, which is typical of fen wetlands (Vitt, 1990). Finally, the peat sites and LFH sites are each expected to support unique plant communities because of their differential physicochemical and hydrological components and prescribed vegetation planting within the upland and centre wetland areas (J. Piercey, Syncrude Canada Ltd., personal communication). Ultimately, this research relates to the overarching question addressed in construction of the Sanhill Fen given the limited availability of water in the Oil Sands region, can landscapes can be built that support both wetland development and forest productivity at the same time?

Methods

I measured the distribution of several hydrological and chemical variables that typical contribute to both the plant and invertebrate compositional fauna of wetlands. Soil characteristics were measured at locations corresponding to sites where invertebrates were sampled to identify gradients, and determine their influence on plant community. Additionally, multiple environmental variables were assessed to determine their importance within the Watershed, their gradients, and the effect of soil type on these variables and the plant community. The plant community was further studied to determine the variation of species distribution within the watershed.

Soil Sampling and Associated Environmental Variables

The objective of the soil sampling was to identify potential environmental gradients within the fen. Sampling locations were selected based on a stratified-random design across longitudinal zones of the watershed. Sites included both peat and LFH soil bases in the wetland and in the upland hummocks. Sites were surveyed using the sampling methods identified in the previous chapter and soil samples collected during the summer of 2016. Soil (300-500 g) from each site was collected using a trowel from the top 10 cm of each of the forty sites across the watershed and stored frozen in Ziploc polyethylene bags until analysis. Soil was collected from relatively bare patches at each site to minimize the amount of roots contained in the sample bag. Soil samples were thoroughly mixed within the bag to homogenize the contents. Roots, rocks, and other debris were handpicked from the samples before testing occurred. Moisture content, soil electrical conductivity, soil pH and nutrient concentration (nitrogen, potassium, and phosphorus) were determined from each sample at Syncrude's Mildred Lake Environmental Research laboratory, the specific methods are outlined below.

Moisture Content

Moisture content was determined by weighing 20-40 g subsamples of fresh soil into a numbered aluminum weighing tray, which was dried an oven at 40 degrees C for 48 h, and then weighed again. Moisture content was calculated by dividing the water weight of the sample (wet sample (g) – tray (g)) by the dry weight of the sample (dry sample (g) – tray (g)), following the methods prescribed by Craze (1990).

Soil Salinity

Soil salinity was measured by creating a solution of soil and deionized water (DI) in a 1:5 soil:water ratio (typically 10 g of soil in 50 mL of water), adapted from the methods of Hardie and Doyle (2012). The solution was then left to settle for 30 min and measured using an EC probe (Fisher Scientific Accumet XL50). This method measures the ability of the soil to conduct electricity. Soil salinity was characterized by inferring the specific conductance of the pore water from the soil sample.

Soil Nutrients

Soil nutrients were measured using a soil testing kit and a solution of the same soil to DI water ratio (1:5) as was used to estimate EC. Testing kits (1601 Rapitest Soil Test Kit) were acquired from Luster Leaf Garden Products (Woodstock, IL). The soil solution was placed into each testing compartment (one for each nutrient test), mixed with a chemical indicator, and left to develop colour for 10 min. Once colour developed, it was compared to a standard scale ranging from 0 (depleted) to 4 (surplus), and recorded. Soil pH was measured using a testing compartment filled with soil, a chemical indicator, and DI water in a 1:4 soil:water ratio. The compartment was shaken and colour left to develop for one minute. Soil samples were then brought back to the University of Windsor for possible future detailed analysis.

Plant Species Identification

Plants located within a 1m radius of each sampling point were identified to species, and were assessed on a presence/absence basis. The number of plant species within the sampling area was recorded.

Statistical Analysis

In order to assess the significance of the environmental variables measured, data were analyzed at the site level, and then by soil type. SPSS 24 statistical software (IBM Statistics, 2016) was used for the analyses, unless stated otherwise.

Environmental Variables

Arithmetic means and standard errors of environmental variables were calculated using data collected from the 40 sites across the watershed (Table 2.1). Simple Pearson correlation coefficients among variables were calculated to summarize relationships between the variables. Principal Components Analysis (Varimax rotation of the correlation matrix) was used summarize variation among sites within the watershed. Cluster analysis (Ward's method applied to squared-Euclidean distances) was performed to identify groups of sites with similar environmental characteristics across Sandhill Fen. When clusters were identified, between group: within group F-ratios were calculated to identify the environmental variables that contributed most to the differences (Green & Vascotto 1978).

Assessing the effect of Soil Type on Environmental Variables

The 40 sampling sites across the fen were classified according to their soil type - either peat or LFH. The mean values of principal component scores from samples collected

from each soil type were compared using *t*-tests. A Bonferroni correction for multiple testing was employed.

Assessing the effect of environmental variables on plant community composition

The mean number of plant species per sample site (richness) was determined for each soil type and compared using a *t*-test. The relationship between environmental variables and plant species richness for all sites was evaluated using multiple regression analysis. The dependent variable was plant species richness and the independent variables were the factors scores calculated from the first two principal components of the PCA. Additionally, soil type (peat=1, LFH=0) was included as a dummy variable. Finally, a one-way ANOVA was used to identify whether there were differences in the frequency of occurrence of key plant species between soil types.

Results

Soil Characteristics

Six variables associated with soil were measured within Sandhill Fen: soil moisture, salinity, pH, and nutrient levels of nitrogen, potassium, and phosphorus (Table 2.1). Highly significant correlations were found to occur among soil moisture, salinity, and soil pH. Additional significant correlations were found between salinity and both phosphorus and soil pH (Table 2.2).

Table 2.1: Arithmetic mean ±SE of environmental variables for all sites and based on soil type (ND=nondetectable).

	All Sites (n=40)	**Peat (n=17)**	**LFH (n=23)**
Potassium (K)	2.0±0.15	2.1±0.17	2.0±0.22
Nitrogen (N)	0.2±0.1	ND	0.4±0.14
Phosphorus (P)	1.5±0.1	1.8±0.22	1.3±0.13
EC (uS/100)	5.51±0.37	7.57±0.57	3.98±0.06
Moisture (g/g)	1.23±0.25	2.59±0.38	0.29±0.11
pH	6.79±0.09	6.47±0.14	7.02±0.09

Table 2.2: Pearson Correlations of Environmental Variables (n=40; *p<0.05; **p<0.01).

	K	**N**	**P**	**EC**	**pH**	**Moisture**
K	---	0.151	0.089	-0.034	-0.241	0.05
N		---	-0.127	-0.273	0.018	-0.181
P			---	0.355*	-0.251	0.302
EC				---	-0.339*	0.660**

pH					--	-0.491**

Table 2.3: PC loadings of environmental variables. Bold-face values indicate association with PC axis (See Appendix B for site loadings)

	PC1	PC2
Moisture	**0.84**	-0.07
Soil Salinity (EC)	**0.81**	-0.28
Phosphorus	**-0.70**	-0.37
pH	**0.59**	0.01
Potassium (K)	0.19	**0.78**
Nitrogen (N)	-0.30	**0.67**
Eigenvalue	2.32	1.27
Variation Explained (%)	38.6	21.2

The PCA extracted 2 axes with eigenvalues greater than 1, which explained approximately 60% of the variation (Table 2.3). Soil moisture, soil salinity, soil pH and phosphorus were associated with PC 1, and potassium and nitrogen concentrations were associated with PC 2. Peat-dominated sites had consistently higher PC1 scores than did LFH-dominated sites (Figure 2.1; t=20.475, p<0.0001). Sites with LFH soil exhibited a broader range of PC2 scores than did peat-dominated sites, but the mean scores of PC2 did not differ significantly by soil type (t = 0.876, $p>0.05$)

The cluster analysis of soil characteristics identified 2 main groups of sites (1 and 2; Fig. 2.2) one of which was apparently constituted of two sub groups (1A and 1B). Group 1 sites differed from those in Group 2 based in having higher pH (ANOVA F=24.47) and lower values of phosphorus (ANOVA F=10.99), soil salinity (ANOVA F=49.36), and moisture content (ANOVA F=75.38) (Table 2.1). Groups 1A and 1B differed in terms of nitrogen levels (F=147.692), with Group 1B containing sites with higher levels (Table 2.1 and Appendix B).

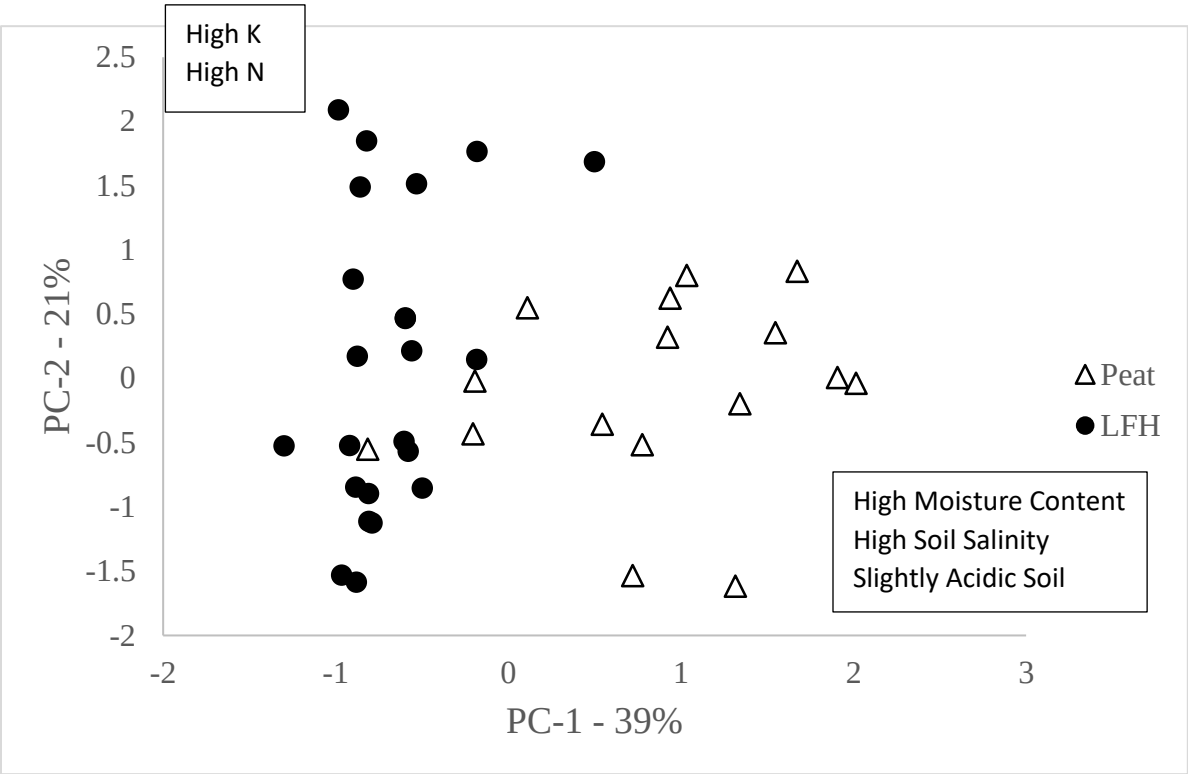

Figure 2.1: Principal Component results of environmental variable site loadings (n=40), plotting PC1 and 2, with loading descriptions.

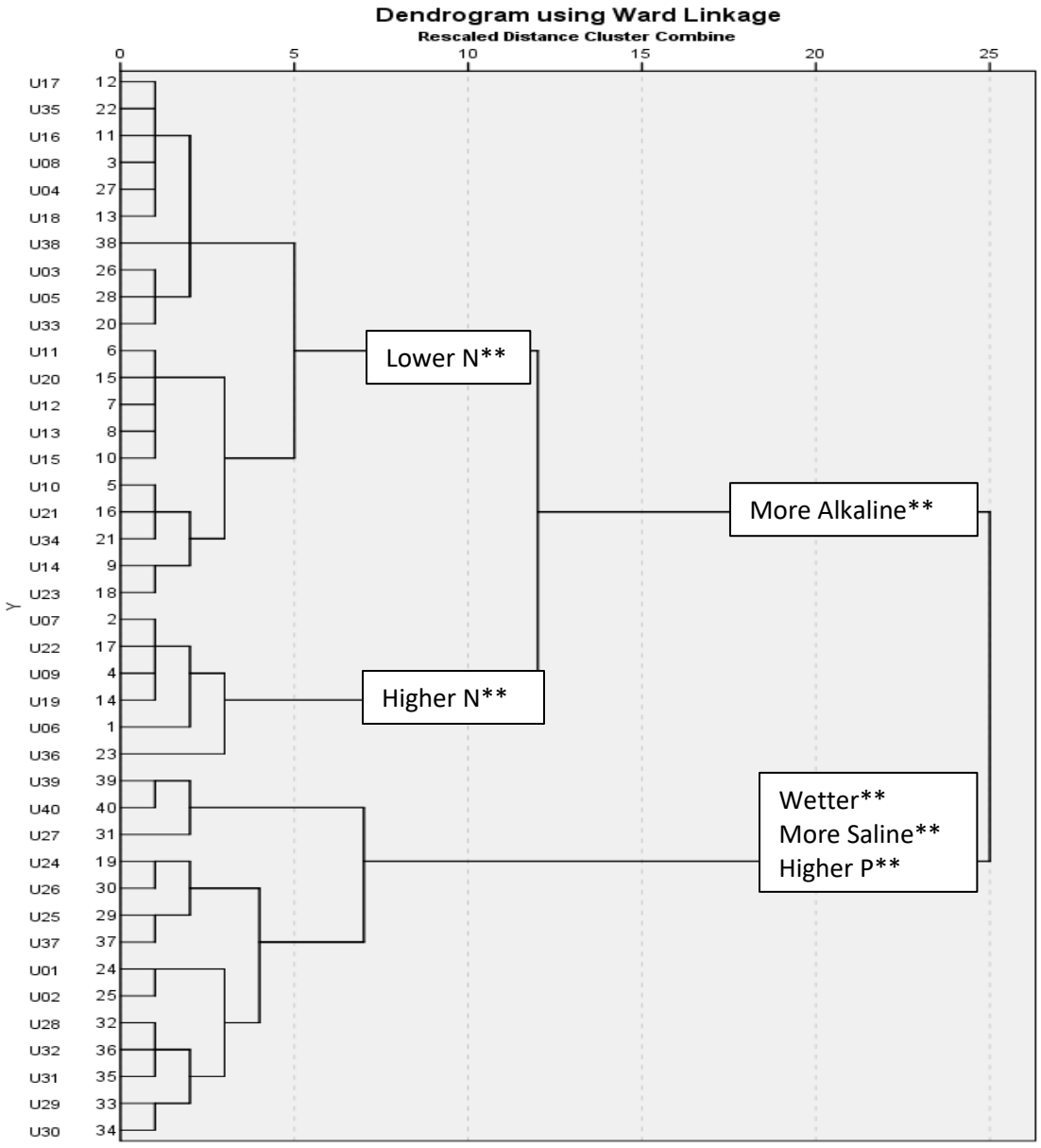

Figure 2.2: Dendrogram of sites (n=40) based on six environmental variables (*p<0.05; **p<0.01).

Vegetation Characteristics

Twenty-five plant species were identified among the 40 sampling sites. The mean ±SE of plant species per site was 2.8 ±0.22. The relationship between soil-associated environmental variables and plant richness was assessed using multiple regression analysis, once again using the PC scores and soil type as independent variables. The multiple regression model was overall non-significant ($p<0.089$) with PC1 and PC2 being non-significant in their influence of plant species richness (Table 2.4). However, the soil type had a marginally significant influence on species richness ($t=-2.068$, $p<0.046$; Table 2.5). According to the model, sites with LFH had 1.3±0.64 more species than sites with peat substrate (accounting for differences in soil characteristics associated with PC1 and PC2).

Several species differed in presence according to soil type (Table 2.6). In particular, cattails (*Typha latifolia*) and sedges (*Carex* spp.) were found only in sites that contained peat, and sow thistle (*Sonchus arvensis*), alfalfa (*Medicago sativa*) and strawberry (*Fragaria vesca*) were found in sites containing LFH soil.

Table 2.4 ANOVA table of multiple regression results

	df	MS	F	Sig.
Regression	3	3.187	2.349	0.089
Residual	36	1.357		
Total	39			

Table 2.5: Summary of multiple regression analysis relating soil characteristics to plant species richness. *=p<0.05

Variable	Reg Coeff	SE	t-value	Sig.
Intercept	2.862	0.328		
Soil Type	-1.322	0.640	-2.068*	0.046*
PC1	0.266	0.317	0.839	0.407
PC2	-0.252	0.191	-1.314	0.197

Table 2.6: ANOVA comparison of significant differential plant species presence between soil type

Plant Species	F-value	Soil Type Present In
Fragaria vesca	7.07*	LFH
Medicago sativa	8.61**	LFH
Carex sp.	71.01**	Peat
Typha latifolia	31.214**	Peat
Sonchus arvensis	10.38**	LFH

Discussion

The goal of this chapter was to identify the important environmental variables within the Sandhill Fen watershed, assess the spatial gradients of these variables, and compare the resulting plants communities that occur because of these gradients. I had predicted that the soil characteristics would differ according to soil type and that peat would have a higher soil moisture content than LFH. However, this was found not to be completely the case. Principal Components Analysis indicated that sites were organized according to two major gradients - a moisture gradient summarized by PC1 and an independent gradient (PC2) with which the nutrients nitrogen and potassium were associated. The variables associated with the moisture gradient are typically correlated with each other, with moisture and soil salinity increasing and pH decreasing (Alvarez Rogel et al. 2001). Thus, sites that have high scores on the PC1 axis are sites that were salty, wet, acidic and enriched in phosphorus. In wetlands, as precipitation flows over the soil, nutrients are dissolved in the water and settle or bind to soil where water flow ceases (Mitsch & Gosselink, 2015). This would lead to an expectation that all nutrients would act similarly, but they do not. In the case of Sandhill, precipitation and subsurface water running down the hummocks results in the basin soil having a higher moisture content and higher phosphorus content than soil at the top of the hummock. Greater moisture and higher phosphorus concentrations are manifested as greater concentrations of phosphates and orthophosphates in the soil. Phosphates are taken up by plants and used, leaving extra hydrogen in the soil, making the soil more acidic (Mitsch & Gosselink, 2015). The difference in soil type may be the reason for the differential nutrient gradients of phosphorus loadings with moisture and potassium and nitrogen loading independently.

Compared to LFH, peat has a higher proportion of organic material, which has high moisture retention capacity, but is poorly buffered. NorthWind's soil survey reported on the mean±SE of Total Organic Carbon (TOC) values of both LFH soil prescriptions and peat sites (LFH 'a/b': 1.6±0.06, LFH 'd': 4.3±0.90, peat: 15.7±2.2; % dry weight). The placement of peat in the lowest-elevation portions of the fen accounts for the associated soil characteristics of being wet, saline, and slightly acidic relative to the drier upland sites. The plant species that are adapted to these conditions would only be able to grow there, typical wetland plants. These plants are able to withstand a higher concentration of salt and moisture content than other vascular plants, and the prediction was supported by the results comparing plant communities among soil types. When the plant species composition was explored, it was found that *Carex* sp. and *Typha latifolia* were found only in peat sites. Both *Carex* sp. and *T. latifolia* are plants tolerant of an increased salinity measurement in wetlands (Mollard et al., 2011), and are typical wetland plants. The differential plant community composition can also be attributed to the plant prescriptions that took place in the watershed. Typical upland plants, such as jackpine, aspen and white spruce, were planted in the LFH soils, and wetland plants, including *Carex* spp., were seeded in the wetland portion of the watershed.

Sites whose PC1 scores were negative had LFH soil, which was is dry, had lower salinity, and was slightly alkaline compared to peat sites. These areas were situated along the periphery of the wetted portion of the fen, and on the hummocks (Vitt & Bhatti, 2012). The dry, porous soil, in these locations supported a completely different (meadow-like) plant community (indicative of an upland or forested community) than was found on the peat soil sites.

Although PC2 explained approximately 21% of the variation among sites across the watershed, this component was not related to soil type. However, the high nitrogen sites were interspersed with sites characterized by low nitrogen across the upland portion of the Sandhill Fen.

Conclusion

The construction goals of the Sandhill Fen project were to test technology for the reclamation of soft tailings deposits and to determine reclamation techniques conducive to initial fen development over time (Wytrykush et al., 2012). Presently, the watershed is still in its infancy in terms of successional processes involving hydrology and the physicochemical components that establish in a fen wetland; however, the patterns of moisture and nutrients observed the fen reflect its topography and are similar to those reported for the majority of natural fen watersheds (Alvarez Rogel et al. 2001). The presence of typical terrestrial plants in upland (LFH) sites and wetland plants in lowest-elevation (peat) sites is in accordance to what was predicted.

Chapter 3 – Invertebrate Community Composition and Distribution in the Sandhill Fen Watershed

Introduction

The landscape of northern Alberta's boreal zone is characterized by the broad extent of wetlands, which encompass approximately half of this natural landscape (Rooney et al., 2012) and sequester approximately one-third of the stored carbon available on Earth, making them highly productive (IPCC, 2007). Wetland ecosystems are in turn highly variable because of the combination of terrestrial, semi-terrestrial, and aquatics habitats, each with their own biotic composition (Mitsch & Gosselink, 2015). Peatlands, bogs and fens, have been studied to and delineate patterns of nutrient composition (Zoltai & Vitt, 1995; Trites & Bayley, 2009), hydrology patterns (NWWG, 1997), vegetation composition (Vitt et al., 1995; Slack et al., 1980; Warner & Asada, 2006; Smith et al., 2007), and invertebrate composition (Rosenberg & Danks, 1987; Williams, 2014).

As previously mentioned (Chapter 1: General Introduction), several hypotheses have been proposed to explain how invertebrate assemblages are organized within communities. Root (1972) suggested that monoculture plant communities can support high abundances of a single species (Resource Concentration Hypothesis). Andow (1991) advocated the Diversity-Stability Hypothesis (Goodman, 1975), arguing complex communities are more stable across time and space than simple communities. For example, a polyculture plant community (multiple species) is expected to support a more diverse invertebrate community than a monoculture community will. Haddad et al. (2001), also found support for this theory in their experiment on plant functional group richness and its effect on invertebrate species richness. Additionally, the question as to whether

communities function through top-down (herbivorous invertebrates affect plant community richness) or bottom-up (plant community composition and diversity affects invertebrate community richness) controls has been studied, with no definitive conclusions (Brose, 2003b; Schaffer et al., 2008).

Whereas plant communities are an essential structural component influencing the characteristics of invertebrate communities, the nutrients and soils that dictate plant community composition cannot be overlooked. Several studies have documented invertebrate community composition varies as soil factors change. Batzer & Wissinger (1996) highlighted the importance of wetland soil moisture and its effect on invertebrate communities. They observed that peatland invertebrate assemblages can be a mixture of both terrestrial and aquatic invertebrates depending on the amount of water and its duration or seasonal presence in a habitat. Pekar & Lubin (2003) studied the importance of a habitat's soil type in predicting the species present in that habitat. Plant species are also influenced by the abiotic soil factors. Lilles et al. (2010) studied how plant community composition changed along a soil salinity gradient, and found that some plant species, thought to be intolerant to high salinities, could grow in areas with saline soil and groundwater. As well, Verhoeven et al. (1994) studied the nutrient composition of wetlands in both North America and The Netherlands and highlighted differences in the nutrients based on the soil type of the wetland (mineral or peat based) and the resulting plant communities.

The recently constructed Sandhill Fen Watershed is an approximately 54 ha area situated on an in-pit tailings deposit. The watershed was constructed to help Syncrude develop reclamation practices for the promotion of wetlands in the closure landscape. The

watershed is comprised of upland hills that separate the growing trees and the surface water flows from the groundwater table. The groundwater is porewater releases from the soft tailings and is elevated in ions (especially sodium (Na)) leading to elevated conductivity. (Wytrykush et al., 2012). Soil prescriptions mirroring natural soil were used in its construction, consisting of placement of either a/b or d-ecosite LFH, or conventional peat-mineral mix in upland areas and recently harvested natural peat in the wetland area.Because the Sandhill Fen Watershed was built in a reclaimed area, it was anticipated that components of the Oil Sand Process Material (OSPM), (CT or tailings sand), and OSPW (oil-sands process water) would ultimately affect the soil and water chemistry of the wetland (MacDonald et al., 2012). Therefore, careful monitoring and study of the soil and its effects on the biotic organisms in the watershed is important.

The objective of this study is to document the composition of the terrestrial and semi-terrestrial invertebrate community in the Sandhill Fen Watershed and determine its relationship with soil-associated environmental variables, plant community composition and their corresponding gradients across the watershed. This objective was met through the identifying the invertebrate community composition in sampling locations distributed across the watershed, identifying the associated environmental features and plant community composition of the sites, and describing how the invertebrate community varies with respect to the key factors.

Because the community composition of invertebrates is complex, there are several predictions for this chapter:

1) Functionally distinct types of invertebrates will be caught with different trap methods, indicating the need for multiple traps during sample procedures

2) The composition of the plant community rather than soil-associated environmental variables (nutrients, soil type, moisture, EC and pH) will be the main correlate of invertebrate community composition,
3) Soil type will influence the plant community, resulting in distinct invertebrate community composition characteristic of LFH-dominate upland sites vs. peat-dominated low-elevation sites.

Methods

Invertebrate Collection

Because of the great diversity of habitats and the close association between invertebrates and their microhabitats, a variety of sampling methods are needed to provide a complete picture of the invertebrate community (Anderson et al. 2013; Doxon et al. 2010; Williams 2014). Traps vary in the effectiveness with which they capture and sample particular types of invertebrates, and relying on one sampling method can lead to biased conclusions of community composition. I used four methods to sample invertebrates in the Sandhill Fen Watershed in an attempt to sample all groups of invertebrate taxa: vacuum sampling (2014, 2015), sticky traps (2014, 2015), sweep net sampling, (2015) and pitfall traps (2014, 2015).

Pilot Study

In summer 2014, a pilot study was undertaken to determine efficacy of sampling methods. Twenty locations were chosen using a stratified random design across longitudinal zones of the fen. At each georeferenced "station" a suite of collection methods was used to sample the invertebrate community – vacuum sampling (Williams, 2014),

sticky trapping (Leonhardt, 2010), pitfall trapping (Pekar & Lubin, 2003), and sweep sampling (Doxon et al., 2010); all detailed in Chapter 3).

Invertebrates were enumerated and identified to lowest practical taxonomic level in the lab. After all samples had been processed, rarefaction species-abundance curves were generated to estimate asymptotic species richness and assess the adequacy of sampling effort. Calculations were performed using EstimateS v.9 software (Colwell et al. 2013). The analyses indicated that there was a need for more intensive sampling for summer 2015. Sampling methods were minimally altered for the summer of 2015, but sweep net sampling was added. A sweep net was used to randomly sample vegetation in the vicinity of each sampling "station" and increase the likelihood of collecting larger, less abundant invertebrates that may not have been captured in the vacuum sampler.

Vacuum Sampling

The vacuum sampler was created by modifying a design described by Hoekmann et al. (2012) to sample soil-dwelling invertebrates (Williams, 2014) using a Stihl© model SH87c leaf blower/vacuum (Stihl Incorporated Canada, London, ON). The exhaust blower tube was placed over the intake port to produce a high-volume suction device. A 30-cm sweep net bag (BioQuip Products, Rancho Dominquez, CA) was placed into the mouth of the vacuum's intake tube and secured with elastic bands to trap sample material and ensure that it did not reach the fan blades.

Following the methods of Williams (2014), a 38-L Rubbermaid Rough Tote© (bottom area 61cm x 40.6 cm) whose bottom had been removed, was placed on the ground and used to delineate a sampling area. The tube of the vacuum sampler was repeatedly

lowered and raised perpendicularly to ground level over all vegetation, covering the leaves and stems, within the delineated area to obtain invertebrates associated with the vegetation. Sampling time averaged 60-90 s. Subsequently, the vacuum unit was turned off, the sweep net removed and emptied into a labelled polyethylene freezer bag. All standing vegetation within the delineated area was clipped to soil level and removed. The vacuum sampler was then applied to the soil layer to collect soil-dwelling invertebrates. The sampling tube was "tapped" on the substrate approximately 20 times to sample the entire expanse of the area within the enclosure. The material retained in the sweep net was then emptied into a separate freezer bag. All samples were stored frozen at -20 degrees C until they were processed at the University of Windsor. This method was used at all sampling stations in both 2014 (n=20) and 2015 (n=20).

In the laboratory, the invertebrates were separated from the vegetation and organic debris prior to enumeration and identification. A sample was placed into a water-filled 46x28 cm metal pan for 30-45 minutes or until all materials were well wetted, and large pieces of vegetation were removed and discarded. The sample was then poured through a stacked series of 6 brass soil test sieves (4 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.09 mm apertures). The contents of each sieve were rinsed under running water to facilitate separation of the debris into size classes. The material retained on each sieve was then placed into a Petri plate. Invertebrates were then sorted from the debris beneath a dissecting microscope, identified to finest taxonomic resolution possible, and preserved in 70% ethanol for storage.

Aerial Sweep Sampling

Aerial sweep sampling was conducted in 2015 because it was found that the invertebrate data from 2014 were underrepresented in larger-bodied invertebrates that had been seen during sampling but not captured by other methods. Samples were collected using a sweep net with a 38.1 cm diameter opening for approximately 30 seconds within a 6-m radius of each sampling station. The sweeper passed the net over and through the vegetation while walking in a haphazard pattern. All material found in the net bag was transferred to a freezer bag and then frozen until processing.

Sweep samples were processed using the same method as for the vacuum samples, except that only the finest mesh sieve (0.09 mm) was used because these samples contained only small amounts of extraneous vegetation. Invertebrates were separated from debris, identified and counted, and stored in 70% ethanol.

Sticky Trap Sampling

The "Sticky Trap" design is based on a method first used by Ryan & Wrubleski (1998) and employed in local wetlands by Leonhardt (2003). The traps were constructed using a PVC-pipe, measuring 7.6 cm in diameter and 30 cm in height. The pipe was wrapped in a clear, acetate transparency sheet painted with Tanglefoot© (Tanglefoot Company, Grand Rapids, MI), which is a natural plant resin. The sheet was secured to the pipe using two elastic bands. The bottom end of the pipe was pushed into a groove cut onto the top of a 30 cm x 30 cm x 5 cm thick blue Styrofoam square (to prevent the pipe from being in direct contact with the ground) and placed around a thin bamboo pole (to stabilize the unit under windy conditions). When collected, the sticky surface of an acetate

sheet was covered in plastic film, and the unit was stored frozen until processing in the laboratory.

The acetate sheets were changed daily for 3 fair weather days in 2014 (following the recommendations of Williams, 2014) to minimize damage to trapped specimens, allowing invertebrates to be identified to finer taxonomic resolution. A "fair weather day" was defined as a day with little wind, and temperatures measuring at least 15 degrees Celsius throughout the day, promoting invertebrate activity. However, the laboratory processing time that this required exceeded the time available. Consequently, in 2015, the acetate sheets were left out for 3 consecutive fair-weather days, which resulted in a greater proportion of damaged invertebrates and lower taxonomic resolution.

In the laboratory, the acetate sheets were immersed in B-X Safety Solvent® (Bird-X Inc., Chicago, IL) in order to dissolve the adhesive and allow the invertebrates and debris to be removed. Because of the number of samples that required processing, the invertebrates collected from 2015 and remaining 15 samples remaining from 2014 were carefully hand-picked from the sheets using Jeweller's forceps and placed directly into a Petri dish filled with the B-X Safety Solvent. These sheets were then examined under a dissecting microscope to find and remove any remaining small invertebrates. The invertebrates were then poured into a 0.09 mm aperture sieve, rinsed with butanol (which is miscible with both solvent and water) and then rinsed with water into Petri dishes. The invertebrates were enumerated, identified to finest taxonomic resolution possible and preserved in 70% ethanol.

Pitfall Trap Sampling

Pitfall trapping is a useful method to collect mobile, ground-dwelling invertebrates (Longcore, 2003; Pekar & Lubin, 2003), especially those that are nocturnally active. Because the vacuum sampler only collects the fauna present at the time of sampling, pitfall traps are effective because they can be left in place for several days. Pitfall traps were deployed in both 2014 and 2015. Traps consisted of 5 cm diameter, 250-mL glass jars, which were buried so that the rim of the jar was flush with soil level. Fifty mL of 70% ethanol was added to each jar. Jars were deployed at the same time at the sticky trap deployment and other sampling, and collected at the same time as the sticky traps. At the time of collection, jars were filled to the brim with 95% ethanol, ensuring that samples were preserved in at least 70% ethanol, capped and stored for processing several months later in the laboratory.

In the laboratory, contents of the jars were poured through a sieve (0.09 mm mesh) and rinsed into a Petri dish. If the jar contained large amounts of debris, the contents were rinsed into a metal tray and the invertebrates handpicked from heavier debris, then poured through the sieve. All invertebrates were sorted from debris, identified to finest taxonomic resolution, and preserved in 70% ethanol.

Statistical Analyses

For each site, total invertebrate abundance and richness was calculated. Abundance was measured as the number of total invertebrates collected at a sampling site divided by the number of traps processed from that site. Richness was measured as the number of families present at the sampling site. Individuals were grouped into invertebrate families

to account for the lowest taxonomic resolution used in identification. The data from each trap type were treated similarly. Though all individuals were documented, families representing less than 10% of the total invertebrate abundance for site totals, and within each trap type, were excluded from multivariate analyses (considered rare taxa). Soil-associated variables were measured using soil samples collected from each sampling site, and plant community composition was assessed on a presence/absence basis (See Chapter 1: Sampling Methodology).

Influence of Soil Type on Invertebrate Richness and Abundance

Soil-related differences (peat vs. LFH) in the abundance and richness of individuals captured in each trap type were evaluated using a MANOVA t-test using SPSS 24.0 (IBM Statistics, 2015). This was done using raw abundance counts and richness counts.

Community Composition – Similarity among Samples:

Relative abundances (percent) of invertebrates were calculated for site totals and for each individual trap type, using values of the invertebrates grouped at family taxonomic level (Equation 3.1). Relative abundance value (percent) was $Log_2(x+1)$ transformed into octaves (Gauch & Whittaker, 1972), with the constant of 1.0 being added to each value so that a value of zero before transformation was zero after the transformation (Equation 3.2). All values were positive.

Equation 3.1

$$Relative\ Abundance\ i\ = \frac{Number\ of\ Individuals\ from\ Family\ x\ at\ Site\ i}{Total\ Number\ of\ Individuals\ at\ Site\ i}$$

Equation 3.2

$$Abundance\ (Octave) = Log_2(Relative\ Abundance\ (Percent) + 1)$$

Richness measurements were the number of invertebrate families present within a trap type and site totals. All assessments of community composition were conducted using the octave-transformed invertebrate values.

The similarity of samples collected by each trap type was assessed using hierarchical cluster analysis (Ward's method performed on Squared-Euclidean distances among samples based on relative abundances of taxa (octaves) within samples). Clusters were identified subjectively. Once each sampling site had been attributed to a group, between:among group F-ratios were calculated to identify the environmental variables that contributed most to the differences (Green and Vascotto 1978). Clustering and ANOVAs were done using SPSS 24.0.

Community Composition – Association with Environmental Variables:

Redundancy analysis (RDA) was performed to assess associations between the plant community assemblages (explanatory variables) and invertebrate community assemblages (response variables) at each sampling site to explain the constrained variation in invertebrate community composition among sites with respect to the unconstrained variation in plant species within each site. This analysis assessed the influence of the plant community on the invertebrate community. A second RDA was conducted using the suite of environmental variables as the explanatory matrix and the invertebrate community data as the response matrix. All RDAs were conducted in R, using the package *vegan* (Oksanen et al., 2016). The scaling method used highlighted the distance measurements between the

explanatory factors (environmental or plant) and the objects/response variables (invertebrates). Invertebrates found grouped closer together indicate that they are found in similar habitats. The perpendicular distance of an invertebrate to a factor vector indicates its relationship to that vector. The closer an invertebrate is to that vector, the higher the association with the vector.

Relationships Among Invertebrate Community Composition, Plant Community Composition and Environmental Variables

To assess the combined direct and indirect effects of environmental and biological (plant community composition) variables on invertebrate community composition, a path analysis was performed, using SmartPLS 3.0 software (Ringle et al., 2015). The community is composed of three separate latent variables: soil chemistry, plant community, and invertebrate community. In this case, 'Soil Chemistry' was measured using site values from the environmental variables identified in Chapter 2, 'Plant Community' was measured using the presence (1) or absence (0) of a plant species at a site, and 'Invertebrate Community' was measured using the invertebrate relative abundance values (octaves) of each site. The effect of both plant community and soil chemistry on invertebrate community was measured, as well as the effect of soil chemistry on the plant community. Information from all 40 sites was used in the analysis. Spearman correlation coefficients identified how the plant community is correlated with specific soil variables and invertebrate communities. A path diagram was created to show those correlations through the partial least squares method (Garson, 2016). This type of modelling attempts to maximize the amount of variance explained between latent variables and focuses on cause-effect relationships between the latent variables.

Results

Site Totals

Overall, 5551 invertebrates were collected from 190 traps in 40 locations across the Sandhill Fen Watershed through the 2014 and 2015 sampling seasons, occurring at approximately the same time of year. The arithmetic mean±SE invertebrate abundance and taxa richness per site (all traps combined) were: 126.4±10.2 individuals and: 18.5±0.6 families respectively (n=40).

Arithmetic mean (±SE) of richness and abundance were calculated independently for peat sites (n=17) and LFH sites (n=23) sampled during 2014 and 2015. Mean peat site abundance and richness were 128±12.4 individuals and 19.8± 1.01 families per site, respectively, whereas abundance and richness at LFH sites averaged 125±15.4 individuals and 17.5±0.63 families, respectively. A one-way MANOVA showed no significant effect of soil type on invertebrate abundance (Figure 3.1: MANOVA, $F=2.667$, $p<0.083$), but there was a marginally significant difference in the mean family richness between the two soil types, with peat being slightly higher than LFH (Figure 3.2: MANOVA, $F=4.18$, $p<0.048$).

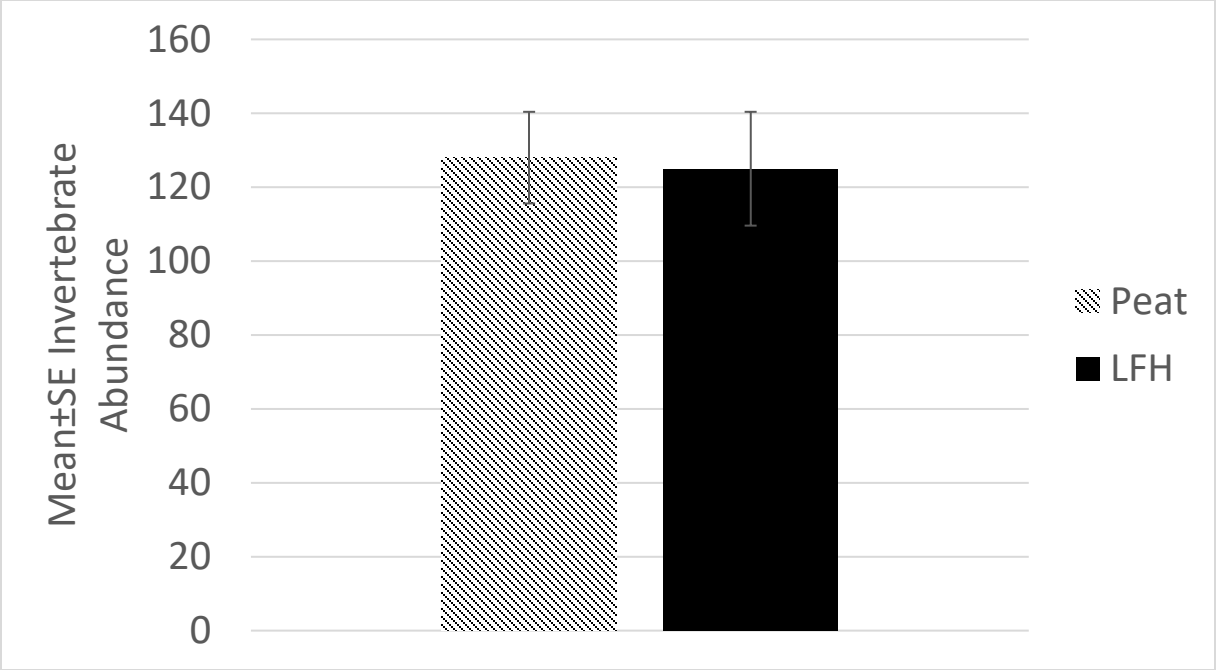

Figure 3.1: Arithmetic mean ±SE invertebrate abundance on peat and LFH soil types. (MANOVA, F=2.667, p<0.083).

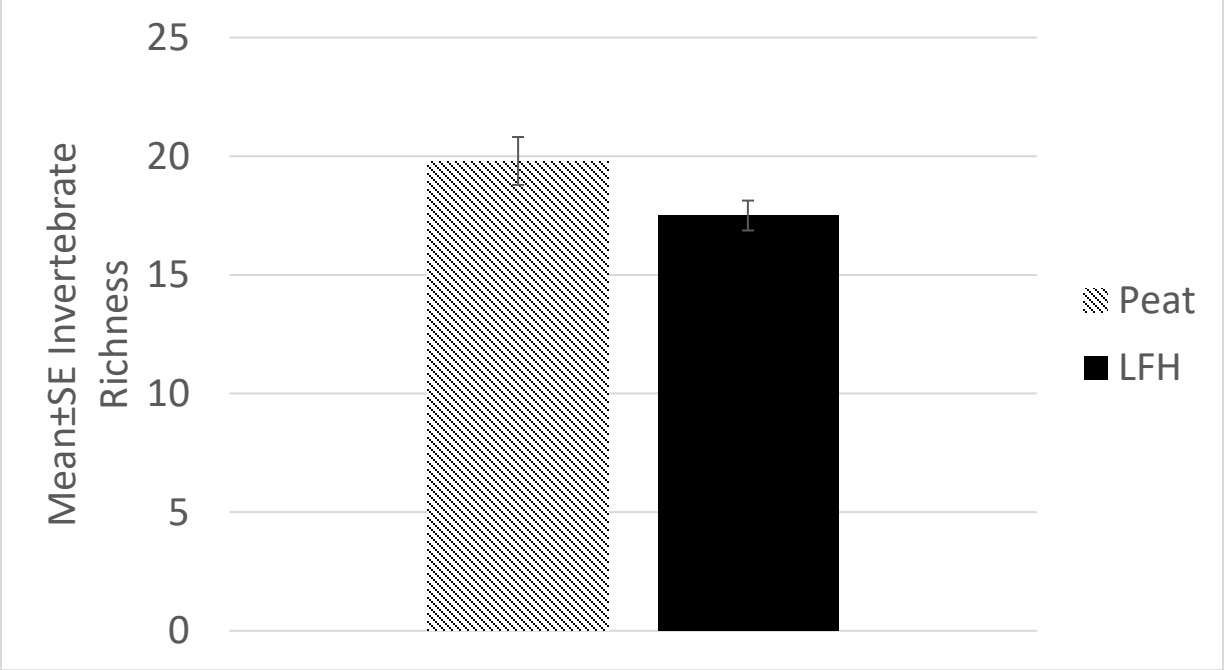

Figure 3.2: Arithmetic mean ± SE invertebrate family richness on peat and LFH soil types. Marginally significant difference (MANOVA, F=4.18, p<0.048).

Cluster analysis of the site-specific invertebrate data (Figure 3.3) identified two group divisions. Analysis of Variance between-vs-within group F-values were used to identify the key invertebrates whose relative abundances differed most greatly between the two groups. This first cluster (Group 1) contained several taxa of small invertebrates whose relative abundances were significantly greater than in Group 2. Group 2 sites also had a unique composition of invertebrates that were more abundant than sites from Group 1 (see Appendix B – for F values). A second ANOVA F analysis identified the soil chemistry variables whose values differed between site group. Group 1 sites were significantly drier (ANOVA $F=41.60$, $p<0.0005$) and less saline (ANOVA $F=15.282$, $p<0.0005$) than Group 2 sites.

Two redundancy analyses were conducted on the data matrices. The first RDA, using the presence or absence of plant species as the explanatory variables, resulted in a model explaining 61% of the variation in invertebrate family relative abundances (Figure 3.4). The first RDA axis identified an association between typical wetland plants (*Carex* sp. and *Typha latifolia*) and semi-terrestrial midges and brine flies (Chironomidae and Ephydridae) as well as planthoppers (Delphacidae and Cicadellidae). The first axis also indicated an association between invertebrates typically found in drier sites (Acari, Latrididae, and Phalangidae) and upland plant species (*Sonchus arvensis*, *Lathyrus ochroleucus*, and *Hieracium umbellutam)*. A second RDA, which used the soil-associated environmental variables as the explanatory matrix, explained 25% of the invertebrate variation (Figure 3.5). The first RDA axis highlighted moisture and salinity having an association with invertebrates found in wetland environments (Cicadellidae, Chironomidae, Coccinellidae, and Delphacidae). The environmental model was

significant ($p<0.001$) and the plant model was almost significant ($p<0.052$). A statistically significant model would indicate that elements of the response matrix and the explanatory matrix are linearly related to each other, shown using permutation tests.

Table 3.1: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using site-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis.

Dominant Peat Invertebrates:	Braconidae, Chironomidae, Cicadellidae, Coccinellidae, Delphacidae, Ephydridae, Saldidae, Sphaeroceridae			
Dominant LFH Invertebrate:	Acari, Chrysididae, Chrysomelidae Thripidae, Formicidae			
ANOVA F		Group 1 vs **Group 2**		
	Soil Variables	**EC, Moisture**		
	Invertebrates	Thripidae, Acari, Cecidiomyiidae, Muscidae, **Braconidae, Cicadellidae, Saldidae, Coccinellidae, Ichneumonidae, Delphacidae, Staphylinidae, Chironomidae**		
RDA		RDA1	RDA2	RDA3
Environmental RDA	Soil variables	Moisture, EC	N	K
	Invertebrates	Acari, Formicidae, Cicadellidae, **Chironomidae, Coccinellidae, Delphacidae**	Braconidae, Miridae, **Cecidiomyiidae, Hybotidae, Thripidae, Sciaridae**	Cercopidae, Membracidae, Platygastridae, **Mycetophilidae**
Plant RDA	Plant Community	**CAREX, TYPHLAT**, SONCARV, MOSS, LATHOCH, HIERUMB	**MEDISAT**, EQUIARV, **CORNSER**	FRAGVES, CICEMIL, PICEGLA, LOTUCOR, EPILANG
	Invertebrates	Acari, Cecidiomyiidae, Latrididae, Phalangidae, **Chironomidae, Cicadellidae, Delphacidae, Ephydridae**	Aphididae, Phoridae, Araneae	Chrysomelidae, Chalicoidea, Membracidae, Carabidae, **Mycetophilidae, Thripidae**

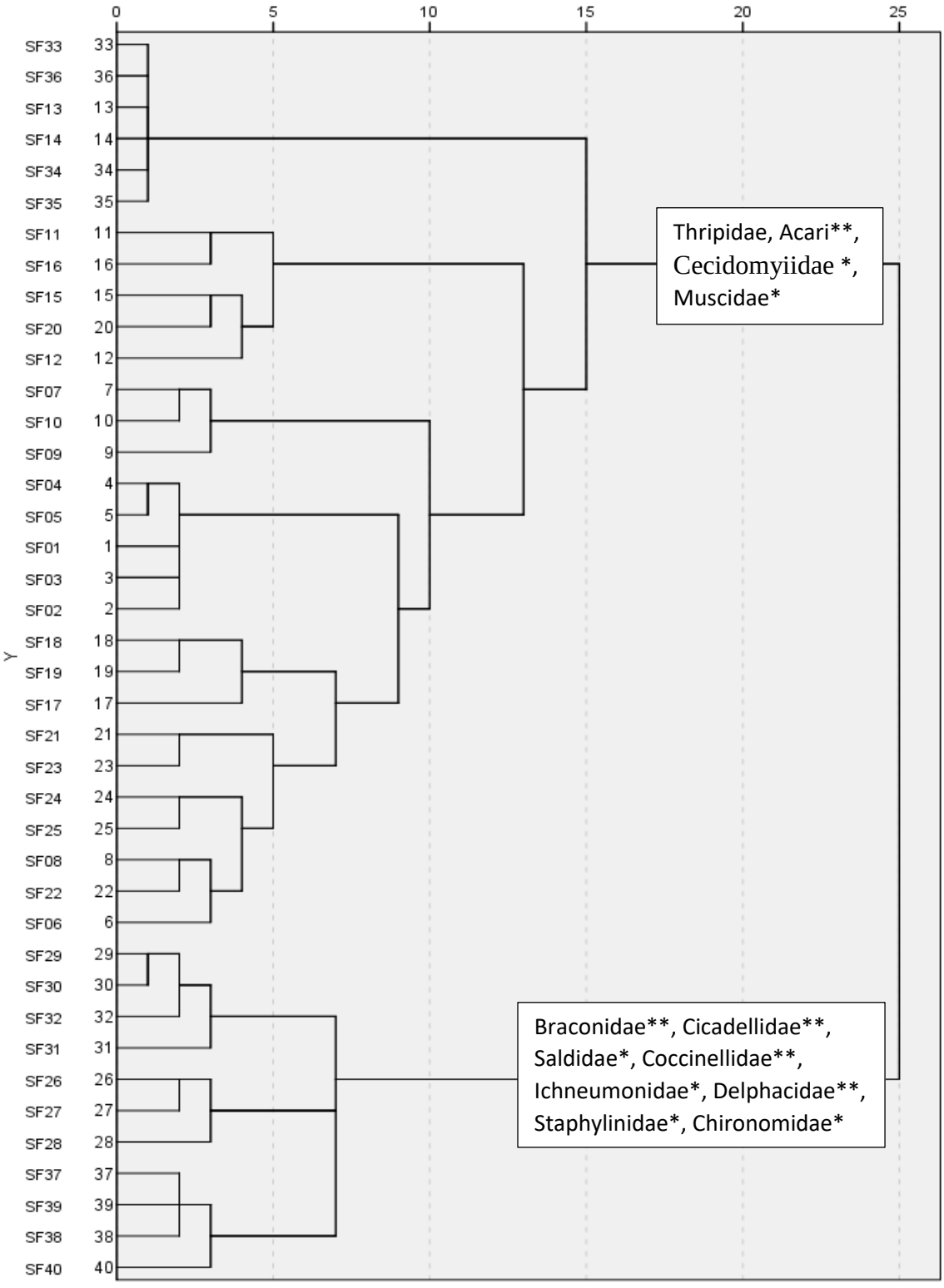

Figure 3.3: Dendrogram showing similarities among sampling sites based on invertebrate relative abundance (octaves) captured in all traps across Sandhill Fen Watershed (*p<0.05; **p<0.01).

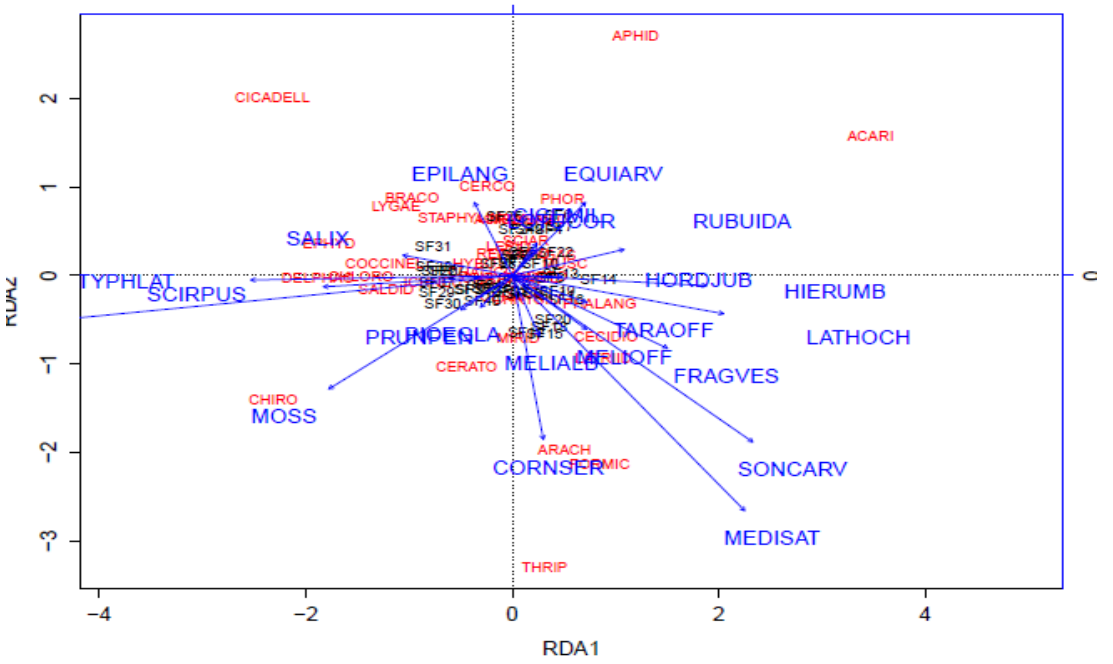

Figure 3.4: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and plant species presence/absence.

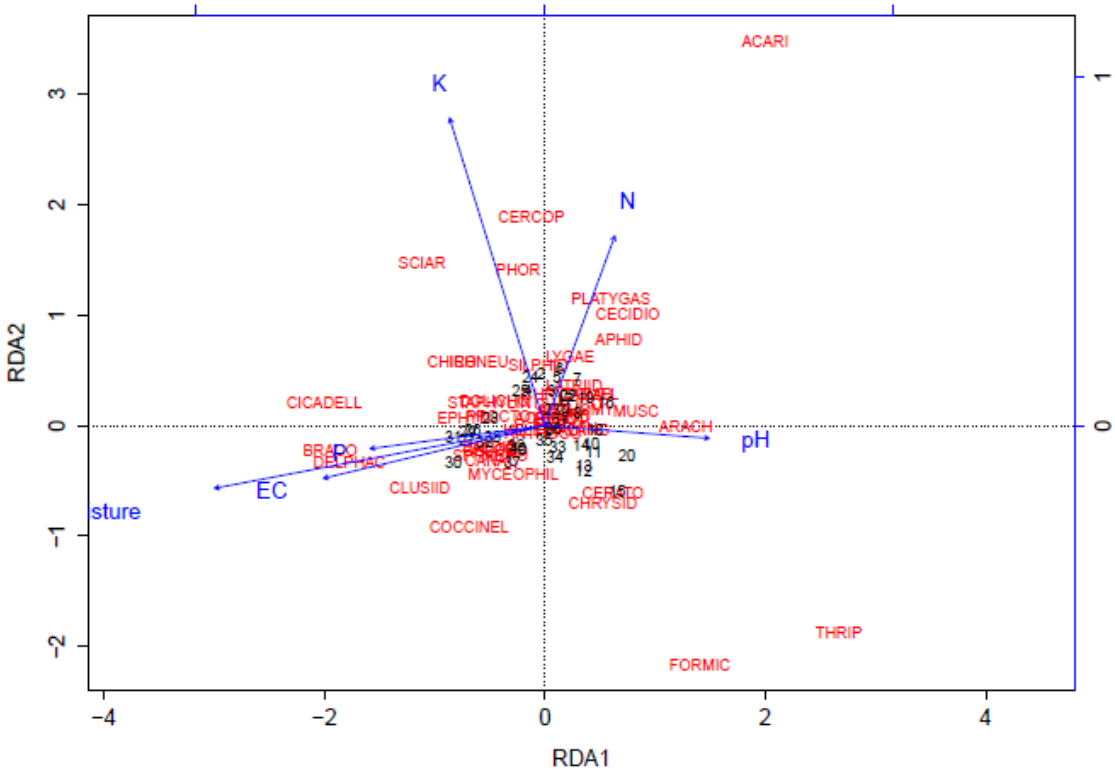

Figure 3.5: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements. Model significant ($p<0.05$).

Pitfall Traps

The mean ±SE invertebrate abundance and richness of pitfall traps (n=30) were 13.2±3.10 individuals and 4.97±0.658 taxa per trap respectively. Abundances and richness were calculated for peat (9.1±3.04 individuals and richness=4.7±0.98 taxa, n=16) and LFH (18.0±5.52 individuals and 5.3±-0.89 taxa, n=14). Pitfall trap abundance and richness were unrelated to soil type. Cluster analysis identified showed two groups of sites (Figure 3.6). These groups differed in their relative abundances of Acari (mites; more abundance in Group 1) and the presence of Araneae (spiders) and Saldidae (shore bugs) (Group 2). A second analysis to assess differences in the soil associated environmental variables indicated that moisture content of the sites in Group 2 was higher than at sites in Group 1 (ANOVA F=5.565).

Redundancy analysis using the plant species data as explanatory variables, explained 63% of the abundance of invertebrate taxa collected in pitfall traps (Figure 3.7). The first axis of this analysis showed a negative association between *Carex* and Acari, Phoridae, and Staphylinidae, indicating these invertebrates are not found in sites with *Carex.* The second RDA used the environmental variables as the explanatory matrix, which explained 26% of the variation in the invertebrate community (Figure 3.8). The first axis of this model indicated that sites with high soil moisture were negatively associated with Muscidae (flies), Silphidae (carrion beetles), Carabidae (ground beetles), and Acari. Neither model was significant, indicating either a non-linear or non-existent relationship between the invertebrate community abundance and either data matrix.

Table 3.2: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using Pitfall-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis.

Dominant Peat Invertebrates:	Latrididae, Cecidiomyiidae, Aphididae			
Dominant LFH Invertebrate:	Formicidae			
DFA		Group 1 vs **Group 2**		
	Soil Variables	**Moisture**		
	Invertebrates	Acari, **Saldidae, Araneae**		
RDA		RDA1	RDA2	RDA3
Environmental RDA	Soil Variables	Moisture, **N**	**EC**	K, **pH**
	Invertebrates	Araneae, **Muscidae, Silphidae, Carabidae, Acari**	**Latrididae, Aphididae, Thripidae, Cicadellidae**	**Cecidiomyiidae, Phoridae, Phalangidae, Formicidae**
Plant RDA	Plant	**CAREX**	SONCARV, **TYPHLAT**	PRUNPEN, MOSS
	Invertebrates	Acari, Phoridae, Staphylinidae	**Thripidae, Silphidae, Latrididae, Aphididae**	Carabidae, **Cecidiomyiidae, Formicidae**

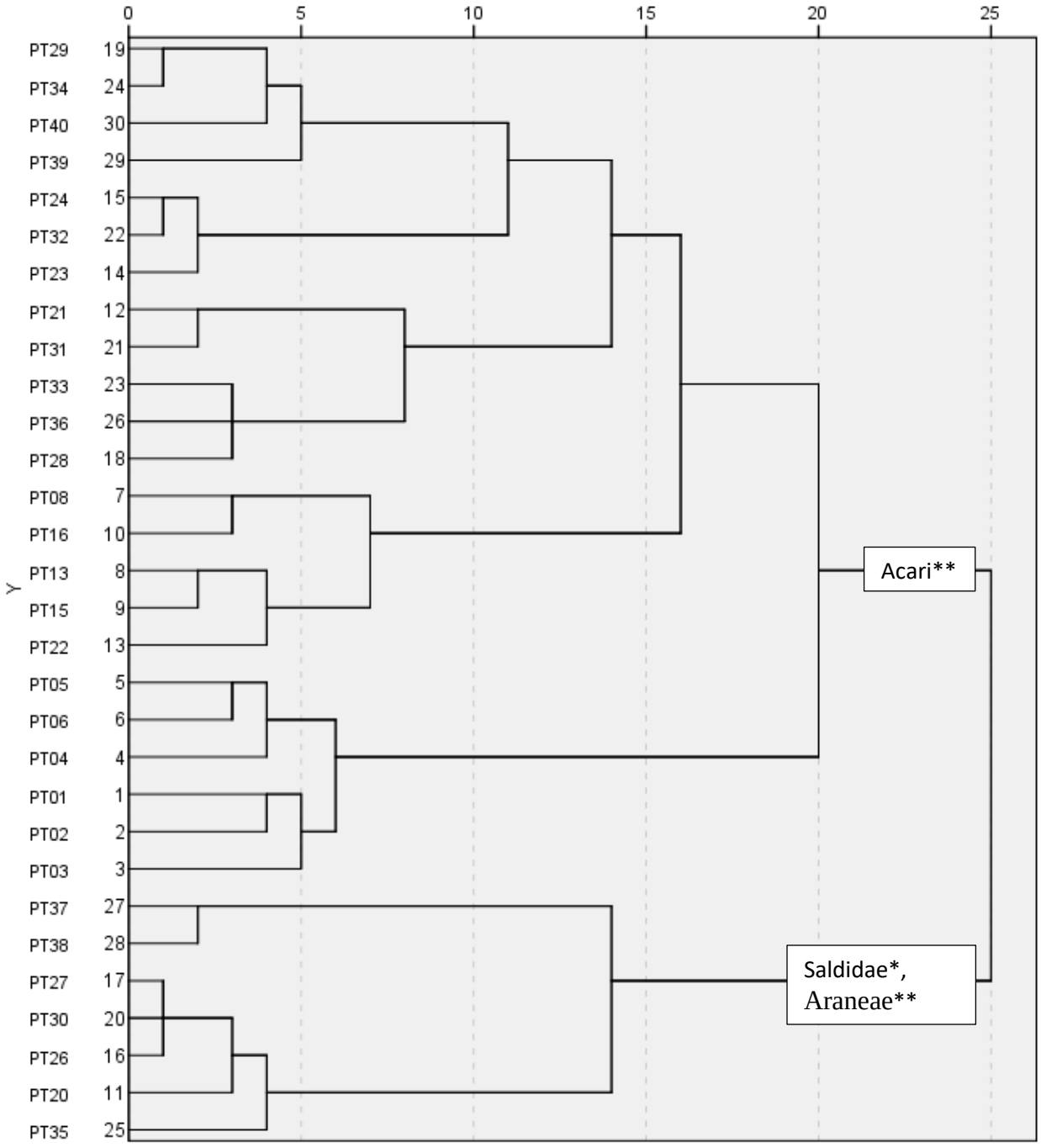

Figure 3.6: Dendrogram showing similarities among sampling sites based on invertebrate relative abundance octaves captured in pitfall traps across Sandhill Fen Watershed (*p<0.05; *p<0.01).

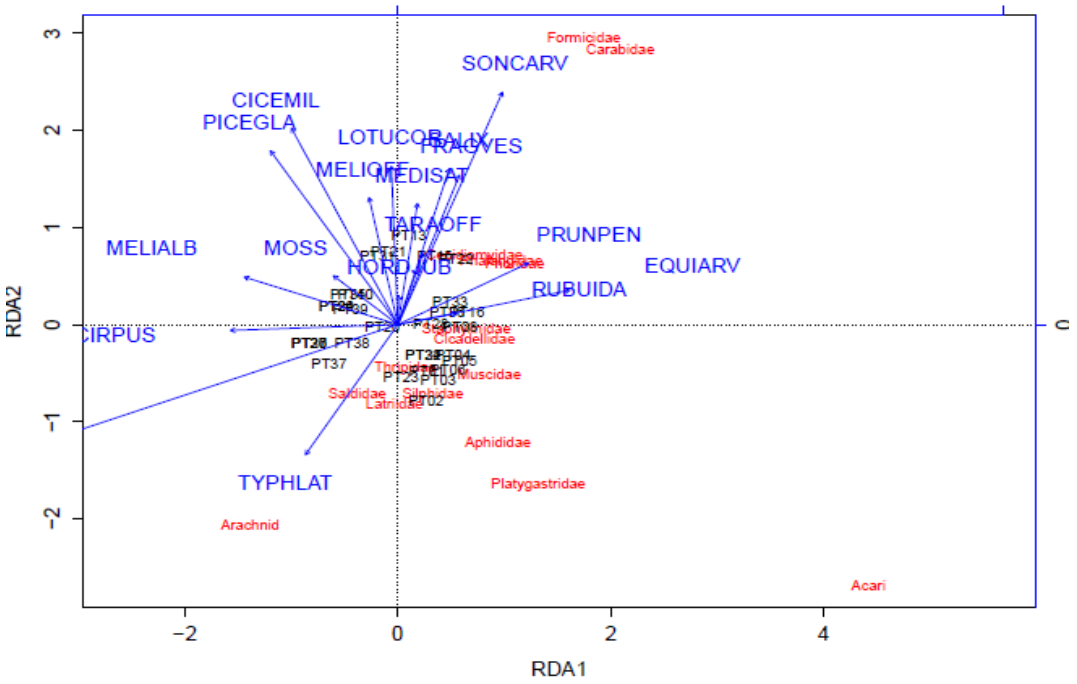

Figure 3.7: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance octaves and plant species presence/absence (Pitfall Traps).

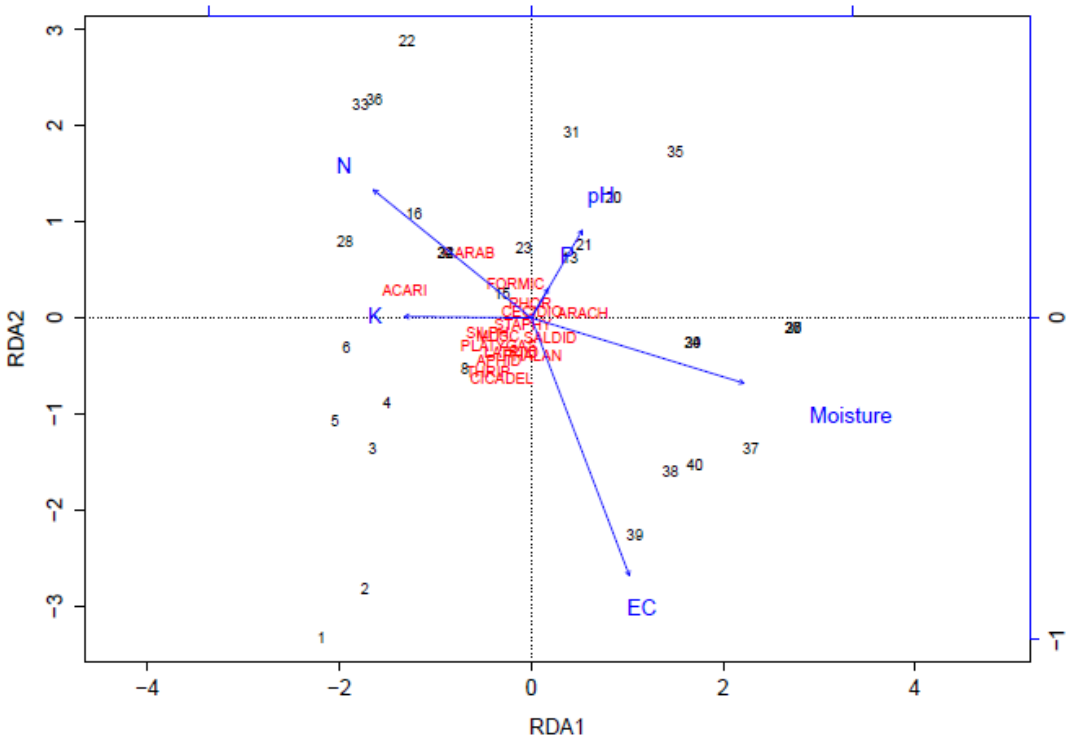

Figure 3.8: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements (Pitfall Traps).

Sweep Sampling

The arithmetic mean ±SE invertebrate abundance and richness of sweep samples (n=30) were 26.3±3.24 individuals and 6.1±0.42 taxa per trap respectively. Abundances and richness were calculated for peat (29.8±4.55 individuals and 6.1±0.56 taxa, n=11) and LFH (21.4±4.22 individuals and 6.13±0.67 taxa per trap, n=8). There was no significant difference found between abundance and richness for soil type.

Cluster analysis of the invertebrate sweep sample data identified two major groups (Figure 3.9). The key invertebrate taxa that differed most between groups were Chironomidae (midges) (more abundant in Group 1: ANOVA F=10.191) and Thripidae (thrips) (more abundant in Group 2: ANOVA F=63.323). The comparison of environmental variable values between groups indicated that sites in Groups 1 had higher soil salinity than sites in Group 2 (ANOVA, F=12.789).

The plant RDA model was statistically significant ($p<0.003$) and explained 78% of the invertebrate variation (Figure 3.10). The first axis of this analysis highlighted an association between the presence of typical wetland plants (*Scirpus sp.*, *Carex sp.*, and *T. latifolia)* and a variety of different invertebrate groups (Chrysomelidae, Araneae, Chironomidae, and Chalicoidea). The environmental RDA explained 34.5% of the invertebrate variation, but the model was nonsignificant (Figure 3.11). The first axis of this analysis indicated an association with high soil moisture and the common wetland plant associated invertebrate species (Cicadellidae, Lygaeidae, Coccinellidae, and Ephydridae).

Table 3.3: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using Sweep Net-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis

Dominant Peat Invertebrates:	Coccinellidae			
Dominant LFH Invertebrate:	Formicidae			
DFA		Group 1 vs **Group 2**		
	Soil Variables	EC		
	Invertebrates	Chironomidae, **Thripidae**		
RDA		RDA1	RDA2	RDA3
Environmental RDA	Soil Variables	Moisture	K	**EC, P**
	Invertebrates	Cicadellidae, Lygaeidae, Coccinellidae, Ephydridae, **Aphididae, Araneae**, **Muscidae**	Chrysomelidae, Ichneumonidae, Platygastridae, **Aphididae, Formicidae**	**Thripidae**
Plant RDA	Plant	FRAGVES, MEDISAT**, SCIRPUS, TYPHLAT, CAREX**	RUBUIDA, CICEMIL, SONCARV, MOSS	EQUIARV
	Invertebrates	Chrysomelidae, Araneae, Chironomidae, Chalicoidea, **Coccinellidae, Cicadellidae**	**Formicidae, Thripidae**	Aphididae

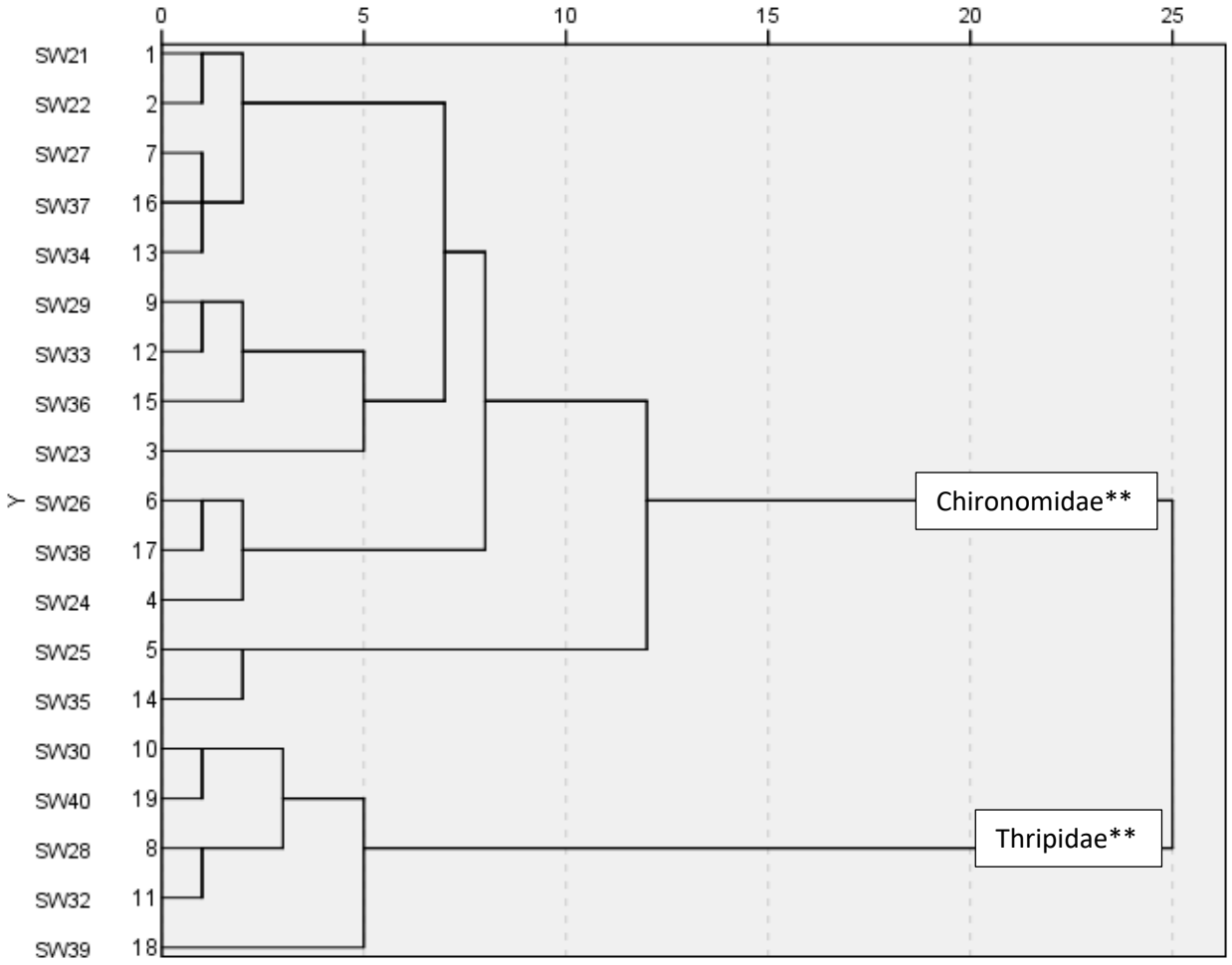

Figure 3.9: Cluster Dendrogram showing similarities among sampling sites based on invertebrate relative abundance octaves captured in sweep samples across Sandhill Fen Watershed (*p<0.05; **p<0.01).

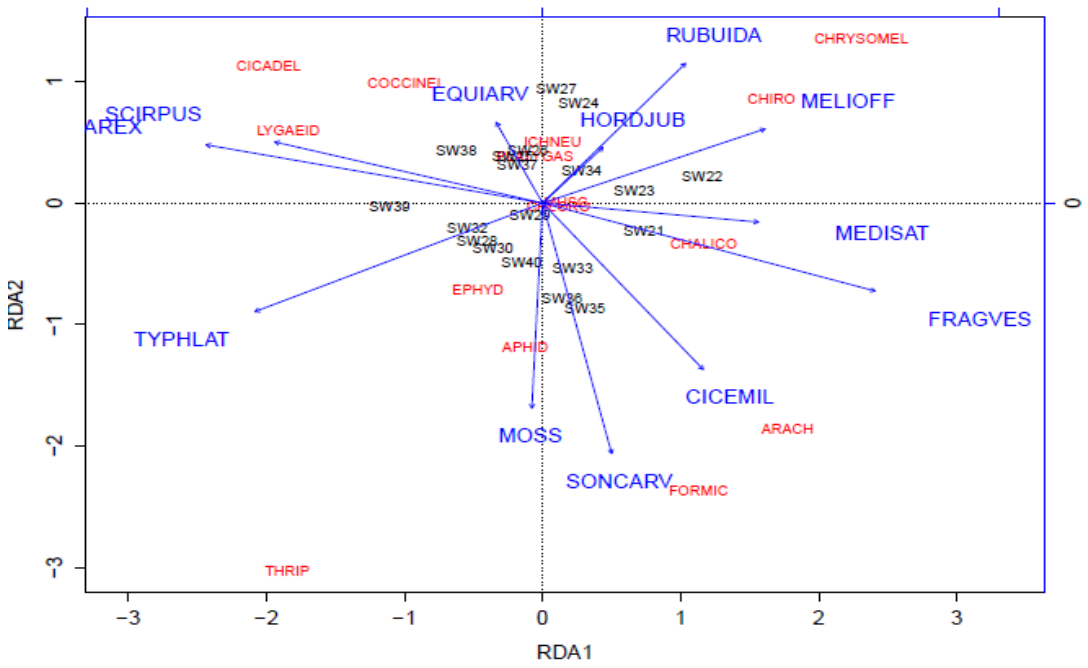

Figure 3.10: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and plant species presence/absence. Model significant ($p<0.003$). (Sweep Samples)

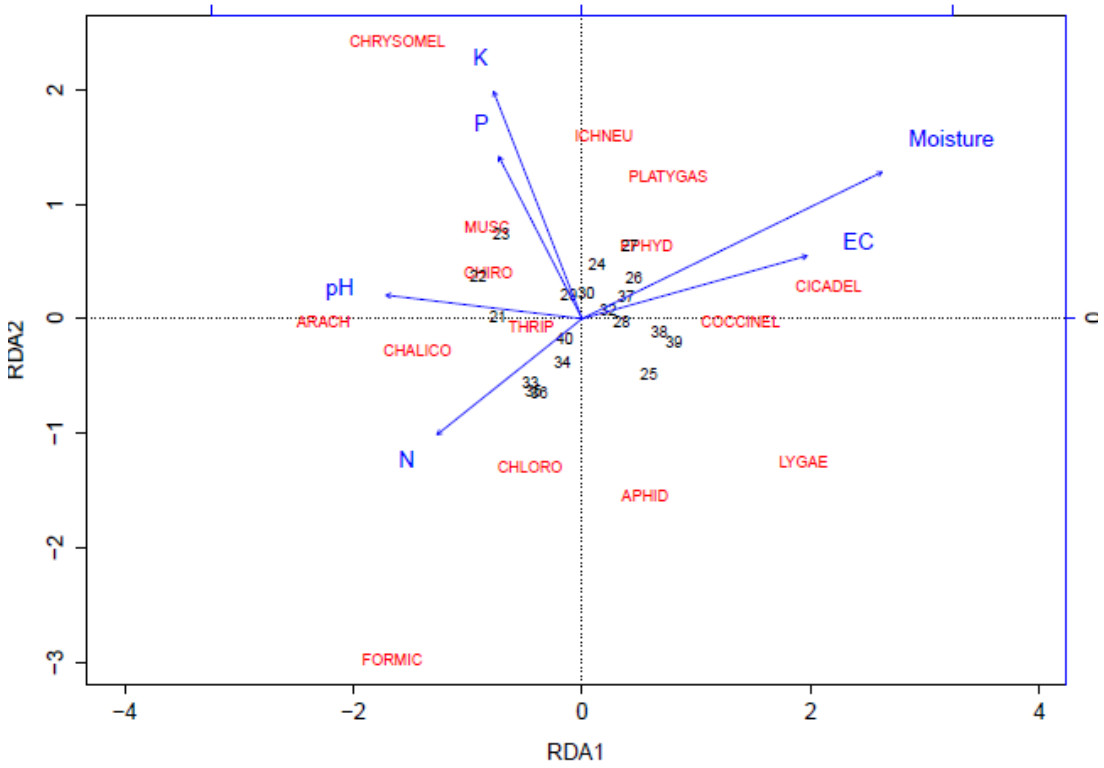

Figure 3.11: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements. (Sweep Samples)

Vacuum Sampling (Vegetation)

The total invertebrate abundance and richness of invertebrates in the vacuum-vegetation samples (n=40), were 25.03±4.67 and 6.83±0.46 respectively. The abundance and richness of invertebrates collected at peat sites (n=17) were 22.7±2.7, and 7.7±0.6, whereas LFH sites (n=23) abundance and richness values were 26.7±8.0 and 6.2±0.7. There was no difference found in invertebrate abundance or richness between the two soil types.

Cluster analysis indicated the presence of two primary clusters of sites and two subgroups within each major division (Figure 3.12). The key invertebrate taxa that differed between the two major groups were Aphididae (ANOVA F=8.84), and Acari (ANOVA F=21.27), which were more abundant in Group 1, and Chironomidae (ANOVA F=30.34), Ephydridae (ANOVA F=11.49), Chalicoidea (wasp; ANOVA F=7.83) and Ichneumonidae (wasp; ANOVA F=7.91) were more abundant in Group 2. The invertebrate taxon that was more abundant in Group 1A were Carabidae (ANOVA F=11.36) and Group 1B had higher abundances of Thripidae (ANOVA F=5.99), Aphididae (ANOVA F=10.09) and Araneae (ANOVA F=21.42). Lastly, the key invertebrate taxa that distinguished Group 2A from 2B were Delphacidae (planthopper; ANOVA F=9.66), Chloropidae (grass fly; ANOVA F=7.83), Staphylinidae (rove beetle; ANOVA F=9.46) and Coccinellidae (ladybird beetle; ANOVA F=62.77), with Group 2B having higher abundances of Chironomidae (ANOVA F=5.30), Formicidae (ants; ANOVA F=4.99), and Araneae (ANOVA F=14.11).

The comparison of environmental variables values between Group 1 and Group 2 indicated that Group 2 sites had higher soil moisture content (ANOVA, F=6.71). There was no significant difference indicated between Groups 1A and 1B. Group 2A had sites

with higher moisture content (ANOVA F=20.0) and Group 2B had sites with higher soil pH values (ANOVA F=7.24).

A redundancy analysis using the plant community as the explanatory variables explained 60% of the response community (invertebrate) variation, but was non-significant ($p<0.052$) (Figure 3.13). Axis one indicated an association with moss and *Salix* sp. with invertebrate groups of Chironomidae, Cicadellidae, Braconidae (parasitic wasp), and Ephydridae, which are commonly found in semi-terrestrial sites. A second redundancy analysis using the environmental variables as the explanatory matrix explained 21% of the invertebrate community variation and showed there was a linear relationship between the matrices resulting in a significant model ($p<0.004$) (Figure 3.14). There was an association between sites with high moisture and invertebrates commonly found with wetland plant species (Cicadellidae, Chloropidae, Ephydridae, and Coccinellidae)

Table 3.4: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using Vacuum (Vegetation)-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis

Dominant Peat Invertebrates:	Cicadellidae, Delphacidae, Chloropidae, Coccinellidae			
Dominant LFH Invertebrate:	Formicidae, Acari			
DFA		Group 1 vs **Group 2**	Group 1A vs **Group 1B**	Group 2A vs **Group 2B**
	Soil Variables	**Moisture**		Moisture, **pH**
	Invertebrates	Aphididae, **Chironomidae**, **Ephydridae**, **Chalicoidea**, **Ichneumonidae**, Acari	**Thripidae**, **Aphididae**, Carabidae, **Araneae**	Delphacidae, Chloropidae, **Chironomidae**, **Formicidae**, Staphylinidae, Coccinellidae, Araneae
RDA		RDA1	RDA2	RDA3
Environmental RDA	Soil Variables	**Moisture**	EC	**N**
	Invertebrates	Araneae, Acari, Formicidae**, Cicadellidae, Chloropidae, Coccinellidae, Ephydridae**	Cecidiomyiidae, Lygaeidae, **Ichneumonidae, Sciaridae, Phoridae**	Cercopidae, Carabidae, **Thripidae**
Plant RDA	Plant	MOSS, SALIX, **HIERUMB, LATHOCH**	CORNSER, SONCARV	FRAGVES, EQUIARV, TARAOFF, MELIALB, **CAREX, TYPHLAT**
	Invertebrates	Chironomidae, Cicadellidae, Braconidae, Ephydridae, **Acari, Aphididae**	Formicidae, Araneae, Phoridae	Muscidae**, Proctoruptidae, Cecidiomyiidae, Thripidae**

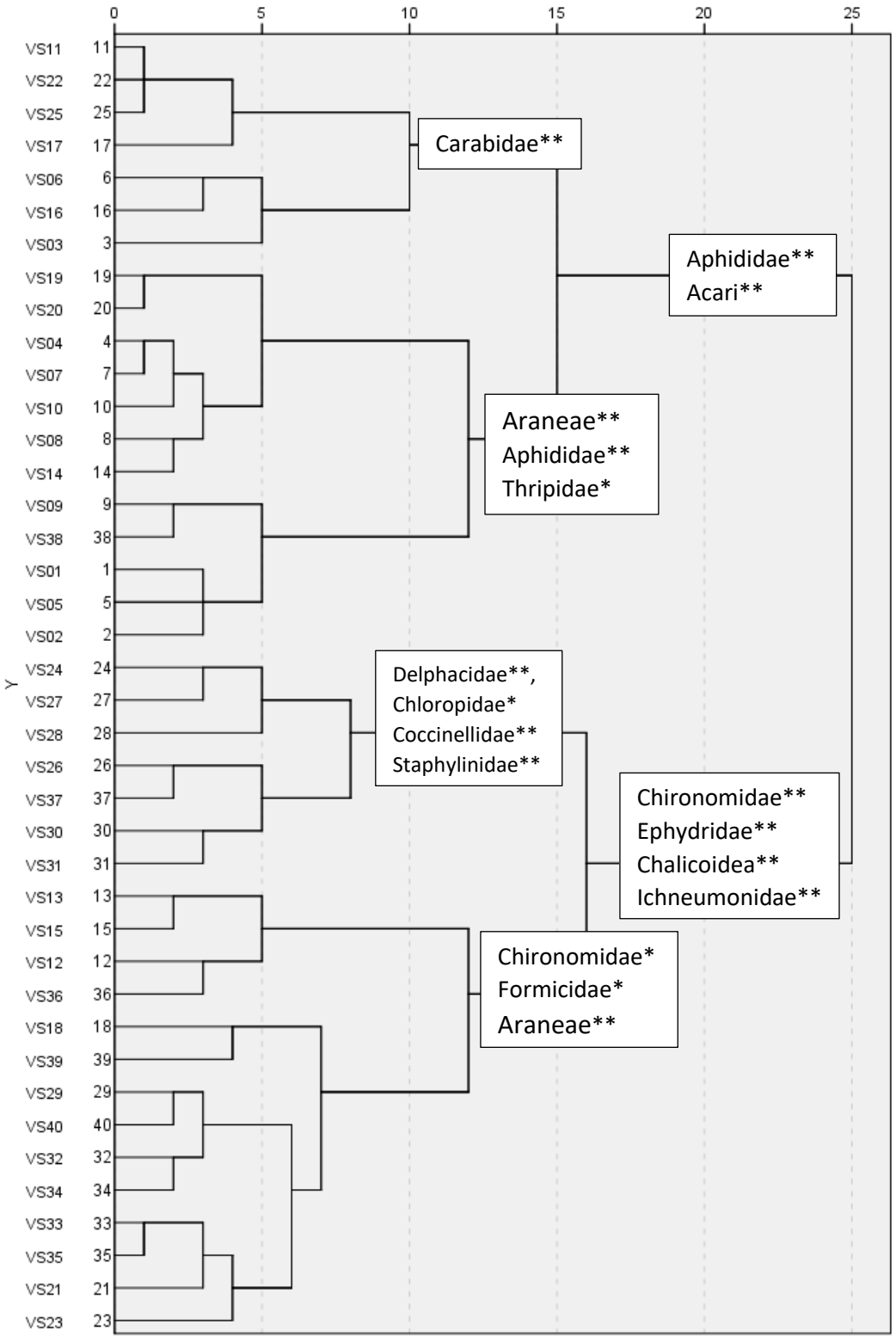

Figure 3.12: Cluster dendrogram showing similarities among sampling sites based on invertebrate relative abundance octaves captured in vacuum – vegetation samples across Sandhill Fen Watershed (*p<0.05; **p<0.01).

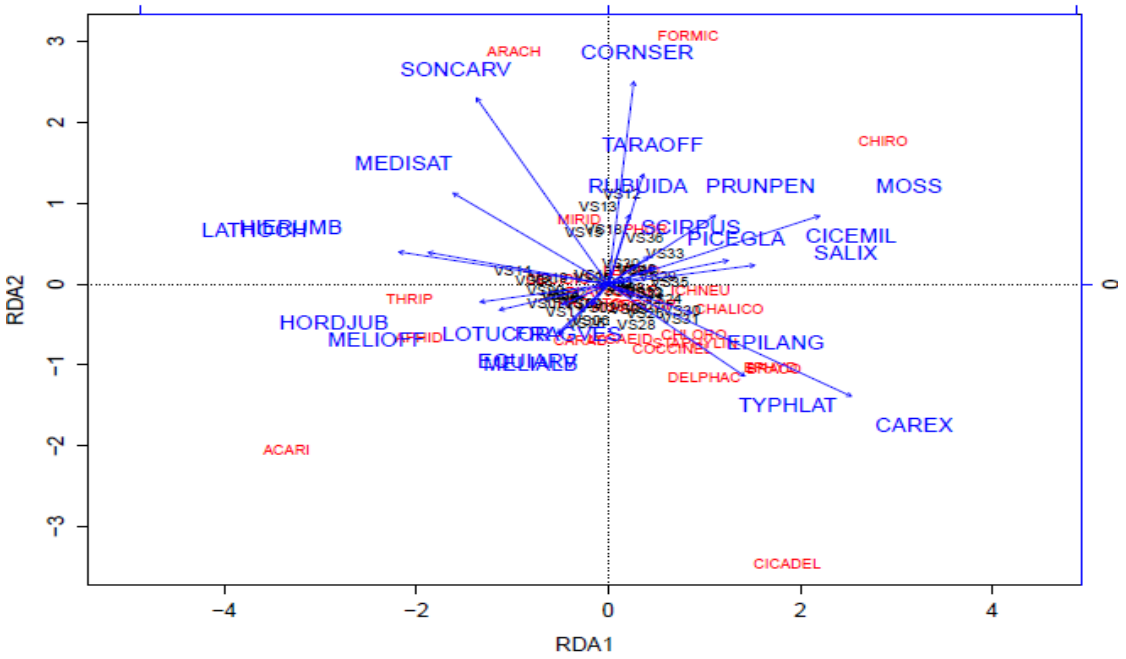

Figure 3.13: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and plant species presence/absence (Vacuum – Vegetation samples).

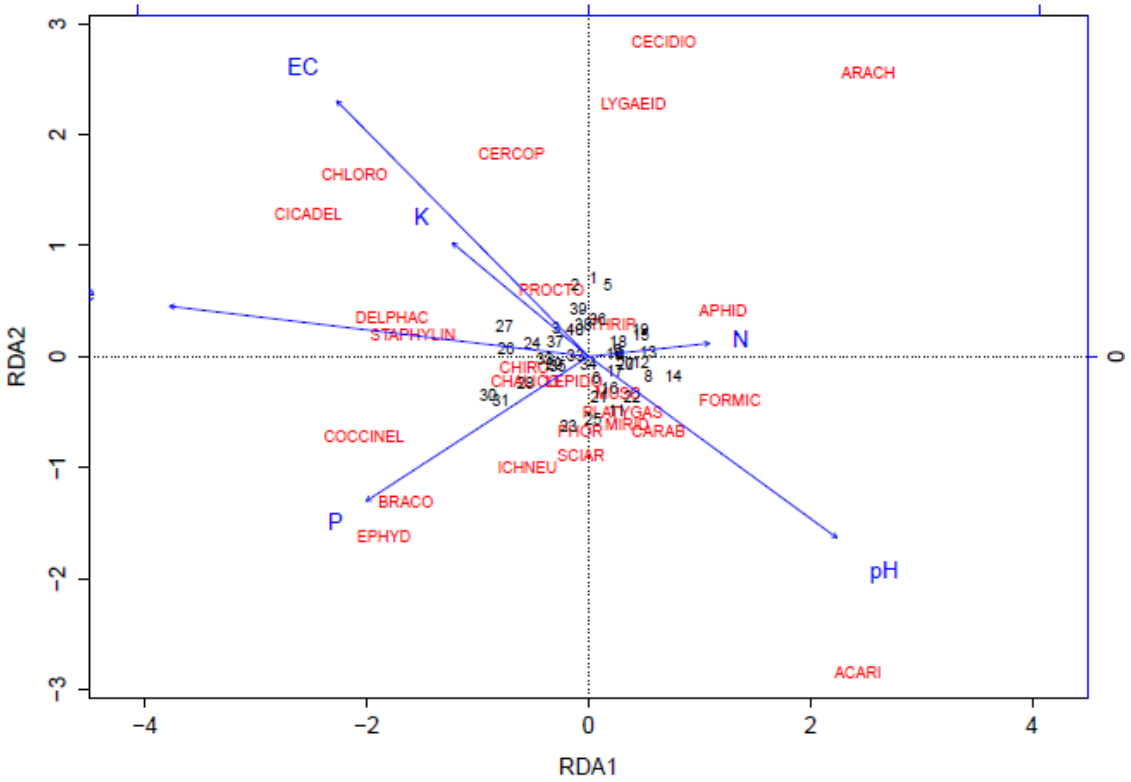

Figure 3.14: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements. Model significant ($p<0.003$). (Vacuum – Vegetation samples)

Vacuum Sampling (Soil)

The invertebrate abundance and richness of invertebrates in the soil samples (n=39) were 7.1±1.6 and 2.5±0.28 respectively. Peat samples (n=17) had an abundance of 6.8±1.53 individuals and richness of 3.24±0.46 families per trap, with LFH samples (n=22) measuring abundance as 7.32±2.63 individuals and richness as 2.00±0.29 families per trap. There was no significant difference in the measure of abundance between peat and LFH, but a slight difference was observed in invertebrate richness between the two soil types (Student's t-test, $p<0.024$).

Cluster analysis indicated two major site clusters (Figure 3.15). The key invertebrates in separating the two groups were Araneae (ANOVA F=15.10), Acari (ANOVA F=115.7), Thripidae (ANOVA F=5.47) and Reduviidae (assassin bugs; ANOVA F=4.46), which all were statistically more abundant in Group 2 than Group 1The most abundant invertebrate taxon among Group 1 sites was Cicadellidae (leafhoppers), but it was not significantly different among groups (ANOVA F=3.80). The comparison of environmental variables among the two groups indicated that Group 1 sites were associated with higher moisture content (ANOVA F=12.9) and Group 2 sites had higher pH measurements than Group 1 (ANOVA F=10.5).

Again, the redundancy analysis using the plant community as explanatory accounted for a high amount of invertebrate variation (61%) but was not linearly related ($p>0.05$) (Figure 3.16). Wetland plants of *Carex sp.* and *T.* latifolia were associated with the Chironomidae, Cicadellidae, Delphacidae, and Ephydridae. The environmental variables explained 25% of the invertebrate community variation, and was linearly related

($p<0.001$), with high moisture and high salinity being associated with Cicadellidae, Chironomidae, Coccinellidae, and Delphacidae (Figure 3.17).

Table 3.5: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using Vacuum (Soil)-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis

Dominant Peat Invertebrates:	Cicadellidae, Delphacidae, Saldidae			
Dominant LFH Invertebrate:	Acari			
DFA		Group 1 vs **Group 2**		
	Environmental	Moisture, **pH,**		
	Invertebrates	**Acari, Araneae, Reduviidae, Thripidae**		
RDA		RDA1	RDA2	RDA3
Environmental RDA	Environmental	**Moisture, pH**	P	**N**
	Invertebrates	Acari, Thripidae, **Cicadellidae, Carabidae, Delphacidae, Saldidae**	Aphididae, Cercopidae, **Phoridae**	Reduviidae, Staphylinidae, Araneae
Plant RDA	Plant	**CAREX, MOSS, SALIX,** SONCARV, CICEMIL	TYPHLAT, **RUBUIDA, PRUNPEN**	MEDISAT, TARAOFF, H**ORDJUB**
	Invertebrates	Acari, Araneae, **Cicadellidae, Saldidae, Delphacidae**	Reduviidae, Staphylinidae	A**cari, Aphididae,** Araneae

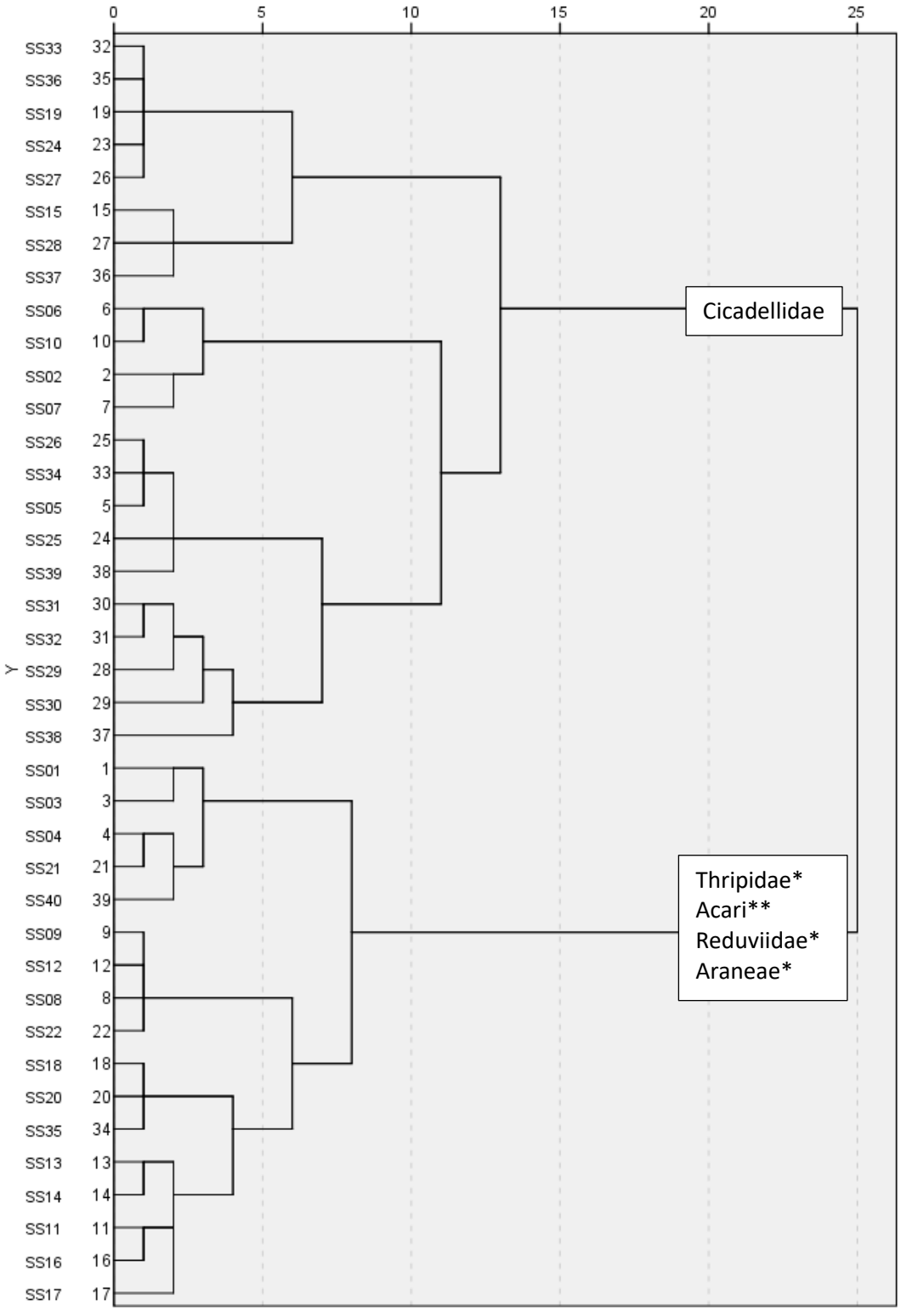

Figure 3.15: Cluster dendrogram showing similarities among sampling sites based on invertebrate relative abundance octaves captured in vacuum – soil samples across Sandhill Fen Watershed (*p<0.05; **p<0.01).

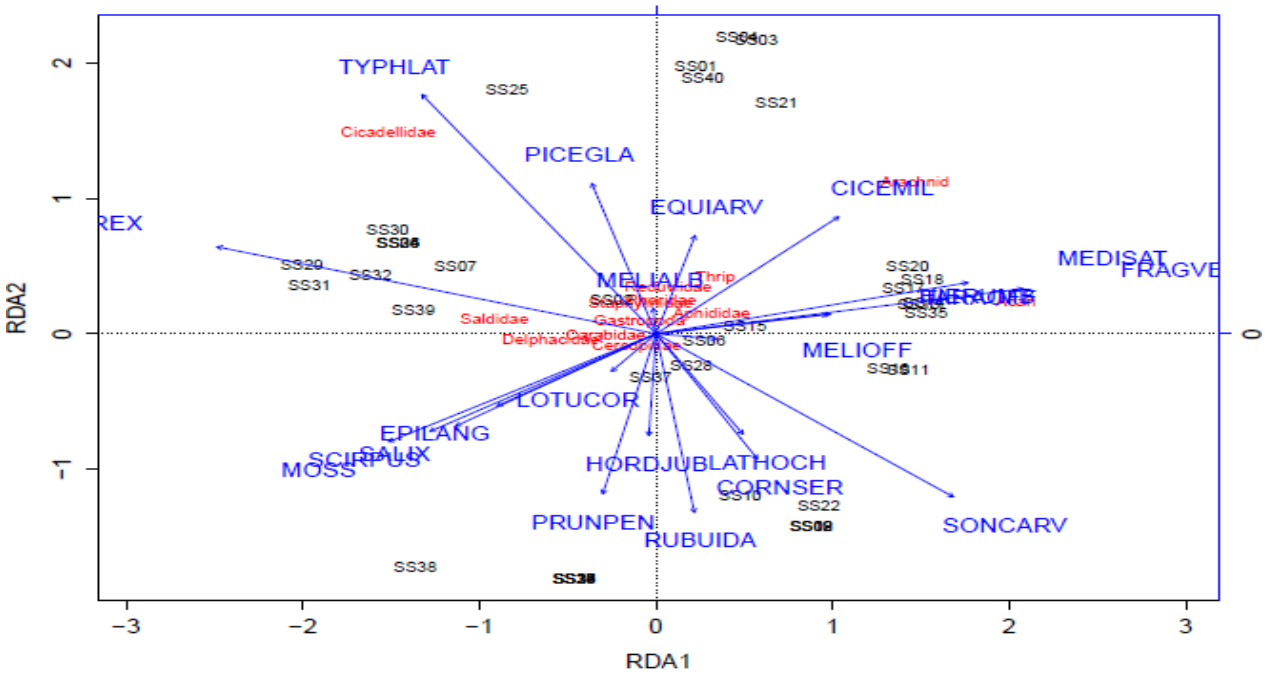

Figure 3.16: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and plant species presence/absence (Vacuum – Soil samples).

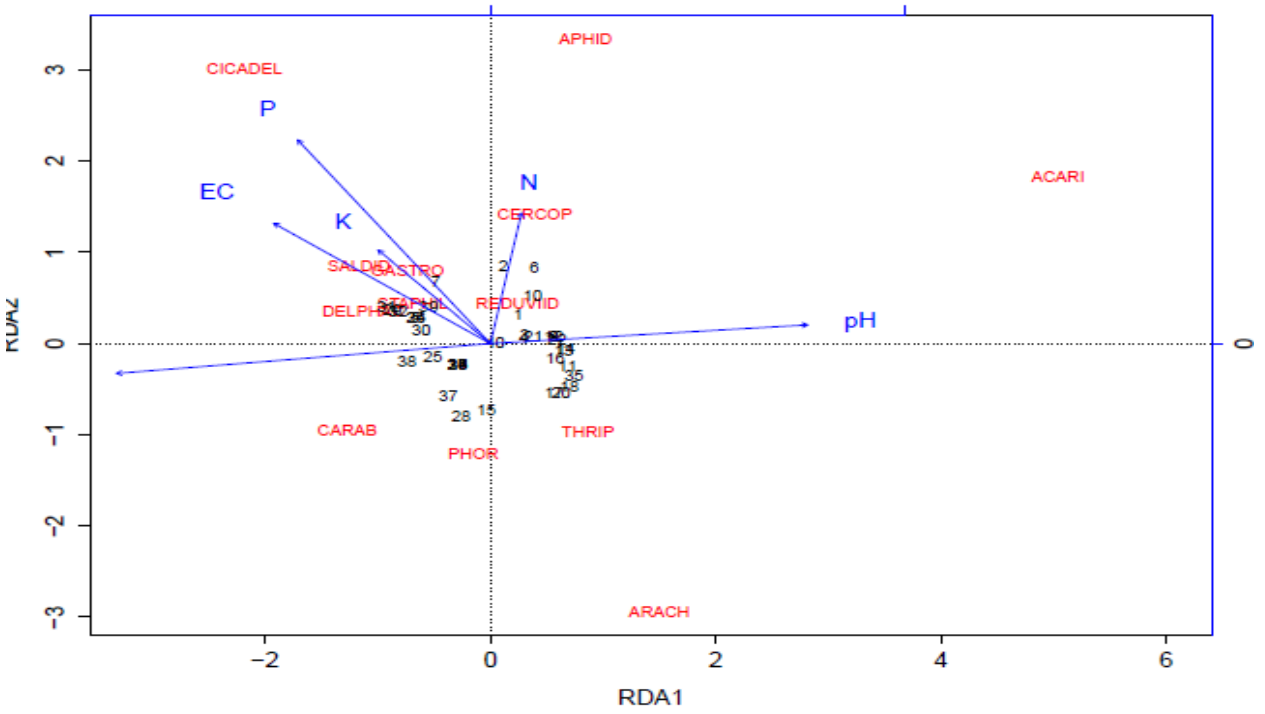

Figure 3.17: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements. Model significant ($p<0.0001$). (Vacuum – Soil Samples).

Sticky Traps

The overall invertebrate abundance and richness of the sticky trap samples (n=39) were 71.00±7.23 and 9.64±0.31 respectively. Peat sites (n=17) had an abundance of 72.9±7.94 and richness of 9.8±0.21. LFH sites (n=22) had an abundance of 69.6±11.52 and richness of 9.5±0.52. There was no significant difference with abundance and richness between the two soil types.

Cluster analysis of the sticky trap data indicated two main groups of the sites, and three subgroups within Group 1 (Groups 1A, 1B, and 1C: Figure 3.18). Comparisons between Group 1 and Group 2 identified Chironomidae (ANOVA F=45.36), Sciaridae (fungus gnat; ANOVA F=6.70), Hybotidae (dance flies; ANOVA F=8.36), Cicadellidae (ANOVA F=4.59) and Chalicoidea (ANOVA F=6.01) as being key Group 1 invertebrate taxa, and Cecidomyiidae (gall flies; ANOVA F=7.88), Thripidae (31.12), and Platygastridae (wasps; ANOVA F=4.80) as key invertebrates in Group 2. Group 1A was distinguished from Groups 1B and 1C by high abundance taxa of Hybotidae (ANOVA F=10.09), Thripidae (ANOVA F=11.19) and Chalicoidea (ANOVA F=15.41) whereas Groups 1B/1C had key invertebrate taxa defined as Phoridae (scuttle flies; ANOVA F=12.65) and Braconidae (wasp; ANOVA F=10.28), Lastly, key invertebrate taxa in Group 1B were identified as Anthocoridae (shore bugs; ANOVA F=36.44) and Braconidae (ANOVA F=8.12), with Group 1C key invertebrates identified as Sciaridae (ANOVA F=24.90) and Cecidomyiidae (ANOVA F=6.98). The environmental analysis identified Group 1 sites as having higher values of potassium (ANOVA F=4.71), phosphorus (ANOVA F=4.90) salinity (ANOVA F=4.61) and moisture content (ANOVA F=7.66). Group 1A was separated from Group 1B/C has it lower values of moisture content

(ANOVA F=6.66). There were no significant environmental differences identified between Groups 1B and 1C.

In this case, the RDA using plant community as explanatory showed a linear relationship with the invertebrate community explaining 64% of the invertebrate community variation and resulting in a significant model ($p<0.042$) (Figure 3.19). The first axis showed a positive relationship between upland plants (*S. arvensis, Medicago sativa, Melilotus album,* and *Melilotus officinale)* and Thripidae. The RDA using the environmental variables as explanatory also produced a significant model ($p<0.001$) and explained 25% of the invertebrate community variation (Figure 3.20). The first axis described an association with high moisture and high salinity indicating the presence of Chironomidae, Sciaridae, Braconidae, and Cicadellidae.

Table 3.6: Summary of invertebrate associations with soil chemistry and plant community variables with ANOVA F identified variables and Redundancy Analysis (RDA) using Sticky Trap-based invertebrate relative abundance (octaves). Bold-faced terms indicate negative association with identified axis

Dominant Peat Invertebrates:	Chironomidae, Cicadellidae, Braconidae			
Dominant LFH Invertebrate:	Thripidae, Lepidoptera			
DFA		Group 1 vs **Group 2**	Group 1A vs **Group 1B/1C**	Group 1B vs **Group 1C**
	Soil Variables	K, P, EC, Moisture	**Moisture**	
	Invertebrates	Chironomidae, Sciaridae, **Cecidomyiidae**, Hybotidae, Cicadellidae, **Thripidae**, Chalicoidea, **Platygastridae**	**Phoridae, Sciaridae**, Hybotidae, **Cicadellidae**, Thripidae, Chalicoidea, **Braconidae**	**Sciaridae, Cecidomyiidae**, Anthocoridae, Braconidae
RDA		RDA1	RDA2	RDA3
Environmental RDA	Soil Variables	**Moisture, EC**	**K**	P
	Invertebrates	Thripidae, Cecidomyiidae, **Chironomidae, Sciaridae, Braconidae, Cicadellidae**	Mycetophilidae, **Phoridae, Acari**	**Chalicoidea**
Plant RDA	Plant	SONCARV, MEDISAT, MELIALB, MELIOFF, **TYPHLAT, CAREX**	MOSS, CICEMIL, PICEGLA, **FRAGVES, EQUIARV**	**EPILANG, RUBUIDA, TARAOFF**
	Invertebrates	Thripidae, **Phoridae, Braconidae, Cicadellidae**	Chalicoidea, Lepidoptera, **Acari**	Mycetophilidae, **Sciaridae**

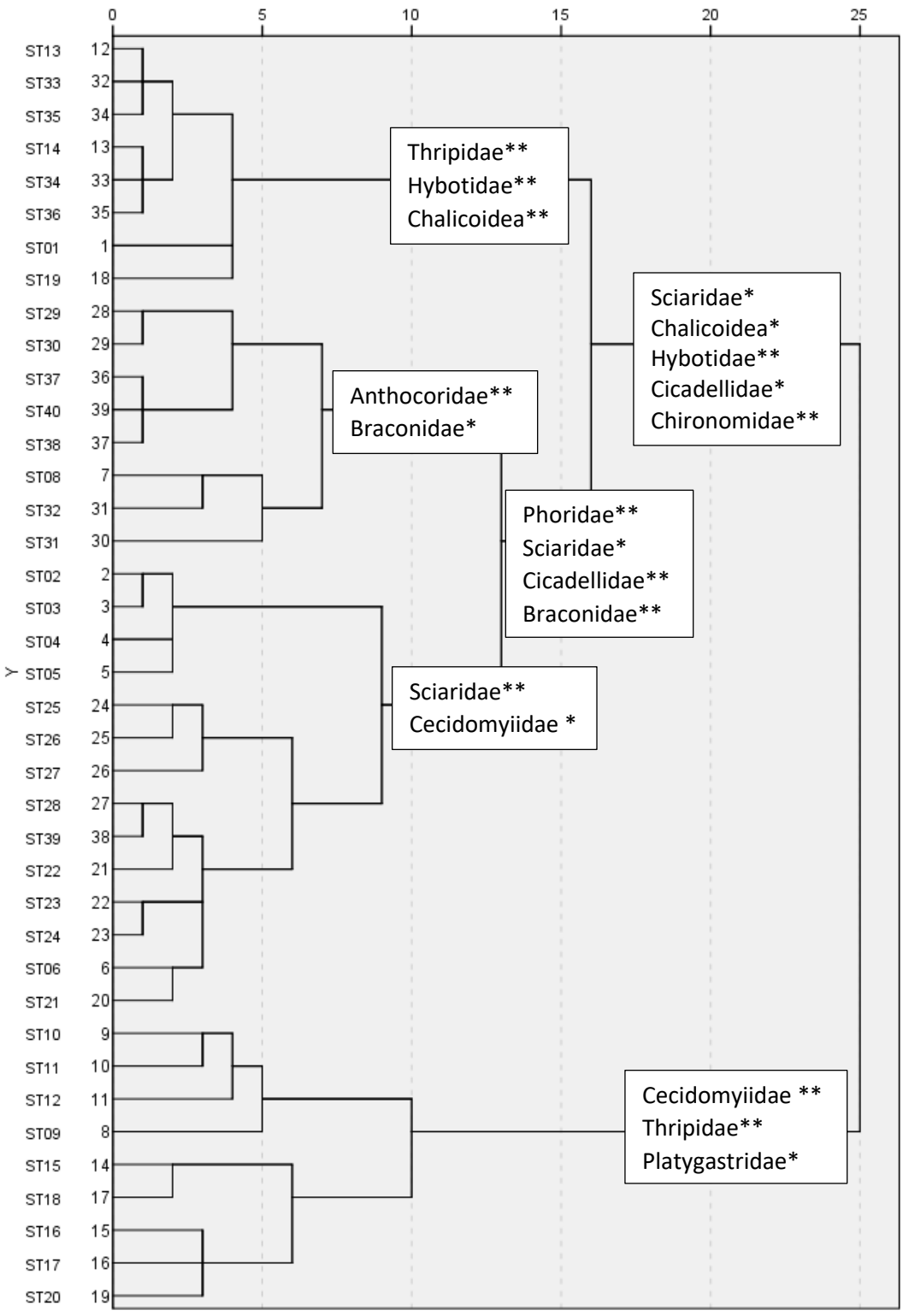

Figure 3.18: Cluster dendrogram showing similarities among sampling sites based on invertebrate relative abundance octaves captured in sticky traps across Sandhill Fen Watershed (*p<0.05; **p<0.01).

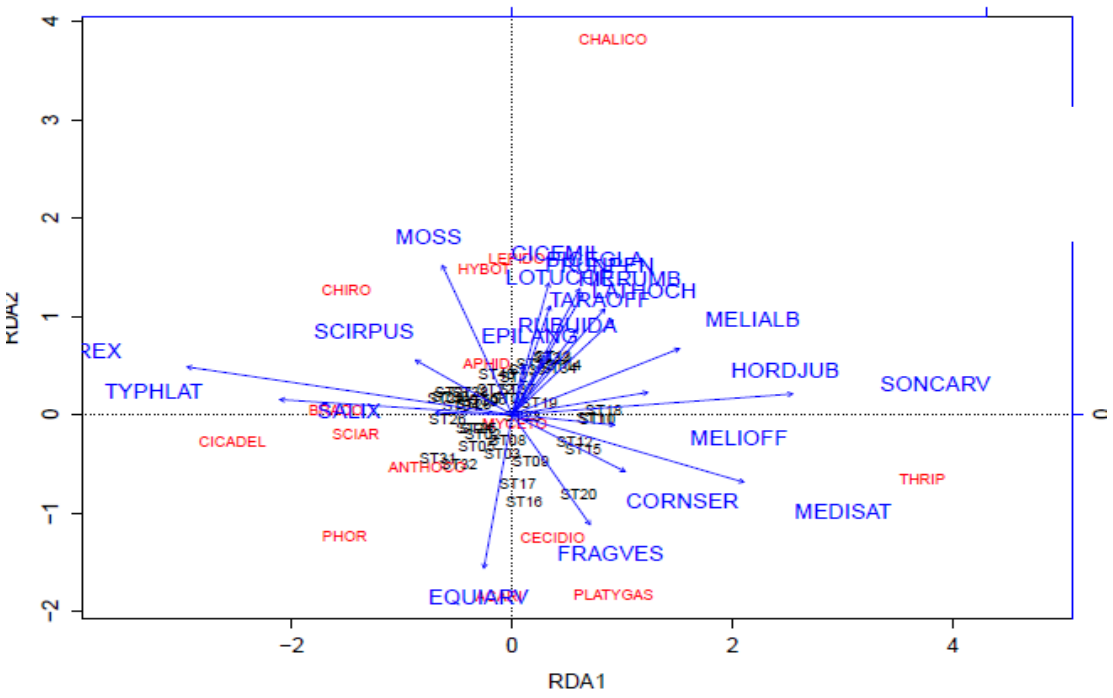

Figure 3.19: RDA biplot of plant community and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and plant species presence/absence. Model significant ($p<0.042$) (Sticky Traps).

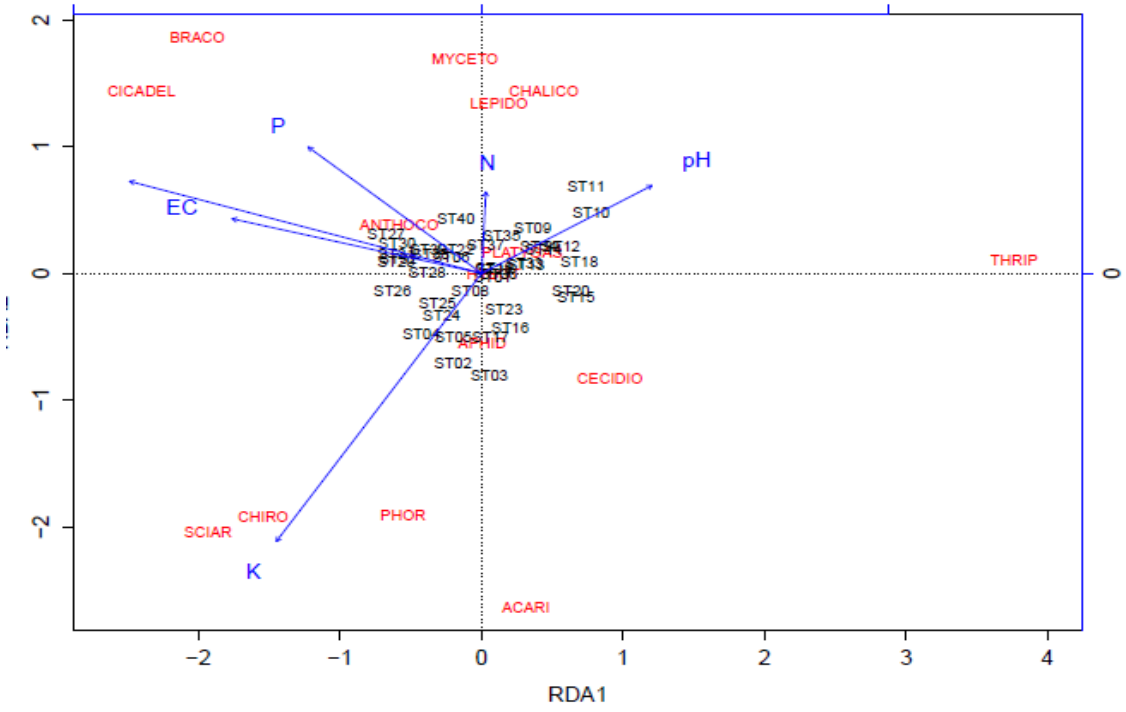

Figure 3.20: RDA biplot of environmental factors and associated invertebrate taxa among all sites using invertebrate relative abundance (octaves) and soil measurements. Model significant ($p<0.001$) (Sticky Traps).

Community Structural Equation Modelling

Using Spearman correlations on the entire data matrix (invertebrate abundance octaves, plant presence/absence, and environmental measurements), two communities were identified based on their plant community, soil chemistry, and invertebrate composition. A path diagram was created for each community. Bootstrapping was used to evaluate the significance of association identified by the SEM. 5000 iterations of the model were completed and a mean calculated. A diagram of the model with t-values was generated for each community, with significant correlations being greater than 1.96 (corresponding to t-values). In Table 3.7, all bootstrapped means were recorded with significant values being bolded.

Table 3.7: Summary table of total effects of latent variable correlations through community path analysis and subsequent bootstrapping (n=5000). Significant values are bold-faced.

	Correlation Values					
	Invertebrate Community			Plant Community		
Habitat 1	Direct	Indirect	Total	Direct	Indirect	Total
Plant Community	0.650	0	0.650	---	---	---
Soil Chemistry	0.079	0.550	0.629	0.846	0	0.846
Bootstrapped Means						
Plant Community	0.589	0	0.589	---	---	---
Soil Chemistry	0.153	0.499	**0.652**	**0.861**	0	**0.861**
Habitat 2						
Plant Community	0.476	0	0.476	---	---	---
Soil Chemistry	-0.453	-0.266	-0.719	-0.558	0	-0.558
Bootstrapped Means						
Plant Community	**0.495**	0	**0.495**	---	---	---
Soil Chemistry	**-0.448**	**-0.279**	**-0.726**	**-0.558**	0	**-0.558**

The predicted models were composed of three sets of latent variables: soil chemistry, plant community and invertebrate community. The direction of the linking arrows between latent variables indicate the direction one variable is affecting the other. In the following two models soil chemistry is affecting plant community composition and invertebrate community directly and plant community is directly affecting the invertebrate community composition. The variables found in the rectangles attached to the latent variables are variables that have measured values. The number values associated with the arrows in Figures 3.23 and 3.25 indicate correlation coefficients between measured variables and latent variables, or between latent variables. The values in the circles are regression coefficients, which indicate the amount of variation explained by the latent variables connected to it. Figures 3.24 and 3.26 are the resulting t-values produced through bootstrapping of the predicted model. Higher values indicated highly significant correlations among variables.

Habitat 1 (Peat) (Figures 3.21-3.22)

This first community was determined through the correlations with sites at which plant species *Carex* sp. and *T. latifolia* were present or absent. The correlating environmental variables were moisture content (having saturated or submerged soils), high soil salinity, and a higher phosphorus content. The soil chemistry explained 71.6% of the variation in the plant community, and 51.6% of the invertebrate community was explained through the plant community and soil chemistry. The invertebrate community in this model was composed of Braconidae, Cicadellidae, Delphacidae, Ephydridae, Saldidae, and Sphaeroceridae. The bootstrapping showed that the soil chemistry was strongly correlated with the plant community present, indicating that the soil chemistry tends to dictate the

plants that grow in a particular soil type. Neither the plant nor soil chemistry directly affected the invertebrate community, but the soil chemistry had a significant total (overall) effect on the invertebrate community mediated through the mediating latent variable of the plant community.

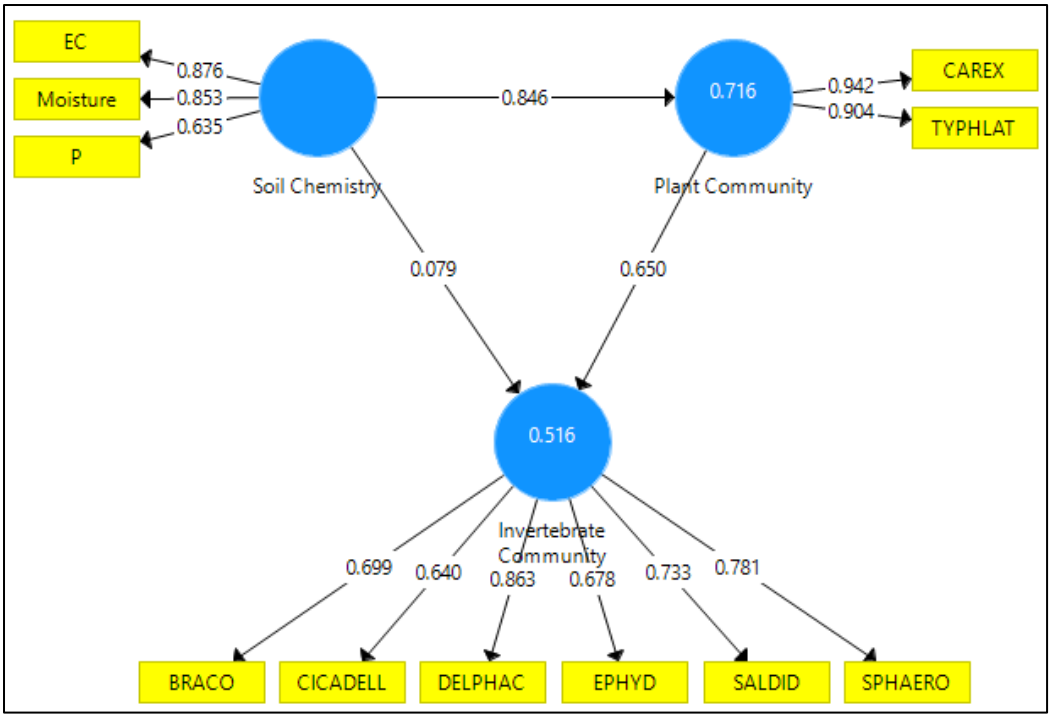

Figure 3.21: Path correlations of Habitat 1, indicative of wet, saline sites with a *Carex* sp. and *T. latifolia* plant community, and presence of Braconidae, Cicadellidae, Delphacidae, Ephydridae, Saldidae and Sphaeroceridae invertebrates.

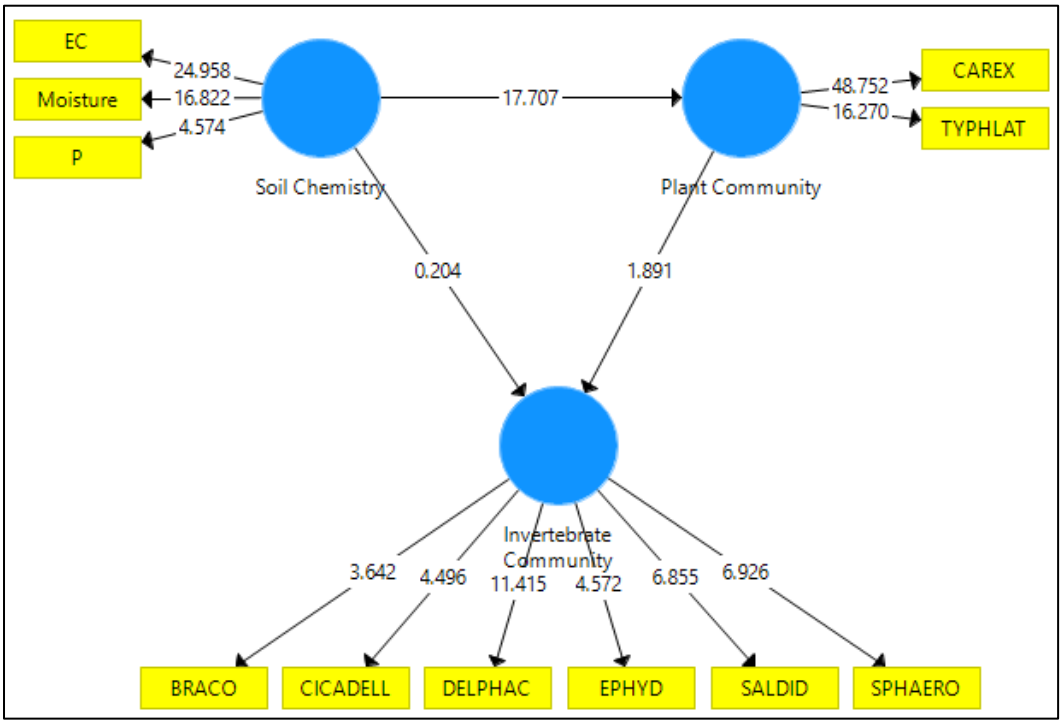

Figure 3.22: Measure of model significance of Habitat 1 (Peat). Values are t-values, with greater values indicating highly significant relationships among variables.

Habitat 2 (LFH) (Figure 3.23-3.24)

The second predicted habitat model was determined through the correlations of components of the plant community *Fragaria vesca* (strawberry), *Medicago sativa* (alfalfa), and *Sonchus arvensis* (thistle) with taxa making up the invertebrate community. The components of the invertebrate community identified to be association with the specified plant community included Acari, Araneae, Thripidae, Chrysomelidae (leaf beetles), and Formicidae. Originally, the model contained all measured environmental variables for the soil chemistry, but only salinity, moisture content and pH had correlation values over 0.5, which is generally the coefficient value at which components are accepted or rejected (Garson, 2016). The soil chemistry explained 31.1% of the plant community variation, with the soil chemistry and plant community accounting for 67.3% of the invertebrate variation. The negative correlation between the soil chemistry and other latent variables indicated that identified the plant community and invertebrate community were found in a soil habitat opposite to the one identified by the model. In other words, strawberry, alfalfa and thistle are found in soils with low moisture content, more alkaline, and low in salinity, which is typically an LFH soil. The invertebrates identified within the model are commonly found in a terrestrial habitat, which is likely composed of LFH soil. This model identified the plant community and soil chemistry as both significantly affecting the invertebrate community composition.

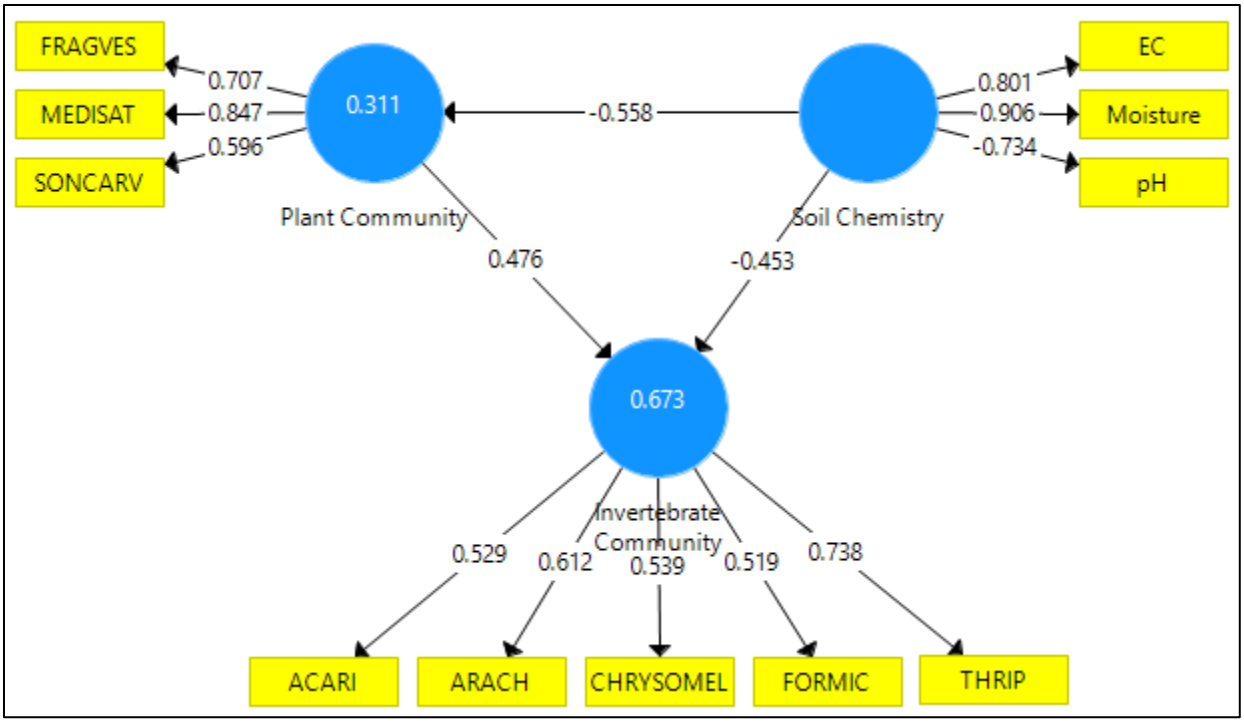

Figure 3.23: Path correlations Habitat 2 (LFH), indicative of dry, fresh sites with a *F.vesca-M. sativa-S. arvensis* plant community, and presence of Acari, Araneae, Chrysomelidae, Formicidae, and Thripidae invertebrate taxa.

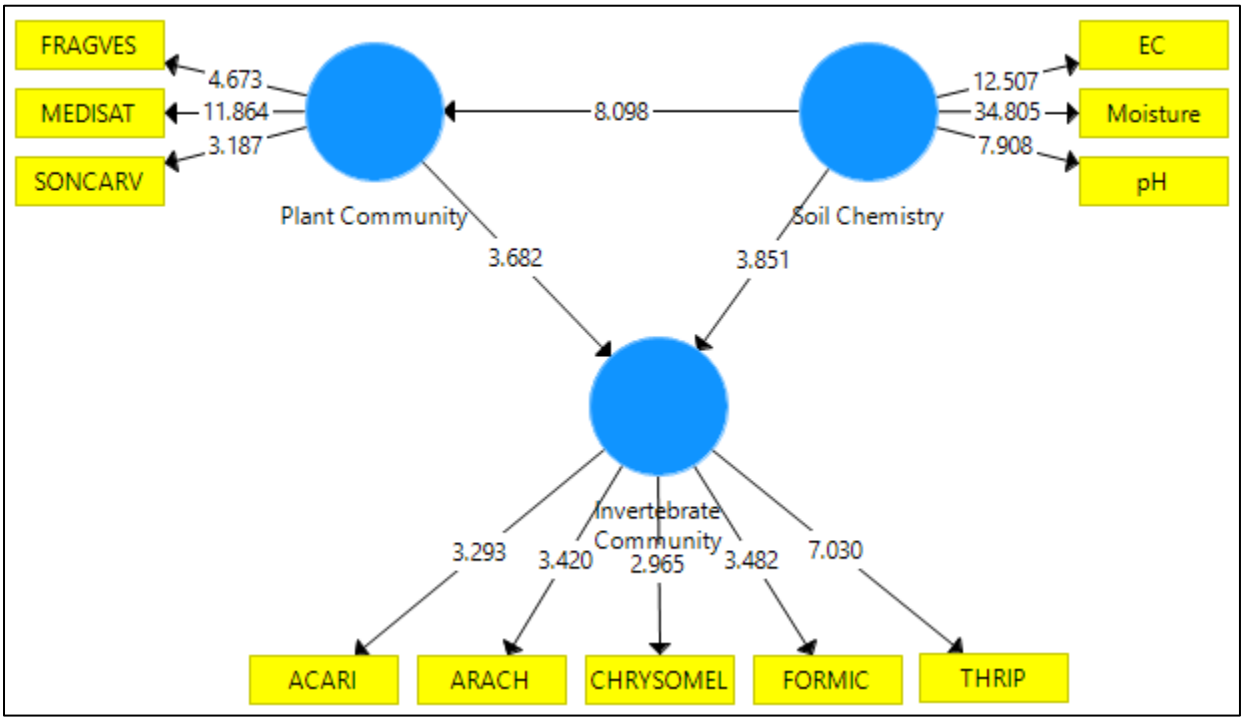

Figure 3.24: Measure of model significance of Habitat 2 (LFH). Values are t-values, with greater values indicating highly significant relationships among variables.

Discussion

Three general predictions were proposed for this study:

1) Different sampling methods would catch unique groups of invertebrates.
2) The plant community would be the main predictor of the invertebrate community composition present at a sampling site.
3) Path analyses would identify distinctly different LFH-based and peat-based invertebrate communities.

In regards to the first prediction, the dominance of most invertebrate taxa varied greatly among the five sampling methods employed (Appendix A – Invertebrates). Additionally, several taxa were found in only a single trap type, albeit only in small numbers. The vacuum samples were dominated by hemipterans (planthoppers, leafhoppers, seed bugs), and predatory arachnids (mites and spiders), whereas sweep samples mainly caught larger-bodied flies, and beetles. These findings differ slightly from the results of Doxon et al. (2011), who found that vacuum samples were dominated by Diptera (flies), Hemipterans (hoppers) and Hymenoptera (wasps) and that sweep samples contained mainly Hemiptera, Orthoptera (grasshoppers) and Araneae (spiders). This difference in the composition of taxa caught reflect differences in the type of vacuum used in the sampling process. Doxon et al. (2011) used a standard Dietrick vacuum aspirator, which is more typically used in insect sampling, but has a bias towards small-bodied invertebrates. The vacuum unit used in my study was similar to the equipment used by Hoekman et al. (2012) and Williams (2014), consisting of a modified leaf-blower/vacuum. Measures of invertebrate family richness were similar to what Williams (2014) reported

for sticky traps in fens, but not with vacuum samples from vegetation, which had Williams reporting greater family richness.

Sticky traps caught many invertebrate taxa, the most abundant groups being Diptera and Hymenoptera. Most of the flies were small-bodied, and semi-terrestrial, whereas most of the wasps were parasitic and varied in body size. Sticky traps caught the greatest number of unique taxa among all traps; primarily small flies and parasitic wasps. Pitfall traps were effective at catching the common ground-dwelling invertebrates such as Carabidae beetles, Opiliones (harvesters) and Formcidae (ants).

Influence of Environmental Factors on the Invertebrate Community Composition

Environmental factors such as soil type, nutrient concentration and moisture can be important determinants of the type of organism that may live in that habitat (Davis et al., 2006). For example, moist or saturated soil is not conducive to supporting ground-dwelling and terrestrial taxa (Rosenberg & Danks, 1987). The Sandhill Fen watershed was built using two main cover soil types- peat in lowland areas and LFH in the upland portion of the fen (Wytrykush et al. 2012), so it was expected that different invertebrate assemblages would be found to associate with the differing soil placements. Overall, neither the total abundance nor family richness differed at a sampling site with respect to soil type. However, distinct compositional differences were observed. For example, peat site catches were composed mainly of semi-terrestrial invertebrates like Chironomidae (adult midges), Saldidae (shore bugs), and Ephydridae (shore flies), whereas LFH sites had a greater prevalence of hymenopterans and mites. The finding of differential invertebrate community composition among soil placement types supports the postulate that wetland (peat) and more terrestrial (LFH) areas would support distinctively different invertebrate

assemblages as has been reported in other comprehensive surveys of peatlands (Rosenberg & Danks, 1987).

In most of the RDA models variation in plant community composition explained the majority of the variation in invertebrate community composition among sites; however, the environmental factors were statistically significant. This means that though less of the variation in invertebrate community composition was explained by soil chemistry attributes, the invertebrate community is mainly influenced by the soil based environmental factors present at the sampling site. This contrasted with the prediction that the plant community would be the greatest determinant of invertebrate community composition. The only sampling method that did not follow this pattern was the sweep samples, where the plant community had a significant influence on the invertebrates. This difference is likely because the sweep samples collect invertebrates on the plants that are conducive to being sampled using that method, such as sedges and grasses, but not woody shrubs such as birches and pines. In addition, the lack of significant association seen through the plant RDA may indicate that relationships between the two matrices evaluated were nonlinear. Since the RDA works through multiple linear modelling, curvilinear relationships may occur, but not be detected (Marakenov & Legendre, 2002). This likely reflects the trapping methods used for invertebrates and their feeding habits. Generalist invertebrates are more likely to be found in a variety of plant habitats, whereas specialist invertebrates will be found with a single or few plant species (Haddad et al., 2001). Additionally, mobile invertebrates will be found in various habitats because they are able to travel longer distances ground-dwelling taxa or those that are confined to one habitat.

Patterns of Invertebrate Community Change Along Environmental Gradients within the Watershed

The research conducted in this study helps to elucidate the invertebrate distributional patterns within the fen watershed. Cluster analyses summarized site groupings based on differences in invertebrate relative abundances. Complementary analyses identified the invertebrate taxa that were responsible for those groupings and the associated environmental variables. The RDA identified the invertebrate association with both plant community and soil chemistry. Finally, the Path Analysis identified the plant and invertebrate associations that constituted two distinct Sandhill Fen Watershed communities and their intercorrelations among the plant community, the invertebrate community and the soil chemistry.

The plant community and soil chemistry characteristics representing Habitat 1 are those indicative of peat locations as determined in Chapter 2. The path diagram of the "Peat" community summarizes the strength of relationships among the three major components of the lowland areas that were constructed with a peat soil base. The model identified a highly significant relationship between the soil variables and the plant community, indicating that the soil components (EC, moisture, and P) are important determinants of the plant community in this type of habitat (primarily *Carex sp.* and *T. latifolia)*. The finding that the plant community mediates the effect of soil chemistry on the invertebrate community is noteworthy. This implies that knowledge of the soil chemistry of a site alone would not be a useful predictor of the invertebrate composition, but needs additional information on presence of the plant to predict the invertebrate community composition. This finding is similar to that of Sanderson et al., (1995), who found that the

relative influences of soil and vegetation varied according to the types of invertebrate studied.

The significant correlation between the plant community latent variable and soil chemistry in Habitat 2 (upland LFH areas) indicates that the three meadow plant species were associated with soils having relatively low moisture content, low salinity, and higher pH (more alkaline) than was found in lowland portions of the watershed. The plant community here was most distinctly composed of *Fragaria vesca* (strawberries), *Medicago sativa* (alfalfa), and *Sonchus arvensis*. The path loadings and subsequent bootstrapping results for the upland LFH sites indicated significant associations with both soil type and plant community composition.

Conclusion

This study described the invertebrate community composition patterns within the Sandhill Fen Watershed using a suite of multivariate analytical techniques including cluster analysis to distinguish distinct groupings of sites according to soil chemistry, and the invertebrate families present. Redundancy analysis indicated that invertebrate community compositional differences were associated with effects of a moisture gradient and nutrient gradient, with which particular plant species were also associated (i.e. upland meadow vs. wetland plants).

Finally, two distinct habitats – upland and lowland (peat) - were identified through partial least squares structural equation modelling. A “Peat” habitat was characterized by the presence of *Carex sp.* and *T. latifolia* in soil that is relatively wet, saline, and slightly acidic. Invertebrates associated with this habitat are common wetland taxa typical of

natural fens. A second habitat, "LFH" was composed of upland plants such as *M. sativa, F. vesca,* and *S. arvense,* in sites with drier, more alkaline soil that is typical of a terrestrial boreal habitat, with invertebrate taxa associations distinct from the wetland invertebrate assemblage. Therefore, sites occurring in areas that were idealized to establish as a wetland have wetland characteristics and sites that occur in areas planned to establish as terrestrial habitats have characteristics similar to natural, terrestrial ecosystems.

Chapter 4 – A Comparison of Sandhill Fen Communities to Reference Fens Communities

Introduction

The hydrologic and chemical composition of peatlands, specifically fens and bogs, in the Boreal Zone of Alberta have been studied over the last few decades. Zoltai & Vitt (1995) classified fens on the basis of hydrology and nutrient composition and documented their associated plant communities. Two types of fens are relevant to the current study. "Rich fens", which are characterized as being hydrologically connected to their surrounding watershed and receiving groundwater and surface water with relatively high, mineral content and alkaline pH. These fens have a plant community dominated by brown mosses and sedges. "Poor fens" are acidic peatlands dominated by *Sphagnum* mosses, which restrict nutrient availability and waterflow. Consequently, the vascular plant flora is depauperate, and decomposition rates are slow. Poor fens are hydrologically similar to rich fens, but chemically and florally more similar to bog peatlands (Zoltai & Vitt, 1995). Slack et al., (1980) studied the vegetation gradient of rich fens in Alberta, and found that the water table was the most important determinant of the type of plants able to survive within the fen. For example, black spruce trees and *Sphagnum* mosses are typically found together in sites with a low pH and low water tables (bogs, some poor fens), whereas the presence of *Carex* sp. and birch shrubs indicate a more alkaline environment with more moisture (poor to rich fens) (Rosenberg & Danks, 1987).

As previously stated, invertebrates are ubiquitous and therefore are a significant component of peatland ecosystems. Because the hydrological and chemical conditions of fens vary through a year, it is not uncommon for the aquatic invertebrate community to

change over the course of a single season (Rosenberg & Danks, 1987). Some sites may host a more aquatic invertebrate community in the early spring after winter thaw because of a raised water table, but dry out and become more similar to a terrestrial habitat later in the year (Rosenberg & Danks, 1987). Additionally, there is limited knowledge on the behaviour of most terrestrial and semi-terrestrial invertebrates within these habitats. (Danks, 1979; Williams, 1979; Rosenberg & Danks, 1987). Sampling of terrestrial, semi-terrestrial and aquatic invertebrates is still important to understanding the dispersal capabilities and extent of the species ecological breadth.

The comparison of natural reference sites to that of the Sandhill Fen Watershed is important because of Sandhill's novelty. It is the first watershed constructed explicitly to support a wetland in the post-mining landscape of the AOSR, and therefore the study of the invertebrates present is an important starting point for further research.

The objective of this study was to assess the environmental and biological characteristics of several reference fens and to assess the relationship between their environmental features and their invertebrate community composition relative to the patterns observed in Sandhill Fen. This was accomplished this by:

1) Assessing the abundance and composition of invertebrate communities within 8 reference fens using collection methods previously employed to study Sandhill Fen
2) Comparing the soil chemistry l variables, plant community and invertebrate community composition between reference sites classified as rich fens (*Carex*-based) and poor fens (*Sphagnum*-based)

3) Assessing the similarities or differences between the invertebrate community composition of Sandhill Fen to that of the reference fens

Because Sandhill Fen Watershed is only a few years old, it is in the early successional stages, unlike the reference sites, which have been productive for much longer, resulting in a plant community that is dominated by one or few species (Southwood et al., 1979). Because of the projected low plant diversity of natural fens, it was predicted that these reference wetlands would have a lower invertebrate richness than the Sandhill Fen Watershed, similarly to the findings of Risch (1981) who reported that low plant richness supported a low invertebrate species richness when compared to sites with a greater plant richness in a study of tropical monocultures and polycultures. In addition, Williams (2014) found low invertebrate diversity patterns in fens compared to wet meadow vegetation zones in marshes that are analogous to peat and LFH zones of the Sandhill Fen. Therefore, I predicted that reference sites, overall, would have lower invertebrate richness than Sandhill Fen sites, but that they would support greater abundance of invertebrates. I predicted that *Carex*-based sites, would host different invertebrate community composition than *Sphagnum*-based sites because of the differential plant communities and invertebrate associations. Finally, taking into account the different invertebrate communities within Sandhill Fen, I predicted that the invertebrate fauna at sites within Sandhill Fen with a peat-soil base would be most similar to the fauna found in *Carex*-dominated reference fens, and that the invertebrate fauna from Sandhill Fen sites underlain with LFH soil (i.e., drier, more upland-like locations) will be unique. With the Sandhill Fen – LFH hosting a separate soil composition and plant community (Chapter 3), invertebrate community of these sites will likely be dissimilar to all reference wetland invertebrate communities.

Methods

Eight reference fens were sampled in 2015 for comparison with Sandhill Fen (Fig. 4.1). They were chosen because of their proximity to the Fort McMurray area and because previous research by others provided background information on plant community composition and water chemistry (Williams, 2014).

Figure 4.1: Location of eight reference fens sampled during summer of 2015.

Soil samples were collected at three locations in each reference fen for comparison with samples from the Sandhill Watershed. Each soil sample was measured for moisture content, soil salinity, and nutrient content, following the methods used for Sandhill Fen (Chapter 2). The presence of plant species within 0.5 m of a pitfall or sticky trap was

recorded, as well as if a plant was passed over by the sweep net during sampling. Plant species presence/absence was determined in each of the eight reference fens.

Two types of reference fens were sampled during summer 2015. One group of reference sites was considered to be "*Carex*-based", in that the locations studied were primarily had peaty soil, and *Carex* dominated the vegetation. These fens are typically considered to be "rich fens" compared to the "Sphagnum-based" fens, which are more acidic and considered to be "poor fens" (Zoltai & Vitt, 1995). The general plant substrate (*Carex vs. Sphagnum)* was subjectively classified at the location at which sampling occurred within each reference fen. Reference sites considered to be "Carex-based" were TR1, TR2, TR3, and BO, with HT, PF, TR5, and TR4 being labeled as "Sphagnum-based" fens. Only sites PF and HT had been previously studied by colleagues (Williams, 2014).

Reference Fen Descriptions

Carex-*based Sites*

Tower Road 1 – UTM 12V 464494E, 6290839N (TR1): This fen was the smallest fen sampled. It was surrounded by coniferous trees, with a small marsh-like area of open water in the centre. Samples were taken from the vegetated zone around the water in areas dominated by *Carex* sp. and *Equisetum* sp. There was very little evidence of mosses.

Tower Road 2 – UTM 12V 464095E, 6290478N (TR2): This fen was located in a shallow valley bordered by white spruce trees (*Picea glauca)*. Standing water at the surface in some areas resulted in limited emergent vegetation growth, but most of the vegetated area was covered by *Carex* sp.

Tower Road 3 – UTM 12V 459922E, 6290849N (TR3): This site is dominated by sedges and other graminoid vegetation (grasses). It is located is a shallow valley, with jack pine (*P. banksiana*) and white spruce (*Picea glauca)* bordering it. Standing water was visible in some areas and there a limited amount of brown moss was presence. A small stream (approximately 0.5 m wide and less than 0.3 m deep) ran through the site.

Bottom Out Fen - UTM 12V 484364E, 6248248N (BO): Located close to PF, this site is in a steeper valley than most of the other fens samples. A large amount of standing water was present towards the southwest end of the fen, and the outside of the fen is surrounded by pine trees (*Pinus banksiana*.). The dominant plant type in this fen was *Carex*, with grasses and weedy plants present on the drier, upper slopes of the borders.

Sphagnum-based sites

Pauciflora Fen - UTM 12V 485501E, 6248074 N (PF): This fen is located approximately 40 km south of Fort McMurray, AB and measured around 7 ha in area (Williams, 2014). It was situated in a valley bordered by hills of coniferous trees. Black spruce (*Picea mariana)* is present within the fen. Dominant vegetation in this fen was mainly *Sphagnum* moss, with presence of Labrador tea (*Rhododendron groenlandicum* sp.*)* and birch plants (*Betula* sp.*).*

High Test Fen UTM 12V 467728E, 6312025N (HT): This fen was the largest sampled, measuring over 150 ha in area (Williams, 2014). It was bordered by coniferous trees, and contained many shrub species, such as birch (*Betula* sp.), and tamarack (*Larix laricina*) along the edges. Most of the fen substrate was moss dominated, with some areas of open water.

Tower Road 4 – UTM 12V 453079E, 6294562N (TR4): One of the larger fens in this area, this site was surrounded by white spruce (*Picea glauca)* and tamarack trees (*L. laricina)* with a base being dominated by moss. Other plants present in this area were birch *(B. glandulosa)*, Labrador tea *(R. groenlandicum*, and some other graminoid grasses.

Tower Road 5 – UTM 12V 452853E, 6294600N (TR5): Much like the previous fen, this site was surrounded by spruce (*Picea glauca)* and tamarack trees *(L. laricina)*, with a low water table. The substrate was mainly moss, and contained birch plants *(B. glandulosa)*.

Invertebrate Sampling

Invertebrates were sampled in each fen using sweep netting, pitfall traps and sticky traps. Ten sweeps, five pitfall traps and four sticky traps were employed in each fen. Sticky traps and pitfall traps were left out and collected after three 'good weather' days (no rain). Sweep netting was conducted on the day of trap deployment. Vacuum sampling was not feasible in the reference fens as most sites were inundated with water causing a large amount of liquid to be drawn into the vacuum sampler.

Invertebrate samples were processed in the laboratory using the same methods outlined in the previous chapters.

Statistical Analysis

The analysis of data in this chapter was broken down into three categories: soil-associated environmental variables, plant community composition, and invertebrate community composition.

Soil Associated Environmental Variables

Measurements of soil moisture content, soil salinity, and nutrient composition were averaged from each of the three samples taken from each reference site. A PCA was performed using normalized data, and rotated using a Varimax rotation. The wetland-specific scores of each Principal Component for *Carex* and *Sphagnum* sites were compared using *t*-tests (Bonferroni corrected for multiple tests) to assess differences between fen type. Data were $Log_{10}(x+1)$ transformed.

Variation in soil characteristics among reference wetlands was assessed using cluster analysis. Squared Euclidean distances of Log_{10}-transformed measurements were calculated, and sites were hierarchically clustered using Ward's Method. Based upon the results of this analysis, each reference wetland was assigned to a group and the between-group vs. within-group variance ratio (ANOVA F) was determined according to the Green & Vascotto (1987) method. The dispersion of NMDS was used to visualize the distances between sites based on their soil chemistry variables using Bray-Curtis similarity. Sites situated closer together in the ordination are more similar, and the closer sites are placed to the vector of a soil chemistry variable, the more important that variable is in defining the position that site in the ordination. The cluster analyses and NMDS were conducted again with the addition of Sandhill Fen measurements to compare its placement among components of reference sites. The inclusion of Sandhill Fen communities into these analyses was to determine whether Sandhill Fen was an outlier among the natural sites, or containing within a reference community. All ellipses were drawn by eye to encompass sites identified as either *Carex* or *Sphagnum* based fens.

Plant Community

Plant species were recorded on a presence (1)/absence (0) basis with a 1-m radius of each invertebrate sampling point in each fen. Plant community richness was measured as the number of plant species present within a fen, in the vicinity of each trap. The mean richness was calculated for all reference fens treated as a single group, and among plant base types (*Carex* and *Sphagnum*). A Principal Components Analysis (PCA) was used to determine whether there were plant community differences between the *Carex*-dominant and *Sphagnum*-dominant fens. The mean Principal Component scores for *Carex* sites and *Sphagnum* sites were compared using a *t*-test (with correction) for the first two Principal Component axes extracted from the analysis. A cluster analysis of only reference sites was performed using binary Squared Euclidean distances and Ward's method. Sites were put into groups and the plant species most responsible for the difference between groups assessed using the ANOVA F method (Green & Vascotto, 1978). Nonmetric MultiDimensional Scaling, with Bray-Curtis distances, was used to visualize the distances between sites and identify the plant species most dominant within those sites. Once again, Sandhill Fen sites were added to both cluster analysis and NMDS and differences assessed to determine whether it was an outlier among reference communities.

Invertebrate Community

For each reference site, the abundance and richness of invertebrates was summarized in three ways – by combining data from all trap types used at a site ("whole site"), by pooling data from all traps of one type at a fen, and by summarizing data for each trap individually. Additionally, the arithmetic mean (±SE) number of invertebrates per

trap per fen was calculated. Differences in invertebrate abundance between the two fen classes were measured overall and by trap type using T-tests. Relative abundance values were calculated and transformed into octaves for all further analyses of community composition. Variation in the composition of invertebrate communities was similarly analyzed using cluster analysis to identify biologically similar groups of wetlands, and then identifying the invertebrate taxa whose relative abundances differed most greatly between cluster groups identified using the ANOVA F method. Reference sites were then ordinated using NMDS of the relative abundances of invertebrate taxa to graphically illustrate relationships among the sites. As was done with the soil variables and plant species data, relative abundances of invertebrates from Sandhill Fen were added into the analyses. Invertebrate community composition was clustered with the reference sites using the same methods. Next, NMDS was employed to ordinate the placement of Sandhill Fen Watershed samples among the reference sites. Finally, distance-based Redundancy Analysis (db-RDA) was used to quantify the amount of invertebrate community variation explained by the environmental variables and the plant community, respectively. The Bray-Curtis distance metric was used to create the distance matrix representing invertebrate community-based dissimilarity on which the db-RDA was based.

Principal component analysis (PCA), cluster analyses and subsequent analysis of taxa whose relative abundance differed most greatly between cluster groups were performed using the Factor Analysis, Cluster Analysis and DFA modules, respectively in SPSS (24.0). Non-metric multidimensional scaling was conducted in R using Bray-Curtis distance measurements (metaMDS function). The distance-based redundancy analysis was also conducted in R (capscale function). Both of the R functions are found in the *vegan*

package, version 2.3-4. (Oksanen et al., 2016). Values from PCAs, NMDS, DFA and RDA are summarized in Appendix B.

Results

As previously described (Chapter 3), the Sandhill Fen invertebrate community composition reflects the chemistry and plants associated with two placement soil types - peat and LFH. Consequently, these two sets of Sandhill Fen invertebrate samples were compared independently to those of reference fens.

Soil Associated Variables

Cluster analysis for soil chemistry including reference fens and Sandhill Fen soil data, TR3 was again identified as anomalous due to its high nitrogen content (Figure 4.2). This analysis placed Sandhill Fen peat sites in one group (TR4+HT+TR1+SF-P+TR5+PF) and LFH sites in a second group (TR2+BO+SF-L), which were significantly different in terms of soil nitrogen content (ANOVA $F=11589$, $p<0.0001$). Finally, Group 1A (TR4+HT+TR1+SF-P) had a significantly higher soil moisture content than Group 1B (TR5+PF+SF-L; ANOVA $F=11.09$, $p<0.029$)). A second NMDS was conducted on the environmental variables with reference fen and Sandhill Fen data. NMDS1 emulated a moisture gradient, and NMDS2 acted as a chemical gradient. Neither site from Sandhill is contained within the reference sites ellipses, and look to be more associated with soil salinity (Figure 4.3).

Table 4.1: Mean±SE value of environmental measurements from soil samples from each reference fen (n=3) and Sandhill fen soil types (SF-P n=17; SF-L n=23).

	Site code	EC (uS)	K	N	P	MOISTURE (g/g)
Carex Based	BO	11.35±1.82	3.3±0.67	0.3±0.33	1.7±0.33	5.96±3.17
	TR1	33.81±8.20	2.7±0.33	0±0.33	1.3±0.33	15.25±3.81
	TR2	97.87±46.88	2.3±0.33	0.3±0.33	2.0±0.58	7.22±1.26
	TR3	124.99±105.92	3.3±0.33	1.3±1.33	2.0±0.33	0.90±0.51
	Mean	67.00±26.64	2.92±0.25	0.50±0.29	1.75±0.16	7.33±2.97
Sphagnum Based	HT	106.66±25.67	3.0±0.58	0±0.33	1.0±0.33	6.16±3.16
	PF	15.88±2.02	3±0.33	0±0.33	1.3±0.33	0.24±0.06
	TR4	37.87±3.64	2.3±0.67	0±0.33	1.3±0.67	6.31±2.81
	TR5	31.23±4.07	1.7±0.33	0±0.33	1.0±0.58	0.84±0.48
	Mean	47.91±20.12	2.50±0.32	0.0±0.33	1.17±0.10	3.39±1.65
Sandhill Fen	SF-P	757.12±70.29	2.1±0.2	0±0.33	1.8±0.24	2.59±0.4
	SF-L	398.57±18.02	2.0±0.61	0.4±0.37	1.3±0.37	0.29±0.30
	Fen Mean	550.96±37.25	2.03±0.15	0.2±0.08	1.5±0.12	1.27±0.25

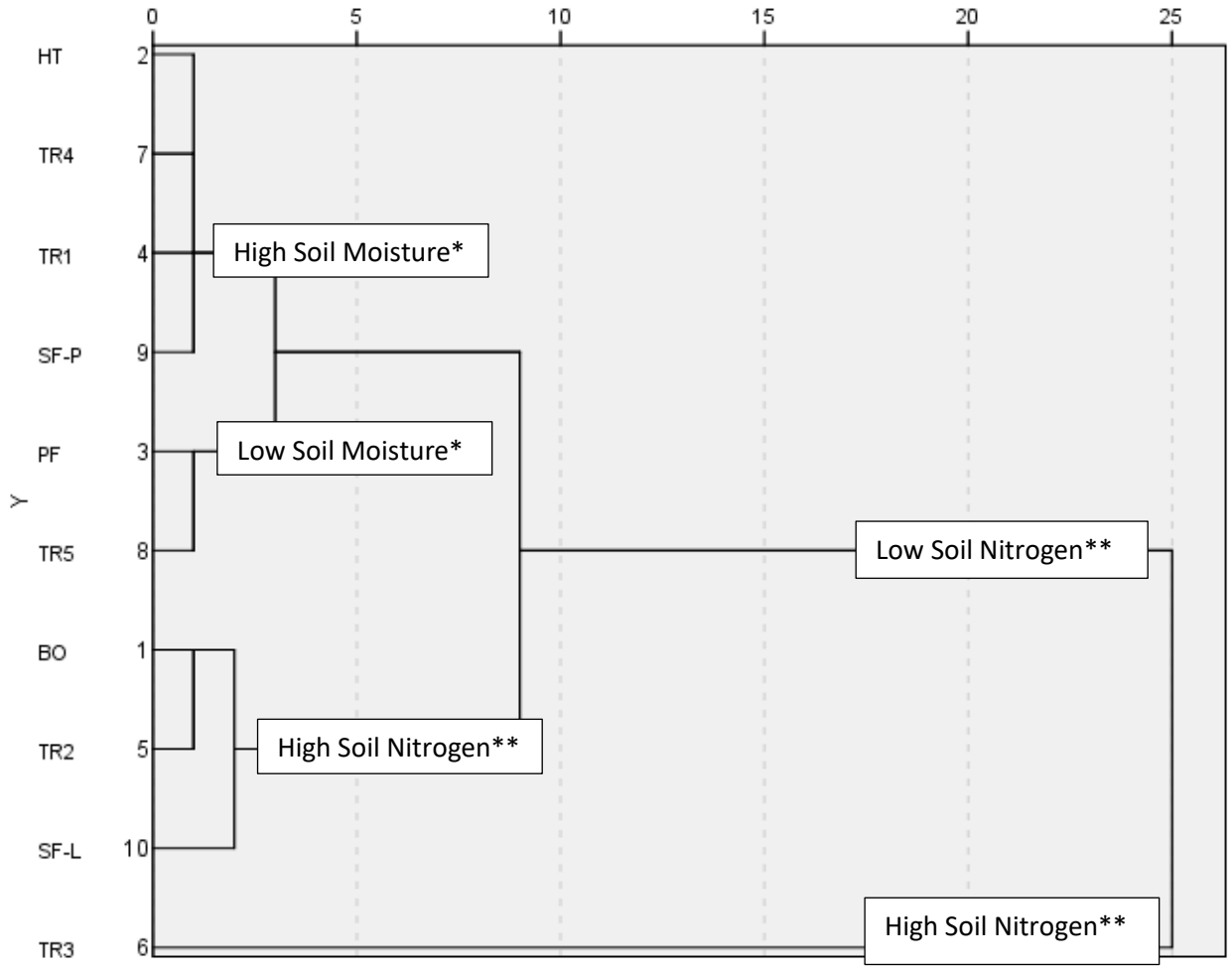

Figure 4.2: Cluster analysis of Sandhill fen communities with reference communities based on environmental variables (**p<0.01; *p<0.05).

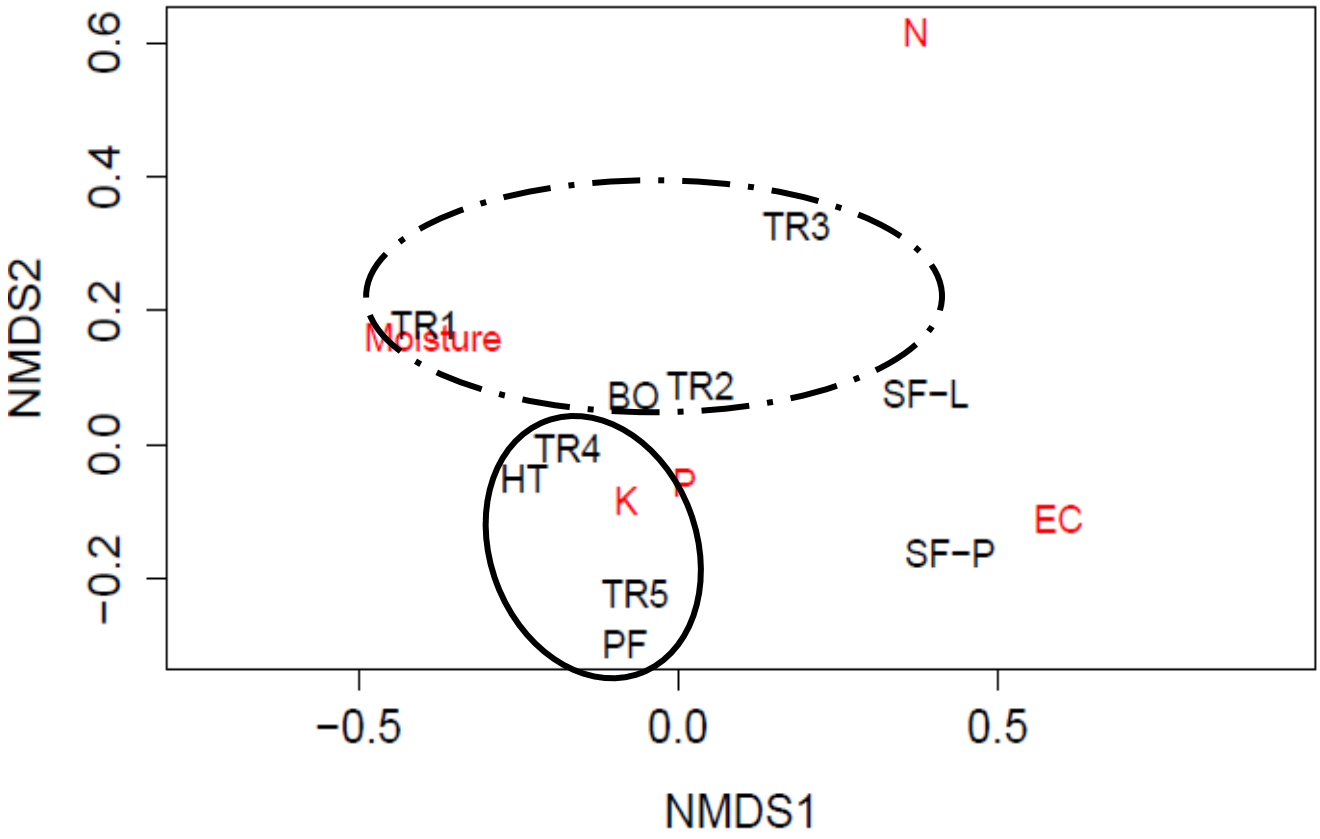

Figure 4.3: nMDS ordination plot showing relationships among reference sites based on environmental variables. Stress = 0.08, dim=3. Dashed ellipse indicates *Carex* sites, and solid ellipse indicates *Sphagnum* sites.

Plant Community Composition

Ten plant species were identified in the 8 reference fens. Mean±SD richness was 5±1.1 species per fen (Table 4.2). *Sphagnum* sites had slightly greater species richness than *Carex* fens (T-test, t = 2.77, p<0.032). When the plant species richness of Sandhill Fen was compared to the plant species richness of the reference sites, there was no significant difference. However, the species composition of SF-L sites was distinct from all of the fens, being the only location to contain typical upland plants (*Medicago sativa, Fragaria vesca, Sonchus arvensis,* and *Picea glauca).*

The analyses based on plant community composition were comparable to that of the soil chemistry analyses (Figure 4.4). SF-L was completely separated from all groups because of its unique community composition (*Medicago sativa, Sonchus arvensis, Fragaria vesca,* and *Picea glauca).* The remaining sites were divided into 2 groups (TR2+SF-P+PF+TR3+TR1) and Group 2 (BO+TR4+HT+TR5), best distinguished by the presence or absence of *Scirpus* (ANOVA F=4.667. p<0.068) and *L. laricina* (ANOVA F= 4.667, p<0.068 and 3.889, p<0.089, respectively). Figure 4.5 shows a NMDS assessing the placement of Sandhill Fen sites with the reference sites (stress=0.11). SF-L is unlike either of the reference communities, but SF-P hosts a similar plant community to *Carex* sites as it is in the same spot as TR2.

Table 4.2: Summary of plant community presence (1)/ absence (0) at each reference site and Sandhill Fen. Shaded rows are *Sphagnum* sites and unshaded rows are *Carex* sites.

Site	CAREX	EQUI	TYPHA	SCIRPUS	SALIX	GRASS	BETULA	LARIX	MOSS	LEDUM	MEDI	FRAG	PICE	SONC
BO	1	1	0	0	1	1	0	0	1	0	0	0	0	0
TR1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
TR2	1	0	1	0	0	1	0	0	1	0	0	0	0	0
TR3	1	0	0	1	0	1	0	0	0	0	0	0	0	0
HT	1	0	1	0	0	0	1	1	1	1	0	0	0	0
PF	1	0	0	1	0	0	1	0	1	1	0	0	0	0
TR4	1	1	0	0	1	1	0	0	1	1	0	0	0	0
TR5	1	1	0	0	1	0	1	1	1	0	0	0	0	0
SF-P	1	0	1	0	0	1	0	0	1	0	0	0	0	0
SF-L	0	1	0	0	1	1	0	0	0	0	1	1	1	1

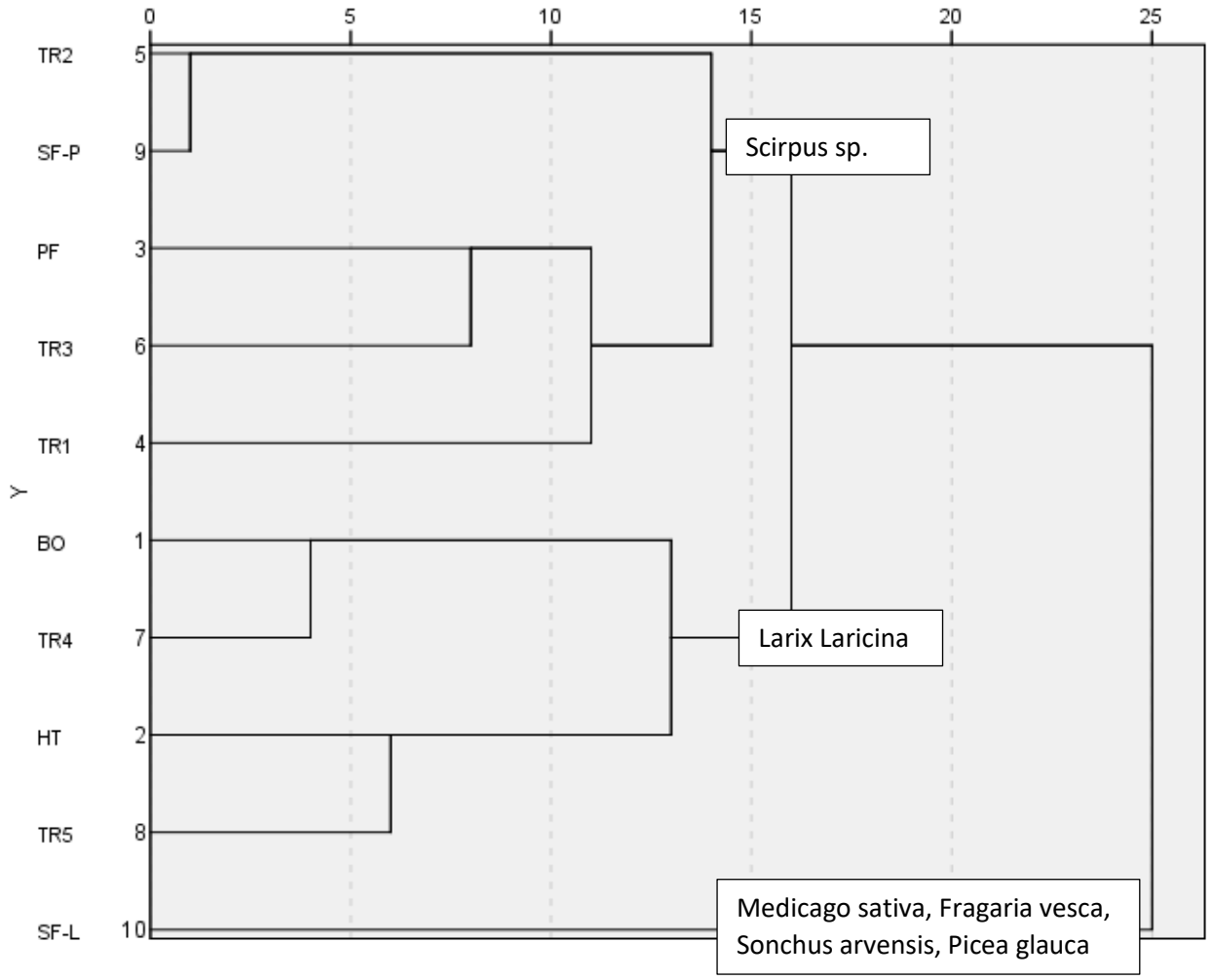

Figure 4.4: Cluster analysis of Sandhill Fen and reference sites grouped based on their plant communities.

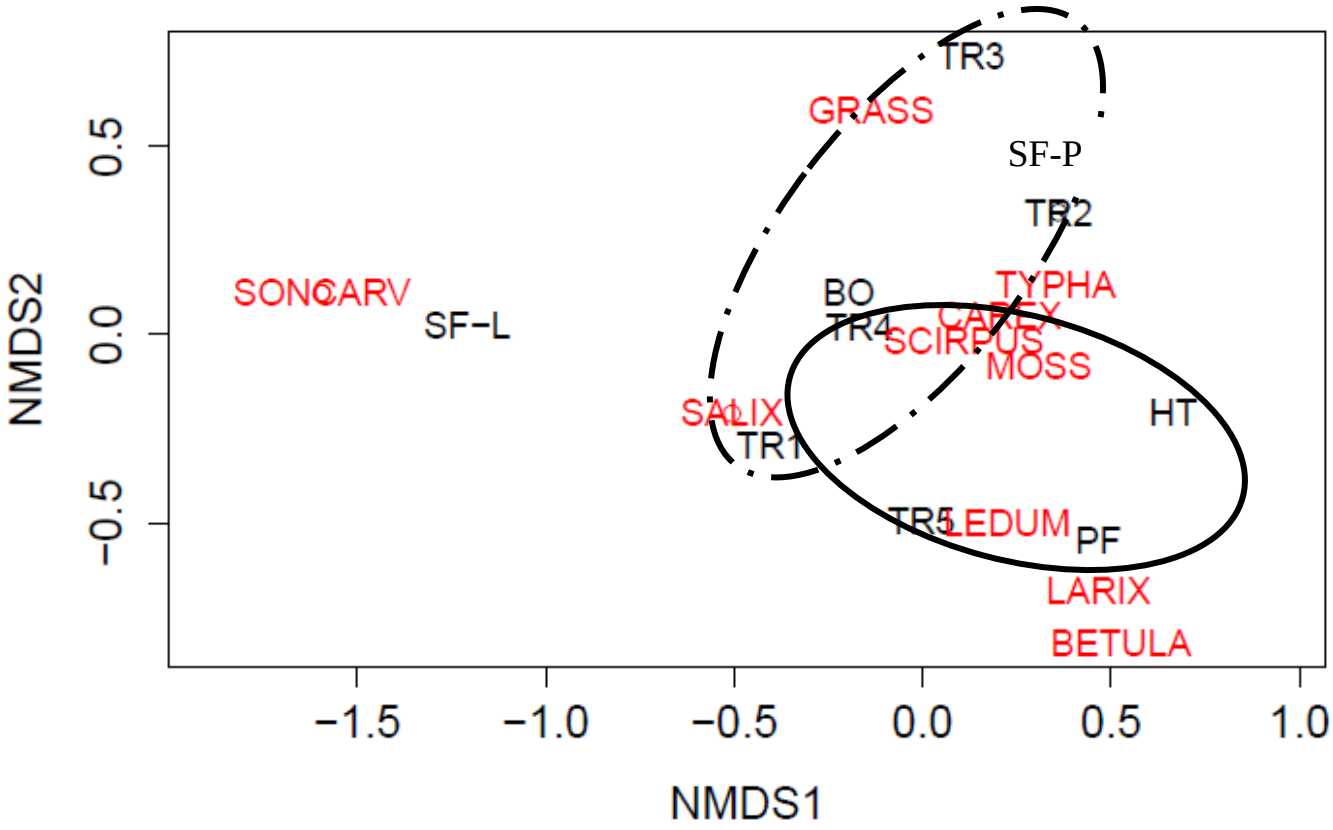

Figure 4.5: nMDS ordination plot showing relationships among reference sites and Sandhill Fen based on plant community composition. Stress = 0.11, dim=3. Dotted ellipse indicates *Carex* sites, and solid ellipse indicates *Sphagnum* sites. SF-P located in same spot as TR2.

Invertebrate Community

A total of 7216 individuals was identified from 167 traps across the 8 reference fens. Table 4.3 highlights the trends of invertebrate abundance and richness by trap type in each reference fen, and overall trap type trends. Sticky traps had the highest invertebrate abundance per trap (110.2±71.2) whereas pitfalls had the lowest overall abundance (10.3±4.97). The two fen types had similar ranges of abundances for each trap type. In reference to trap taxa richness, sweep net samples had the greatest richness of invertebrates (25.4±4.41 families), and again, pitfall traps collected the lowest richness (4.0±1.85 families). Neither the overall abundance nor the family richness of invertebrates differed between the two types of reference fens (Student's *t*-tests, $p>0.05$; Figures 4.6-4.7). When data were analyzed by trap type, a significant difference was found in sweep sample catches between fen types. The "*Carex*-based" sites had both higher mean abundance (Figure 4.8), and greater mean invertebrate family richness (Figure 4.9) than *Sphagnum* fens. Neither the all-trap invertebrate abundance nor richness of Sandhill Fen were statistically significantly different from the means of all reference sites. However, when the data were compared by trap type, sticky trap and pitfall trap family richness in Sandhill fen was significantly greater than the measurements of reference fens taken as a group (T-test, Sticky trap: $t=4.594$, $p<0.003$; Pitfall trap: $t-=6.110$, $p<0.0005$).

Table 4.3: Mean (±SD) Invertebrate Abundance and Richness from 8 reference sites and overall totals organized by dominant plant base type

		Invertebrate Abundance by Trap				Richness			
		Sweep	Sticky	Pitfall	Total	Pitfall	Sweep	Sticky	Total
Carex Based	TR1	22.2	103.5	16.33	47.3±28.13	6	28	25	19.7±6.89
	TR2	47.4	235.3	6.4	96.4±70.45	4	31	22	19.0±7.94
	TR3	38.8	135.3	11.4	61.8±37.59	4	26	20	16.7±6.57
	BO	38.5	61.0	4.8	34.8±16.3	6	29	18	17.7±6.64
Sphagnum Based	TR4	28.2	107.7	8.4	48.1±30.33	6	26	21	17.7±6.01
	TR5	13.4	32.5	17.5	21.1±5.81	2	18	19	13.0±5.51
	HT	15.9	176.0	5.0	65.6±55.27	2	25	23	16.7±7.36
	PF	19.0	30.3	12.7	20.4±5.14	2	20	21	14.3±6.17
	All Sites	27.9±12.4	110.2±71.21	10.3±4.97		4.0±1.85	25.4±4.41	21.1±2.23	

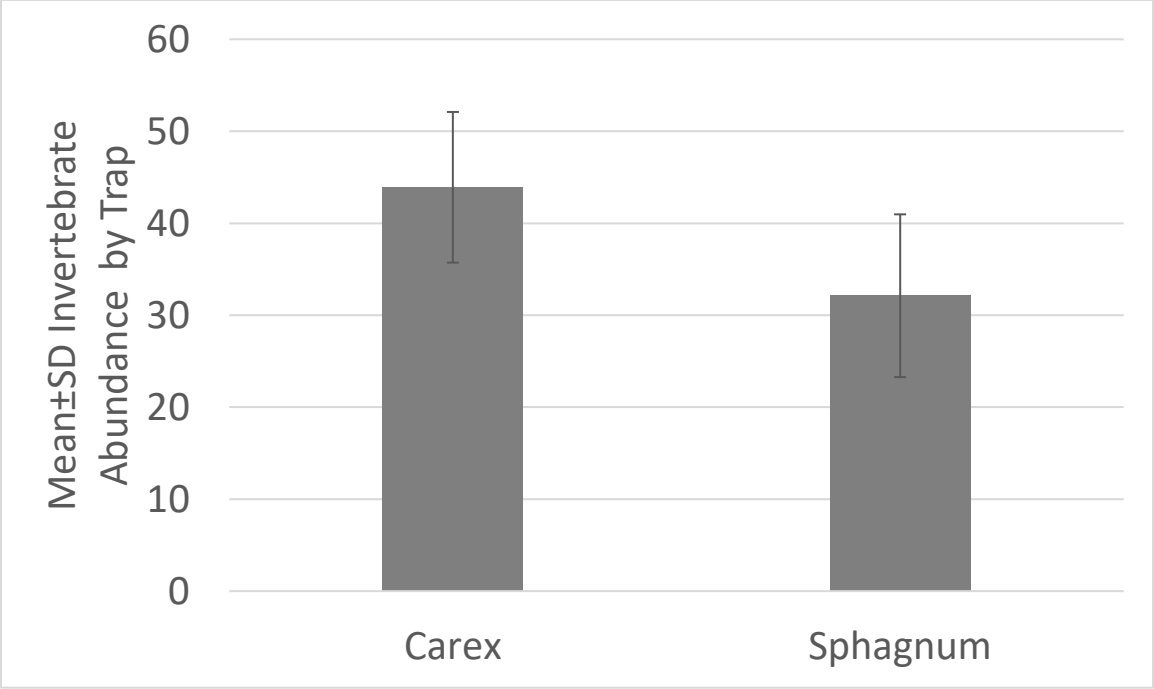

Figure 4.6: Mean ± SD invertebrate abundance in *Carex*-dominated and *Sphagnum*-dominated fens (n=4 for each type; T-test, t=0.978, p<0.366).

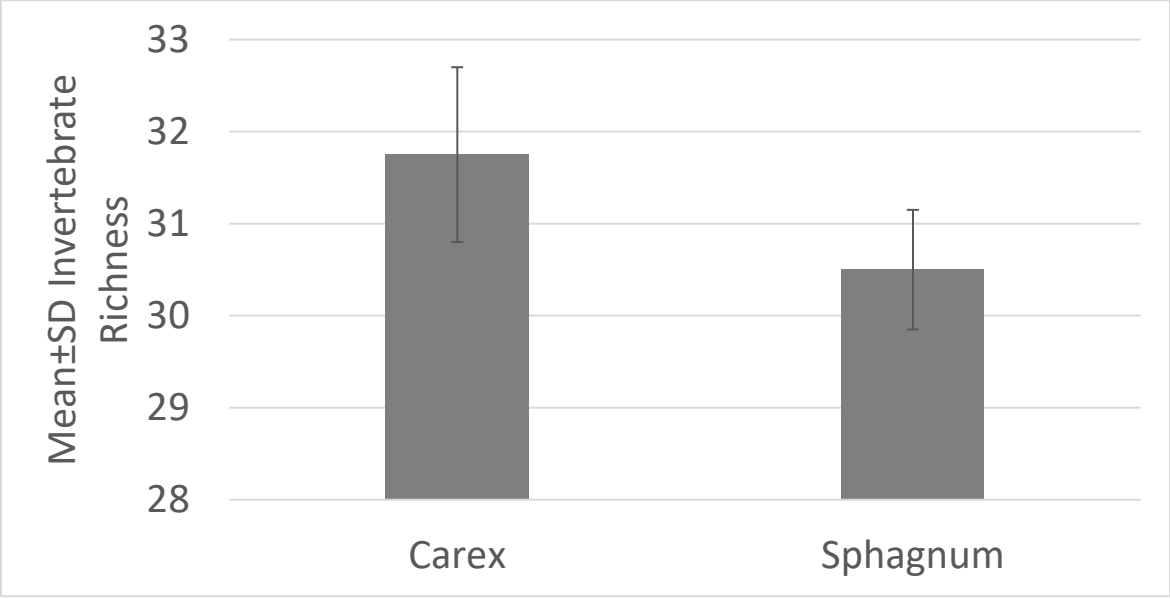

Figure 4.7: Comparison of invertebrate taxa richness between two types of reference fens (n=4 for each). (T-test, t=0.349, p<0.317).

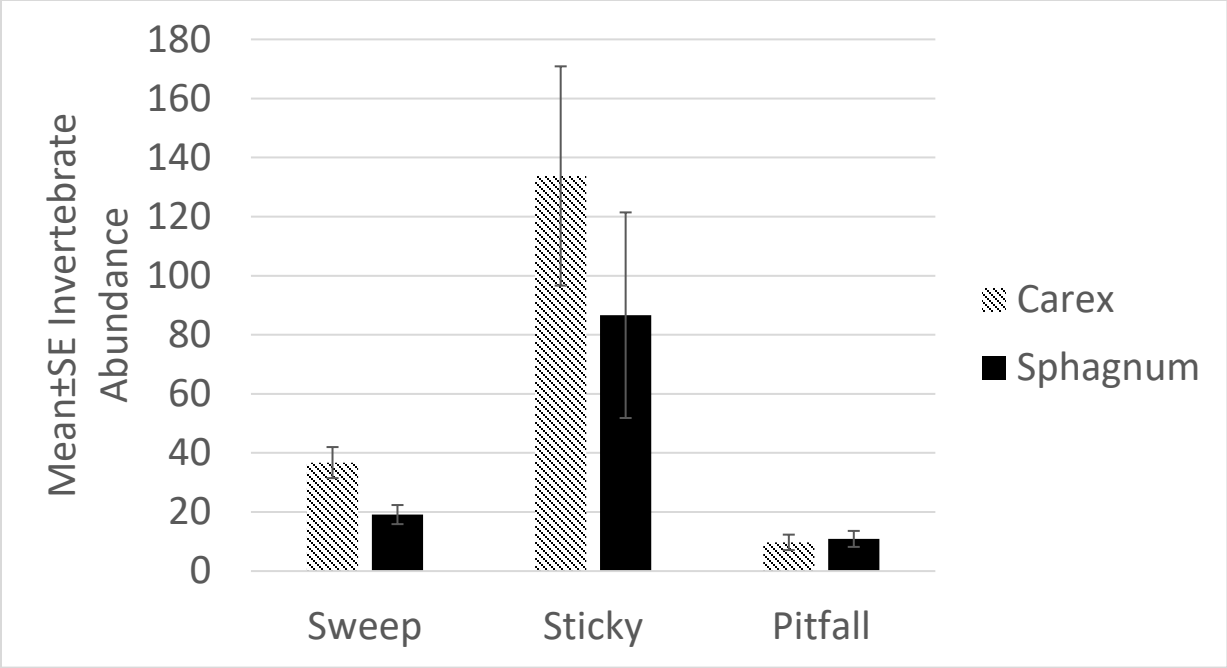

Figure 4.8: Comparison of trap type invertebrate abundances between *Carex* and *Sphagnum* dominated reference fen types (n=4 for each). Significant differences were found between the sweep samples (Independent samples T-test, t=2.849, p<0.029).

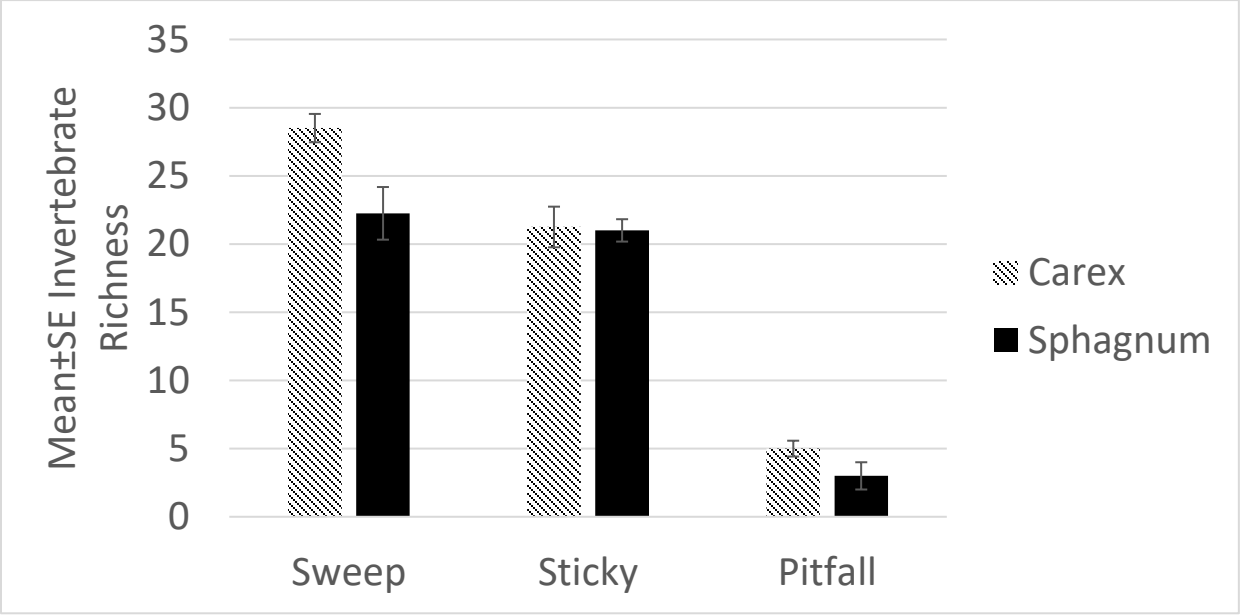

Figure 4.9: Comparison of trap type invertebrate richness between *Carex* and *Sphagnum* dominated reference fen types (n=4 for each). Significant differences were found between the sweep samples (Independent samples T-test, t=2.849, p<0.029).

A cluster analysis was done to compare the invertebrate samples from the Sandhill Fen soil types to those of the reference sites (Figure 4.10). Sites were divided into 2 major groups and 5 subgroups. Sites in Group 1 contained high abundances of Sciaridae ($F=15.65$, $p<0.004$) and Chloropidae ($F=16.451$, $p<0.004$) whereas Group 2 fens (consisting only of PF, TR5, and the Sandhill Fen LFH site) contained with high relative abundances of Acari ($F=8.898$, $p<0.018$). Within Group 1, fens TR1, TR4, HT and Sandhill Fen Peat sites hosted a higher relative abundance of Cicadellidae ($F=12.865$, $p<0.016$) whereas Group 1C contained Acari ($F=7.198$, $p<0.014$) and Ephydridae ($F=11.736$, $p<0.019$). Group 2A contained sites with Thripidae ($F=1772$, $p<0.015$) and Group 2B contained sites with high abundances of Chalicoidea ($F=272.16$, $p<0.039$). The nMDS (stress 0.075, dim=3; Figure 4.11) analysis of the invertebrate community indicated that SF-L fell outside of the ellipses representing the range of variation for both *Sphagnum* and *Carex* dominated fens. The position of the point representing Sandhill Fen peat sites fell within the ellipse representing the range of invertebrate community composition for *Carex*-dominate sites and at the very edge of the confidence ellipse for the *Sphagnum* dominated sites.

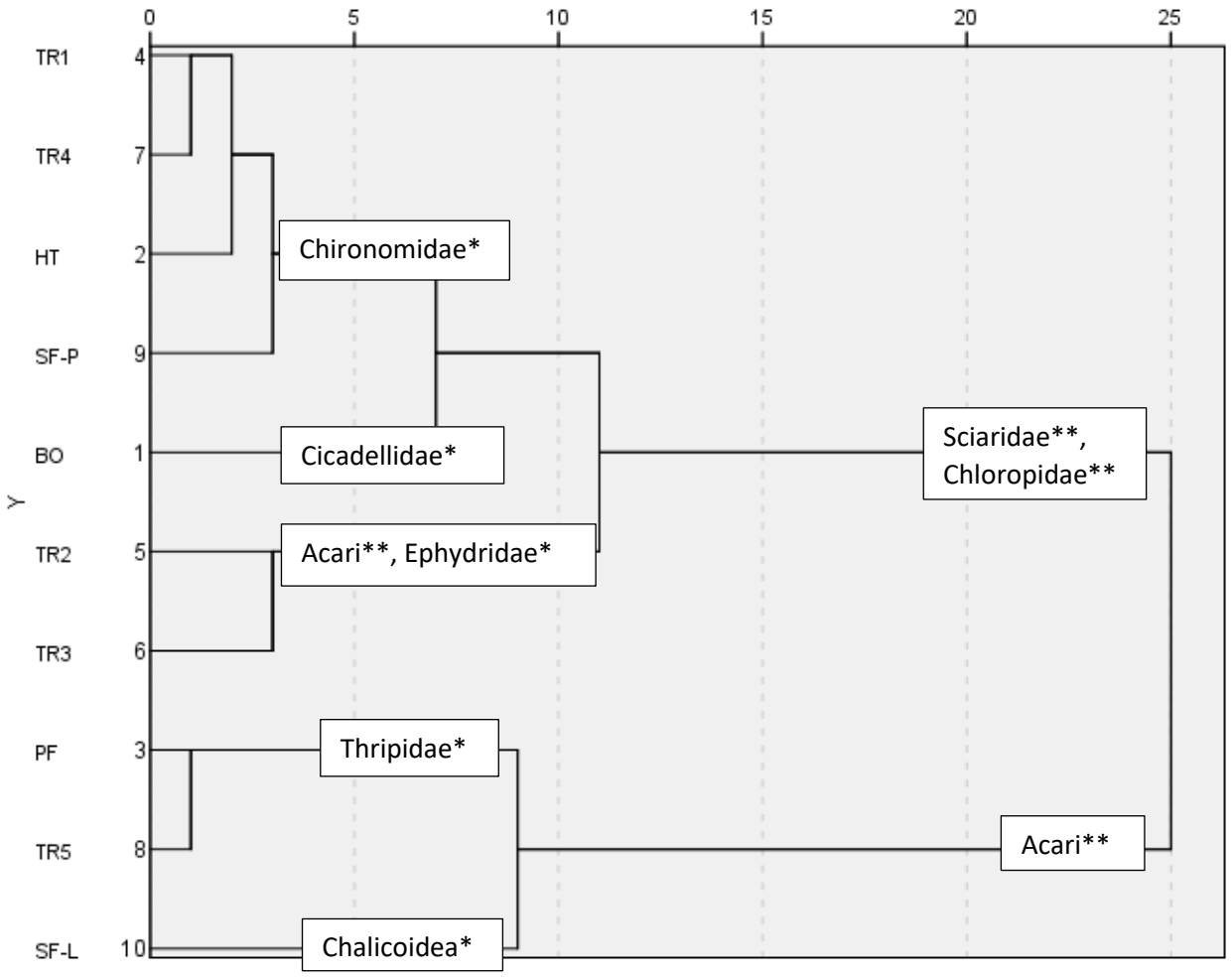

Figure 4.10: Cluster analysis of Sandhill Fen and reference sites grouped based on their invertebrate community composition (*p<0.05; **p<0.01).

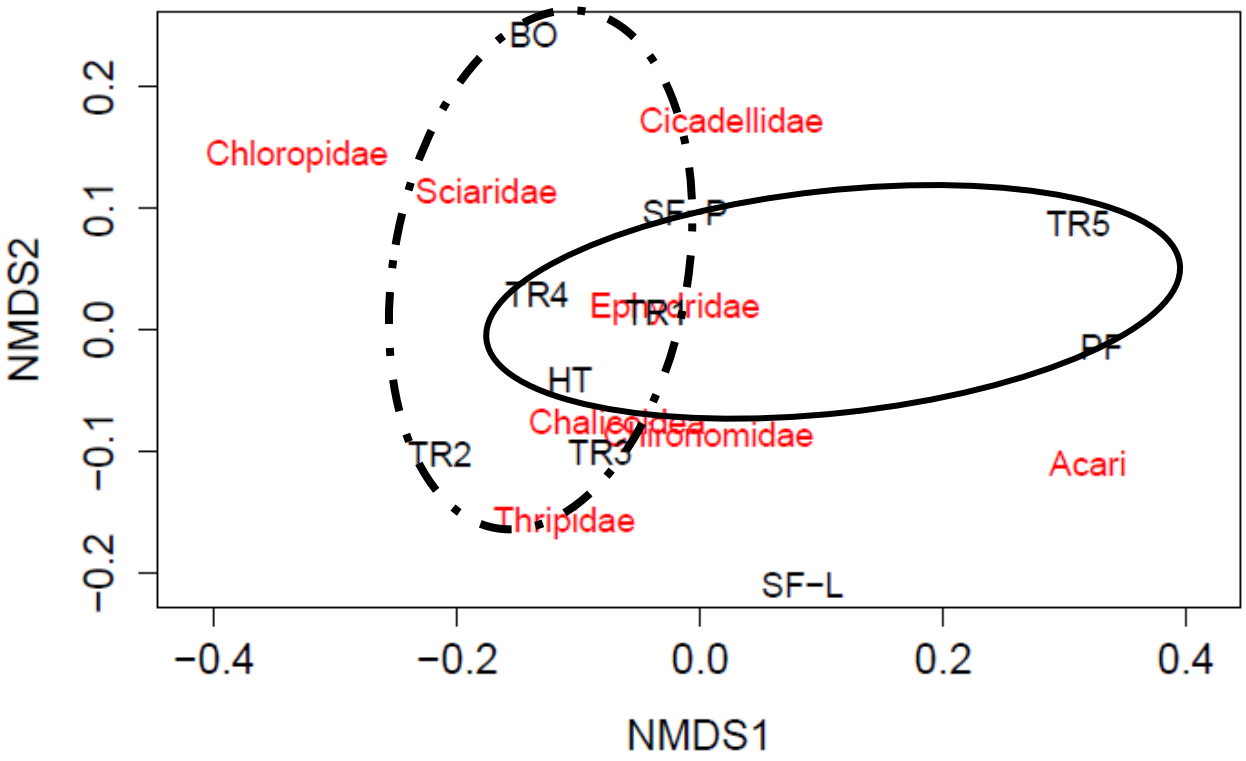

Figure 4.11: nMDS ordination plot showing relationships among reference sites and Sandhill Fen sites based on invertebrate community composition. Stress = 0.08, dim=2. Dotted ellipse indicates *Carex* sites and solid ellipse indicates *Sphagnum* sites.

The distance based-RDA (Appendix B – soil chemistry db-RDA) showed that approximately 52% of the variation in invertebrate community relative composition was constrained by the environmental variables. This analysis uses a Bray-Curtis distance matrix to analyze the sites and variables. The placement of the sampling sites indicates the relationship between the environmental variable and invertebrate taxa. The closer the sites are placed to another site or invertebrate indicates a higher association. Sites falling on the right side of the graph (Figure 4.12) are those found in Group 2 of the cluster analysis. They were negatively associated with moisture content, indicating they are drier than the sites in Group 1, and SF-L has high soil salinity measurements. The db-RDA (Appendix B – Plant Community dbRDA) attributed 76% of the invertebrate variation to the plant community. SF-L was separated from the majority of wetland sites indicating markedly different plant community composition, however it still has invertebrate components of a wetland habitat (Figure 4.13).

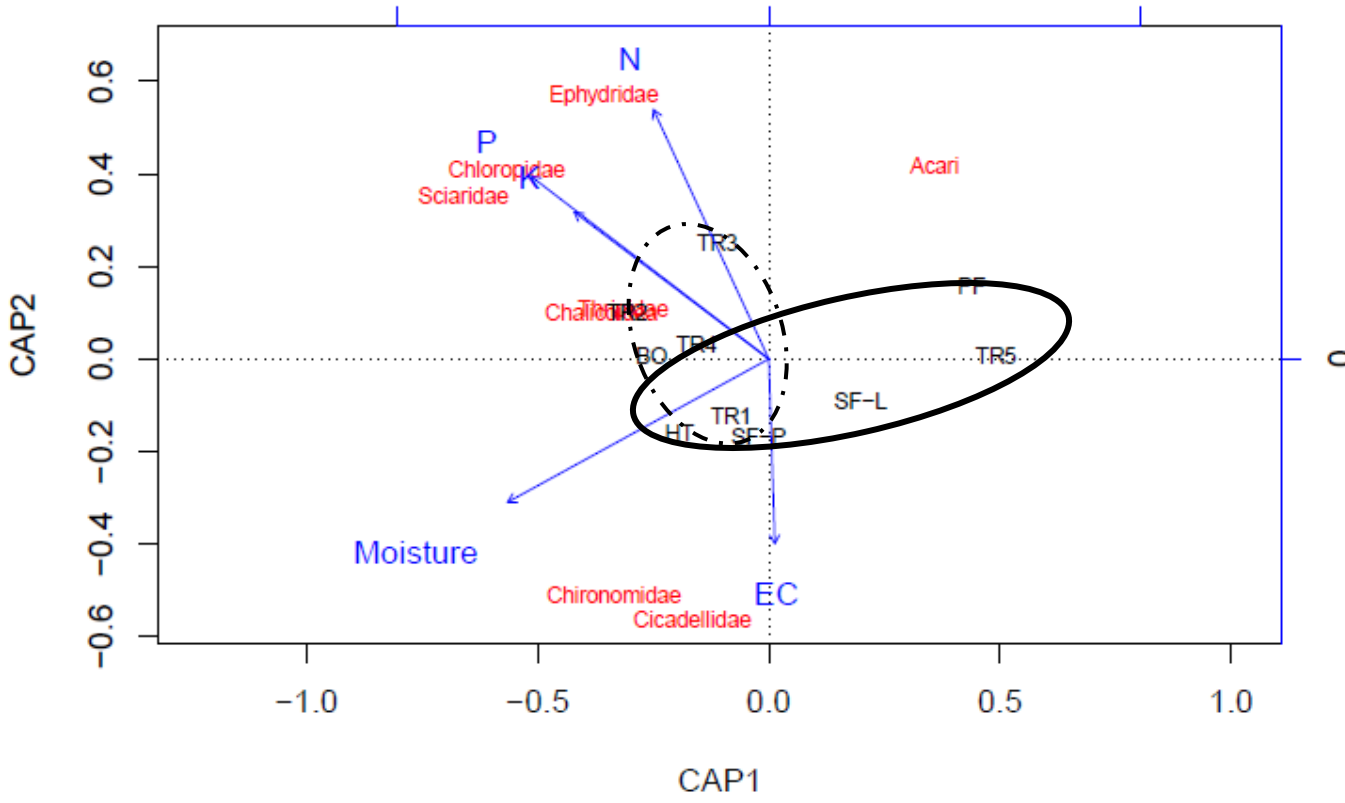

Figure 4.12: db-RDA graph showing all sites in relation to each other with the soil chemistry factors constraining the invertebrates. Solid ellipse indicates *Sphagnum* sites, and dotted ellipse indicates *Carex* sites.

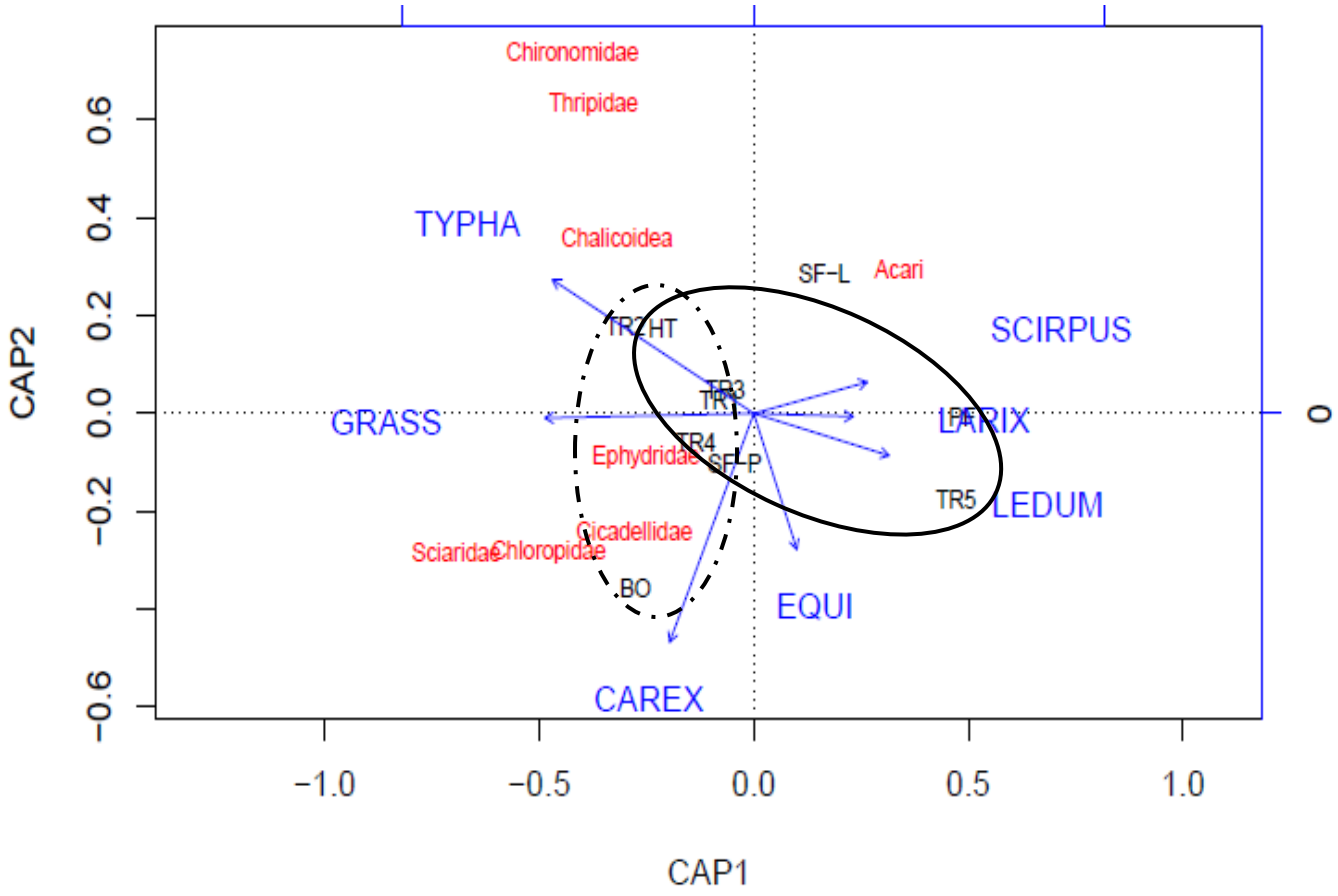

Figure 4.13: db-RDA graph showing all sites in relation to each other with the plant community constraining the invertebrates. Solid ellipse indicates *Sphagnum* sites, and dotted ellipse indicates *Carex* sites.

Discussion

The three main objectives of this study were to assess the invertebrate community within a suite of reference fens, compare the invertebrate communities among the reference fens based on their dominant plant base (*Carex* or *Sphagnum*), and finally, compare the communities of Sandhill Fen to those reference sites. The soil chemistry and plant communities were also compared.

Assessment of Soil Chemistry Features Among Fen Types

The chemical and hydrological gradients of boreal fens are variable and can occur along a nutrient/mineral gradient that differentiates poor fens from rich fens (Zoltai & Vitt, 1995). Both fen types are common in the AOSR. I operationally considered rich fens to be "*Carex*-based", and poor fens to be "*Sphagnum*-based" when classifying the reference sites sampled. I predicted that Sandhill Fen - Peat sites would be more chemically similar to rich fens because of the similar plant communities each are able to support. I also predicted that Sandhill Fen - LFH sites would be distinctive from all reference fens as it is more chemically similarly to a terrestrial habitat than to a wetland habitat.

The analysis of all reference sites and Sandhill Fen sites resulted in an unexpected NMDS result. It was predicted that Sandhill Fen – Peat sites would have grouped with the *Carex*-based reference fens. Although this was true for the ordinations of vegetation (Figure 4.5) and invertebrates (Figure 4.11), the NMDS for soil chemistry illustrated that both Sandhill soil types fall outside of the range of variation of the reference fens studied. This seems to be primarily a reflection of the high soil salinity measurements (Table 4.1). This distinction likely reflects the suite of reference sites examined in this study. Trites &

Bayley (2009a) and Purdy et al., (2005) reported that some natural wetlands had soil conductivities equal to or higher than oil sands wetlands. Lilles et al. (2010) suggested that the high salinity or conductivity measurements may be caused by leached oil sand tailings material that was used in the construction of the reclaimed site. They also found that Boreal forest habitats, similar to Sandhill Fen - LFH sites, should be relatively low in soil salinity, which was in contrast to what was found in this study. The high salinity measurements could equally stem from the saline-sodic overburden used as the mineral soil cap in the Sandhill fen (BCG Engineering, 2008) or from upwelling of oil sands tailings groundwater, which saturates the tailings sand used to contour the Sandhill Fen landscape soil composition, as it is marine in origin (Lilles et al., 2010). Further testing should be done to confirm the cause of the high salinity.

Assessment of Vegetation Community Patterns Among Fens

Natural, established fens tend to have a single, dominant plant community, and stable water conditions that promote the accumulation of peat over time (Mitsch & Gosselink, 2015). As stated previously, two types of fens can be distinguished as influenced by their hydrology and nutrient input - rich fens (*Carex*-based) and poor fens (*Sphagnum*-based). The greater plant species richness found in *Sphagnum*-based sites may be because the fens studied contained both fen- and bog-like components. Specifically, *Rhododendron groenlandicum* and *Larix laricina* plant species are more commonly found in bog habitats than fen habitats. Warner & Asada (2006) reported that fens had higher species richness in terms of herbs and ferns but that bogs were host to a greater richness of tree species. The *Sphagnum*-sites studied hosted both herbs and tree species, allowing for

a great plant species richness over *Carex*-sites. This was contrary to my prediction that *Carex*-sites would be the richest in plant species.

Finally, it was predicted that Sandhill Fen – Peat sites would be florally similar to rich fens because of the dominance of *Carex* sp. within these Sandhill sites. The inclusion of both Sandhill Fen communities into the clustering showed similarities between SF-P and other *Carex*-sites, and the complete isolation of SF-L because of its unique community. The distinctiveness of SF-L is a function of the upland meadow species that were common in the dry, LFH portions of Sandhill Fen. Johnson & Miyanishi (2008) describe *Picea glauca* (white spruce) as an upland plant, thus further classifying SF-L sites as upland. The second NMDS (Figure 4.5) illustrates the predicted grouping of SF-P with *Carex*-sites because of the plant species present within those sites and confirms that SF-P are similar to natural reference sites in terms of the plant community.

Assessment of Invertebrate Community Composition Among Fens

The final goal of the comparison was to assess the similarity, or dissimilarity, of the invertebrate assemblages of Sandhill Fen sites to those of reference fens. The objective of the Sandhill Fen Project was to create a self-sustaining watershed with a fen wetland. A complementary measure of the Project's 'success' would be to demonstrate that the biological complement of the Sandhill Fen ecosystem mirrors that of reference fens. I had predicted that Sandhill fen sites with peat substrate would be host to an invertebrate community more similar to that of reference fens than would the invertebrates collected from LFH locations on Sandhill Fen, and that LFH sites would host a dissimilar invertebrate community because of its different substrate base and upland plant community, as outlined in Chapter 3.

The analysis of invertebrate community among reference fens identified fauna typical of a wetland community, comprising of semi-aquatic flies (Sciaridae, Chironomidae, Ephydridae, and Chloropidae) (Rosenberg & Danks, 1987). The high relative abundance of soil-dwelling Acari (mites) distinguished two of the four *Sphagnum*-based sites. When Sandhill Fen sites were included in the analyses, SF-L sites were distinctive from all reference fens, indicating that its invertebrate composition is unique. This likely reflects the influence of the plant and soil components that separate the LFH zone from a typical wetland site (see Chapter 3).

The joint analysis of two matrices provided more information about the fen communities as a whole. For example, the distance-based RDA triplot (Figure 4.12) showed the relationships among invertebrate community and reference fens as constrained by the soil chemistry features characteristics of each site. The nearness of an invertebrate taxon to a variable indicates the strength of association with that variable. Additionally, one can infer the soil chemical and invertebrate community characteristics from the location of a reference fen within the biplot. For example, sites 'PF' and 'TR5' can be said to have low moisture content because of their position along the CAP1 axis (with which moisture content is highly negatively correlated). Furthermore, these fens tended to have a limited invertebrate community, mainly dominated by Acari (mites). When db-RDA analysis was used to assess patterns in invertebrate community composition as constrained by plant community composition (Fig. 4.13), the PF and TR5 fens were found to be distinguished by having plants such as *Scirpus sp*. (bulrush), *Larix laricina* (tamarack), and *Rhododendron groenlandicum* (Labrador tea). This analysis indicated that the relative dominant invertebrates in these fens were Acari (mites).

Conclusion

An examination of soil, plant and invertebrate attributes of reference fens indicates that soil chemistry influences the invertebrate and plant communities within and among reference sites. Although invertebrate abundance and family richness did not greatly differ between the two types of reference fens, some invertebrate taxa were more likely to be found in one type of fen over the other. The invertebrate communities characteristic of the lowland Peat and LFH soil areas of Sandhill Fen exhibited both similarities to and differences from those of reference fens sites. The Sandhill Fen LFH area was found to be unique in its plant community relative to natural fens. It can be said that though the plant community, invertebrates, and soil chemistry features are variable among reference sites, the habitat of SF-P falls within this range, indicating that these communities and habitats are consistent to natural conditions.

Chapter 5: General Discussion

Project Overview

The goal of this project was to document the composition and distribution of semi-terrestrial and terrestrial invertebrates in the constructed Sandhill Fen Watershed. Soil-associated environmental variables (moisture content, soil salinity, pH, and levels of potassium, nitrogen, and phosphorus) and plant community composition at sample sites were measured as covariates to explain spatial variation in invertebrate abundance and composition. Additionally, the composition of invertebrate communities in two classes of reference fens were determined and compared to Sandhill Fen assemblages.

Major Findings

Assessing the soil variables of the Sandhill Fen Watershed identified two gradients

Sandhill Fen sites were distributed along both a moisture gradient (soil moisture content, soil salinity, pH, phosphorus; correlated with elevation) and a chemical gradient (potassium and nitrogen). These attributes have been identified as important by others in determining biological characteristics in both natural wetlands (Zoltai & Vitt, 1995; Sanderson et al., 1995) and in reclaimed habitats (Purdy et al., 2005). The presence of these gradients within the watershed indicates that the construction of this landscape has resulted in patterns consistent with those of natural landscapes.

In addition to the gradients within the watershed, the 'typical' plant community is developing. As mentioned earlier, the upland portion of the watershed was planted with species that reflect target ecosites. The wetland portion was seeded with species collected from natural fens in the region. The planted species are persisting, and other native species,

not planted are also becoming established. Some of these species include weedy, invasive, or undesirable species, such as *Sonchus arvensis* (sowthistle) and *Medicago sativa* alfalfa). The invertebrates associated with the lowland and upland zones vary according to the plants within the community. For example, typical wetland invertebrates such as Chironomidae, Ephydridae, and Saldidae were commonly found at sites within the peat-dominated portion of the watershed, which are most similar to a natural wetland (Rosenberg & Danks, 1987). As well, upland areas tended to have greater invertebrate richness, influenced by a higher plant species richness, similar to the findings of Sanderson et al., (1995), Risch (1981), and Haddad et al., (2001), all of whom indicated that higher plant community richness was correlated with higher invertebrate richness in a community.

Finally, a comparison of Sandhill Fen communities to reference fen communities indicated that the "Peat" flora and fauna of Sandhill Fen was similar to that of rich fens, which comprise graminoid plant species and more plant-associated invertebrates (Warner & Asada, 2006). The soil chemistry of both low-elevation and upland Sandhill Fen zones was different from that of natural reference fens, primarily in terms of the soil salinity. Sandhill Fen LFH had an expected plant community that differed from a typical wetland community (Zoltai & Vitt, 1995).

Limitations

The study of the soil chemistry could be improved by conducting a more detailed analysis of the nutrient and chemical composition of the soil, as well as its physical properties. The soil tests used in this study provided ranges of the concentration of only a few nutrients. Nitrogen, potassium, and phosphorus are the most important promoters of plant growth, and they had previously been quantified through soil surveys of the Sandhill

Fen Watershed. A previous soil survey (NorthWind Land Resources Inc., 2013), which sampled multiple sites both in the upland hummocks and within the wetland basin indicated that most sites contain low concentration of detectable nitrogen (primarily in the form of nitrates and ammonium), and relatively high concentrations of total phosphorus, relative to the detection limit. The soil test kit used in our study assayed nitrate and phosphates, which may explain the differences in estimates of elemental concentration between this study and the NorthWind (2013) study. Additionally, NorthWind (2013) measured the concentration of potassium at the elemental level, whereas the assay used in this study reacted to potassium compounds. NorthWind (2013) reported finding large variation in the potassium measurements from sites in similar areas, indicating a lack of identifiable gradient in terms of this element. Further study of elements related to salinity (sodium or calcium) or those related to the oil sand processes, should be measured to provide an understanding of how they may change over time and possibly influence community dynamics of the Sandhill Fen Watershed.

In addition to additional measurements of soil chemistry, this study would benefit from analysis of community composition at finer taxonomic resolution of invertebrates. Although many invertebrates were identified to genus or species level, the limited resolution of certain groups necessitated analyses at the family level. The level of identification was limited primarily by the condition of some of the invertebrates. The insects retrieved from sticky traps that had been left in place for 72 h were often damaged, and had lost key body parts needed for identification past the family level. There are both advantages and disadvantages of working at family level classification. Limiting identification at family level reduces processing time, and allows for larger sample size.

Family level identification is sufficient to identify the basic invertebrate interactions seen within a community (Babin-Fenske & Anand, 2010), but finer resolution would allow functional groups to be better identified. Most invertebrate families are comprised of species belonging to a variety of functional feeding groups. For example, some species of Ephydridae (shore fly) are herbivores or detritivores, whereas other species are predators (Agriculture Canada, 1981). The family level provides insufficient resolution to accurately classify functional feeding groups of this family and others. Consequently, functional group analysis was not considered in this thesis.

As previously stated, multiple trap types were used in this study to sample as many varieties of invertebrates as possible, including those associated with soil (vacuum sampling after clipping vegetation and pitfall traps), plants (vacuum sampling and sweep netting) and flying insects (sticky traps). Each method has advantages and limitations. Vacuum sampling of the vegetation and sweep netting provided information on the plant associated invertebrates, as was reported by Doxon et al. (2011). Sweep netting captured large-bodied invertebrates that were not collected by other means, as was found by Doxon et al. (2011). The biases of both the vacuum sampling of vegetation and sweep netting suggest that they should be used together to best detail the invertebrate community. Sticky traps caught the greatest number and variety of invertebrates, but required the most time to process catches, and many individuals were poorly preserved. Smith et al., (2014) proposed another method using Petri dishes instead of the acetate sheets and cylinders. The use of Petri dishes reduced trap preparation time and placement time by 2/3, and were more efficient to place, recover and store. However, Smith et al. (2014) did not report on the

processing time of their samples. A comparison of the processing time of each trap type would be useful before altering collection methods.

Pitfall traps caught ground dwelling invertebrates that would not normally be caught using the other methods. However, on a few occasions the traps caught organisms that were not meant to be caught (i.e. voles, frogs). This method is commonly used because it is efficient and collects a wide variety of invertebrates (Longcore, 2003; Pekar & Lubin, 2003; Brose, 2003b).

Soil vacuuming was the least productive method of sampling in this study. It provided little information that the pitfall and sticky traps did not. The use of a Berlese funnel would provide a better record of the soil associated invertebrates, especially in areas where vegetation sampling is not feasible (i.e. in natural fens; Williams, 2014).

The sampling of reference fens was modified because the water able at most of the sites was high, meaning that vacuum sampling could not be used for plants or soil. Accordingly, only sticky traps, sweep netting and pitfall traps were used. Sweep netting was more effective in *Carex*-based fens because *Sphagnum*-based fens had woody plants, such as birch, tamaracks, and spruce, whose branches and leaves were difficult to sample effectively with a sweep net. An alternative method to overcome this problem would be to use a smaller handheld vacuum, like a Dietrick vacuum (Duffey, 1980) to sample moss dominated fens and woody plants more effectively.

Implications and Future Studies

This study provides an important baseline against which the compare the findings of terrestrial invertebrate research in the reclamation industry. The Sandhill Fen Watershed

is the first of its kind built in the mineable oil sands region, and is the only constructed watershed in which the early invertebrate colonization of both aquatic and upland sites has been recorded. The terrestrial and semi-terrestrial invertebrate fauna are potentially useful indicators of terrestrial habitat condition in combination with the aquatic invertebrates. Assessing both terrestrial and aquatic condition provide a better overall picture of the ecosystem function and early succession across multiple gradients than focusing on single guilds. Several studies have assessed terrestrial invertebrates in post-mining restoration projects. Majer et al., (2007) highlighted that value of ants and other hymenopterans in assessing the "success" of a reclaimed habitat. It was reported that after 30 years, invertebrate communities in reclaimed mine areas were similar to natural communities. Longcore (2003) identified species that could be used as potential indicators of restoration success. Finally, Babin-Fenske & Anand (2010) reported that terrestrial invertebrates could provide some information on the success of mine reclamation projects, and higher taxonomic identification could provide essential details of the functional or guild partitioning of invertebrates within these habitats. This is important for future research when designing new habitats in the post-mining landscape. We can further study the uplands of other fen watersheds to identify 'natural' invertebrate assemblages and the landscape features that support them.

The findings of this research are based on a snapshot taken during the early development and primary succession period of the watershed's first few years. Because of its relatively recent construction, developmental processes are variable are unlikely to stabilize for some years, if then. Continuing the monitoring of the invertebrates within

both aquatic and terrestrial portions of the watershed, will help illustrate how primary succession is reflected in compositional changes in the invertebrate and plant communities.

The data collected in this study suggest that hygric or hydric (low-elevation) portions of the Sandhill Fen Watershed have an invertebrate community that is similar to that of rich fens in the area. Invertebrate composition is more similar in the peat communities of the watershed than in the LFH communities, but this is to be expected because the LFH-placed areas were designed to develop into mesic upland rather than wetland communities. The congruence of invertebrate assemblages between reclaimed areas of Sandhill Fen Watershed and reference fen is a positive finding in documenting the effectiveness and functional capability of the early stages of this reclamation project.

Returning to the hypotheses detailed at the start of this thesis, the concept of a community is at the forefront. A more stable, or "diverse" community is one that is resilient to both external perturbations and to changes within the community (Goodman, 1975). The Sandhill Fen Watershed was built as an analog of natural landscape to ultimately support diverse communities. The upland hummocks apparently support mesic plant and invertebrate communities, and the wetland supports a typical assemblage of wetland vegetation and invertebrates. The presence of such patterns indicates that Sandhill Fen Watershed has potential to develop into what may become a stable community. Long-term monitoring of the aquatic, semi- terrestrial and terrestrial invertebrate communities would be useful in documenting the next stages of community development. A greater number of sampling sites in each zone would allow for better documentation of the associations and possibly help identify thresholds in the key gradients that distinguish the various assemblages. Methods of sampling terrestrial fauna, including sweep netting, vacuum

sampling and soil invertebrate sampling (through pitfalls or vacuum sampling) should be used collectively to provide as much detail as possible regarding the invertebrate community diversity and function. This would complement the use of common wetland sampling methods to summarize and delineate the aquatic portion of the watershed.

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Appendix A – Reference Fen Environmental, Vegetation and Invertebrate Analyses

This section details the analyses conducted on the reference fens sampled as part of Chapter 4. Environmental soil variables were measured and compared between the two types of reference fens, *Carex* vs *Sphagnum.* The analysis of data in this chapter was broken down into three categories: soil-associated environmental variables, plant community composition, and invertebrate community composition.

Soil Associated Environmental Variables

Measurements of soil moisture content, soil salinity, and nutrient composition were averaged from each of the three samples taken from each reference site. A PCA was performed using normalized data, and rotated using a Varimax rotation. The wetland-specific scores of each Principal Component for *Carex* and *Sphagnum* sites were compared using *t*-tests (Bonferroni corrected for multiple tests) to assess differences between fen type. Data were $Log_{10}(x+1)$ transformed.

Variation in soil characteristics among reference wetlands was assessed using cluster analysis. Squared Euclidean distances of Log_{10}-transformed measurements were calculated, and sites were hierarchically clustered using Ward's Method. Based upon the results of this analysis, each reference wetland was assigned to a group and the between-group vs. within-group variance ratio (ANOVA F) was determined according to the Green & Vascotto (1978) method. The dispersion of NMDS was used to visualize the distances between sites based on their soil chemistry variables using Bray-Curtis similarity. Sites situated closer together in the ordination are more similar, and the closer sites are placed

to the vector of a soil chemistry variable, the more important that variable is in defining the position that site in the ordination.

Results

The mean and SE of five variables measured from the soil of each reference site are summarized in the table (Table 4.1), grouped according to fen type (*Carex* or *Sphagnum*-dominated). Soil from Sandhill Fen Watershed had higher salinity than any of the reference fens. *Carex* sites also had higher soil nitrogen content and soil moisture content on average than *Sphagnum* sites.

Results of the PCA of the soil chemistry variables are summarized in Figure A-1. Principal Component 1 was identified as a chemical gradient, on which nitrogen (0.901), phosphorus (0.851), salinity (0.672) and potassium (0.667) loaded most heavily. PC2 was identified as a moisture gradient, as soil moisture content was highly correlated with this component (0.973). There was a marginally significant difference in mean scores for PC1 between *Carex*-dominated and moss dominated fens (Student's *t*-test, t=2.476, $p<0.048$, adjusted for multiple tests), and no difference in terms of the mean values for PC-2 (moisture gradient; Student's t-test, t=1.260, $p<0.254$, adjusted for multiple tests). Thus, the *Carex*-dominated fens had higher values of the variables associated with PC-1 (Table 4.1). The values of the soil chemistry variables were log10(x+1) transformed prior to cluster analysis. The cluster analysis of the reference fens distinguished three groups (Figure A-2). One group consisted of a single fen (TR3) that had anomalously high concentrations of nitrogen ANOVA F =25.99, $p<0.002$). The remaining fens fell into two Groups (TR4+HT+TR1+TR5+PF TR2+BO). The soil phosphorus content of Group 2 (TR2+BO) was significantly higher than that of Group 1 (ANOVA F=13.01, $p<0.015$)

whereas Additionally, Group 1A (TR4+HT+TR1) had a significantly higher soil moisture content than Group 1B (TR5+PF; ANOVA F=23.62, p<0.017).

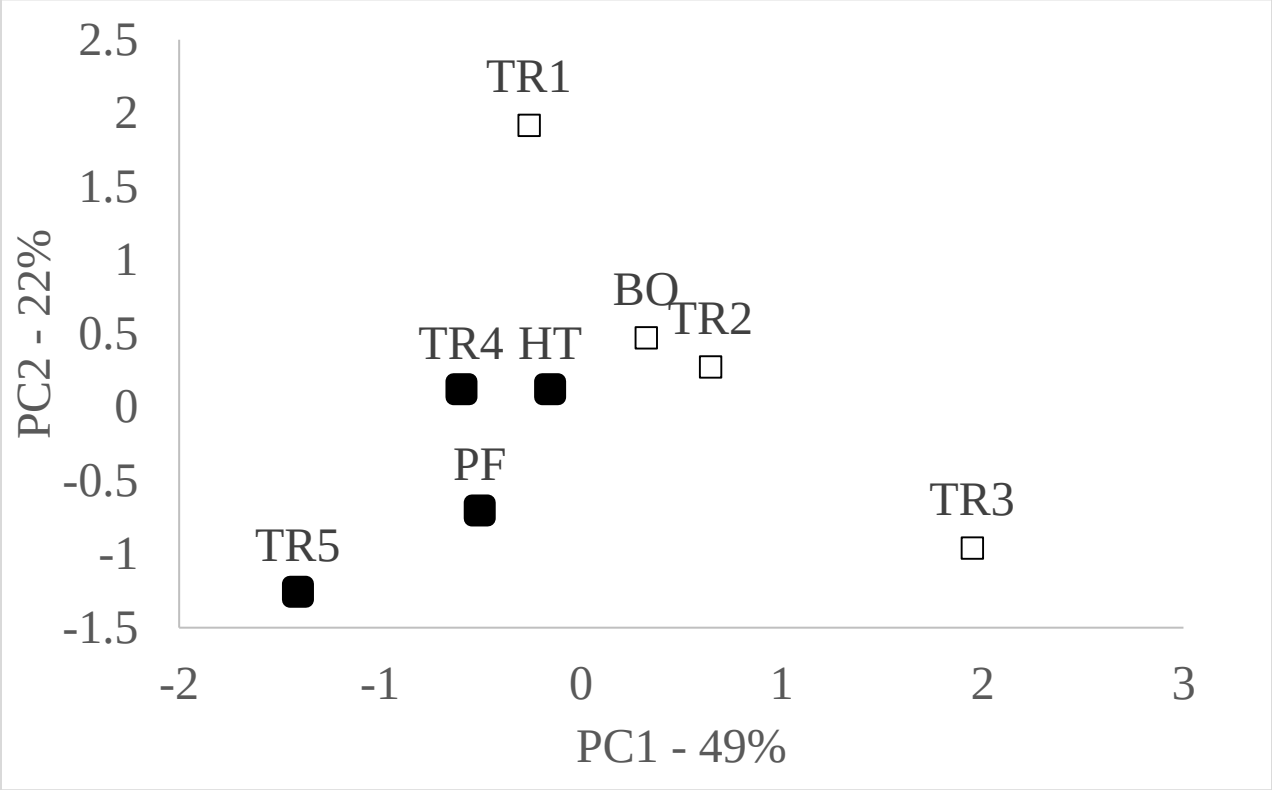

Figure A-1: Principal Component analysis of environmental variables among reference sites based on their plant base (Carex-dominated site – empty; Sphagnum-dominated sites - filled). Marginally significant differences found in between plant base sites based on PC1 (T-test, *t*-value=2.476, p<0.048).

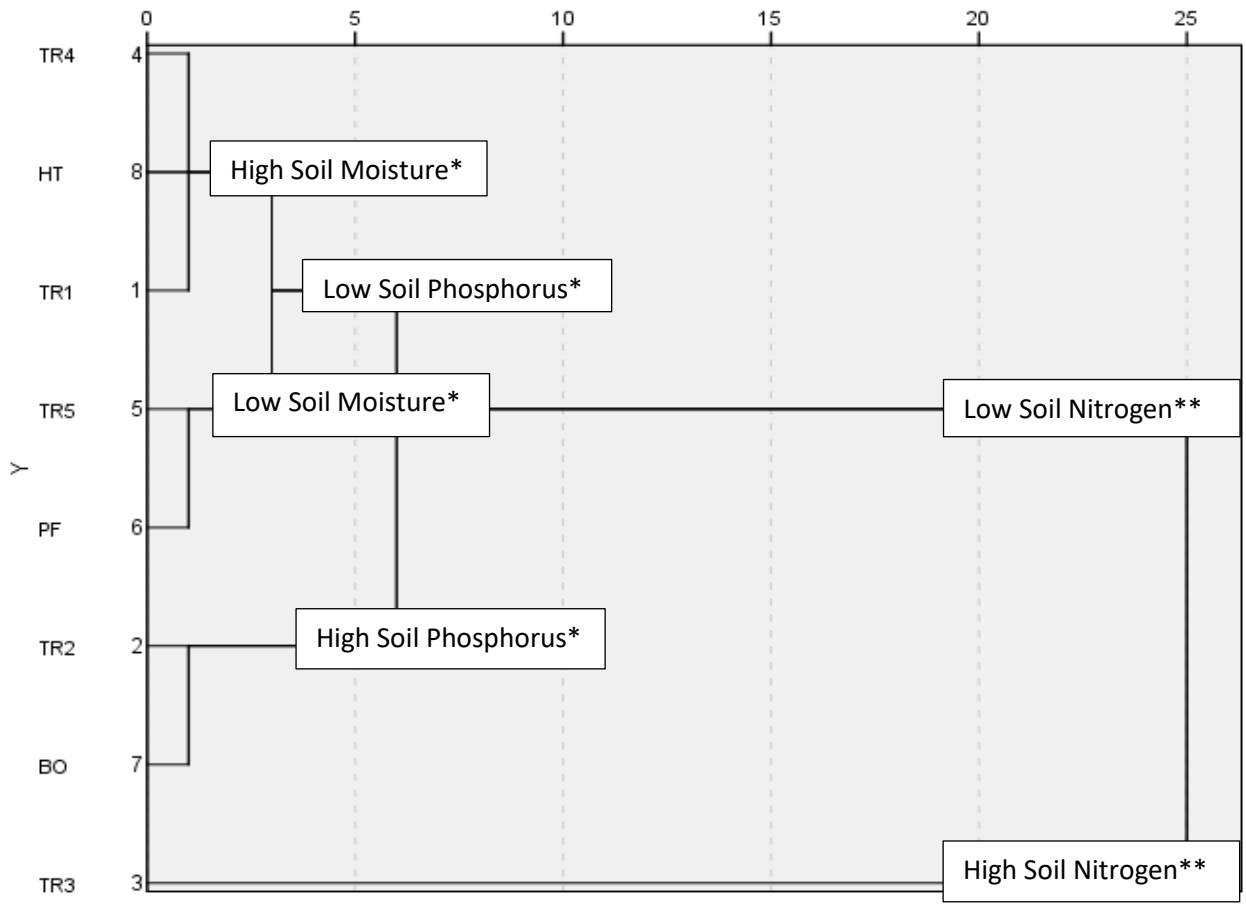

Figure A-2: Cluster analysis of reference fens based on environmental variables (*p<0.05; **p<0.01).

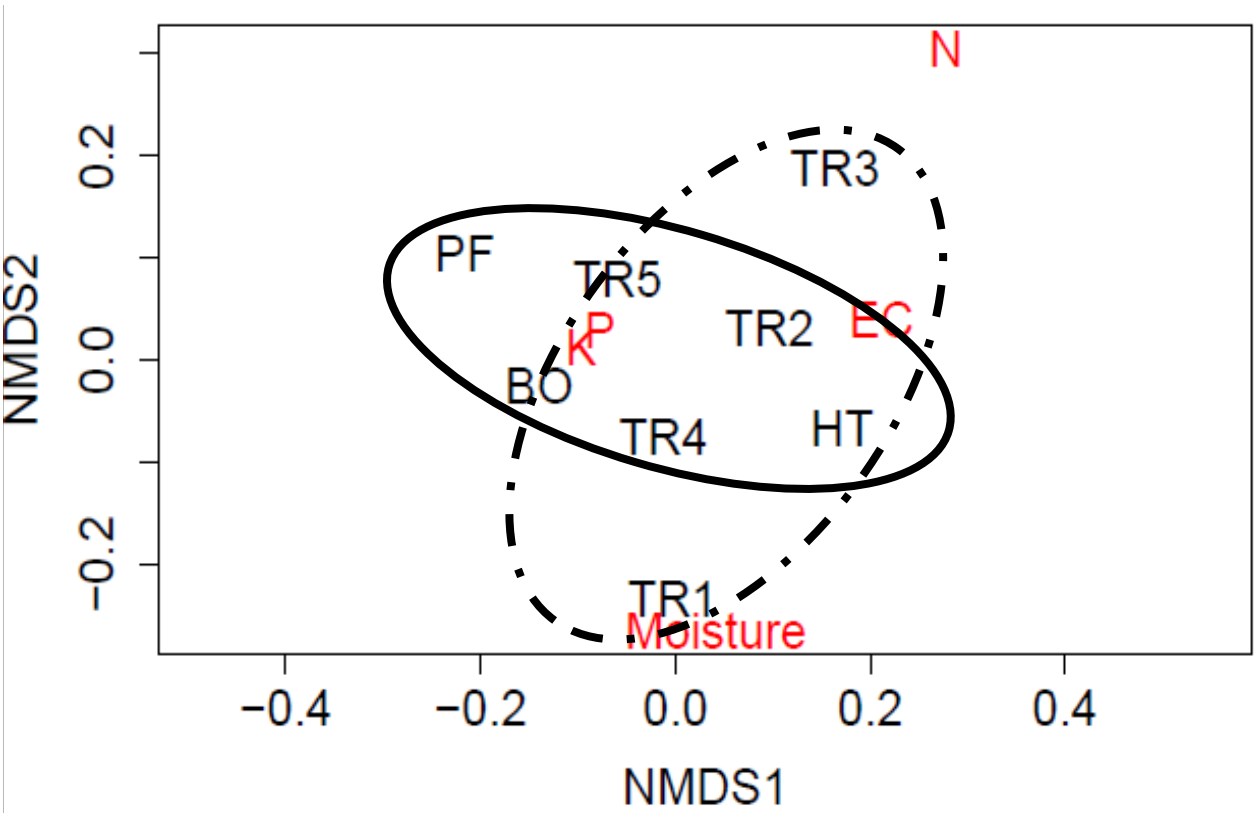

Figure A-3: nMDS ordination plot showing relationships among reference sites based on environmental variables. Stress = 0.07, dim=2. Dashed ellipse indicates *Carex* sites, and solid ellipse indicates *Sphagnum* sites.

The first dimension of the soil chemistry nMDS ordination illustrates the range of the chemical composition of the soil among sites, highlighting K, P, and N. The second dimension highlighted differences in the nitrogen content in the soil and moisture content, with TR3 having the highest nitrogen content on average and TR1 having the highest moisture content (Figure A-3). Stress was measured to be 0.07, indicating a good fit.

Discussion

The soil chemistry ordinations of the reference fens were similar to those found in data presented in Chapter 3, identifying axes representing a chemical gradient and a moisture gradient. Sanderson et al. (1995) identified the importance of a moisture gradient when assessing the effect of soil, vegetation and space on invertebrate communities. They identified soil moisture as a major factor in the establishment of both plant and invertebrate communities. Additionally, the chemical gradients, in the form of nutrients are also important for plant growth and establishment. Lawniczak (2011) measured the uptake of soil nutrients in wetland plants and identified nitrogen as a key nutrient determining growth of wetland plants. The differences in locations the *Carex* reference sites and *Sphagnum* reference sites along the nMDS chemical gradient corroborated my classification of the fens as belonging to two separate types. However, the results of the plant-based NMDS (Figure A-6) indicate that the fen types may not be vegetatively distinct of the large amount of overlap between the classes

Plant Community

Plant species were recorded on a presence (1)/absence (0) basis with a 1-m radius of each invertebrate sampling point in each fen. Plant community richness was measured

as the number of plant species present within a fen, in the vicinity of each trap. The mean richness was calculated for all reference fens treated as a single group, and among plant base types (*Carex* and *Sphagnum*). A Principal Components Analysis (PCA) was used to determine whether there were plant community differences between the *Carex*-dominant and *Sphagnum*-dominant fens. The mean Principal Component scores for *Carex* sites and *Sphagnum* sites were compared using a *t*-test (with correction) for the first two Principal Component axes extracted from the analysis. A cluster analysis of only reference sites was performed done using binary Squared Euclidean distances and Ward's method. Sites were put into groups and the plant species most responsible for the difference between groups assessed using the ANOVA F method (Green & Vascotto, 1978). Nonmetric MultiDimensional Scaling, with Bray-Curtis distances, was used to visualize the distances between sites and identify the plant species most dominant within those sites.

Results

A second PCA was done on the plant community composition of the reference sites to compare fen types (Figure A-4). Four Principal Components were extracted. Loadings of four species indicated a strong association with PC-1 among *Equisetum arvense* (0.957), *Salix* sp. (0.957) and *Carex* (-0.748) indicating a hydrophilic species along a plant gradient. Species associated with PC2 were *B. glandulosa* (0.935), *L. laricina* (0.776) and grass (-0.930) producing a gradient indicating the presence of shrubs and trees. There was no statistically significant difference in the plant community composition between *Carex*-based fens and *Sphagnum*-based fens (PC1; Student's *T*-test for PC-1, $p<0.898$; for PC2, $p<0.071$). Cluster analysis (performed using binary Squared Euclidean distances, and Ward's method, Figure A-5) identified three groups (Groups 1, 2 and 3), with of which

contained 3 subgroups (Groups 2A, 2B, and 2C). Group 1 contained sites TR4+BO, which were characterized by the presence of *Equisetum arvense* (horsetail), and *Salix sp.* (willow) (ANOVA F=4.00. $p<0.116$ for both plants). Group 3, containing sites HT+TR5, was significantly different from Groups 1 and 2 with respect to the presence/absence of *Betula glandulosa* (ANOVA F=7.50, $p<0.034$). The NMDS performed to ordinate the sites according to plant community composition (Figure A-6) was consistent with the results of the cluster analysis in that the site groupings tended to overlap with respect to plant community. The stress of the ordination (0.08) indicated a good fit to the data.

Discussion

The cluster analysis and subsequent NMDS showed that while there were slight differences in the community richness among fens, the differences were not necessarily significant. The cluster analysis showed groups of *Sphagnum*-sites were typically distinguished by the presence of shrub species such as *Betula glandulosa* and *Salix* sp., which is consistent with the work of Zoltai & Vitt (1995) who identified these species as being indicative of poor fen sites. The NMDS (Figure A-6) indicated that rich fen sites were closely related, mainly due to their plant community, composed of *Carex* sp., *Typha latifolia*, and graminoid grasses.

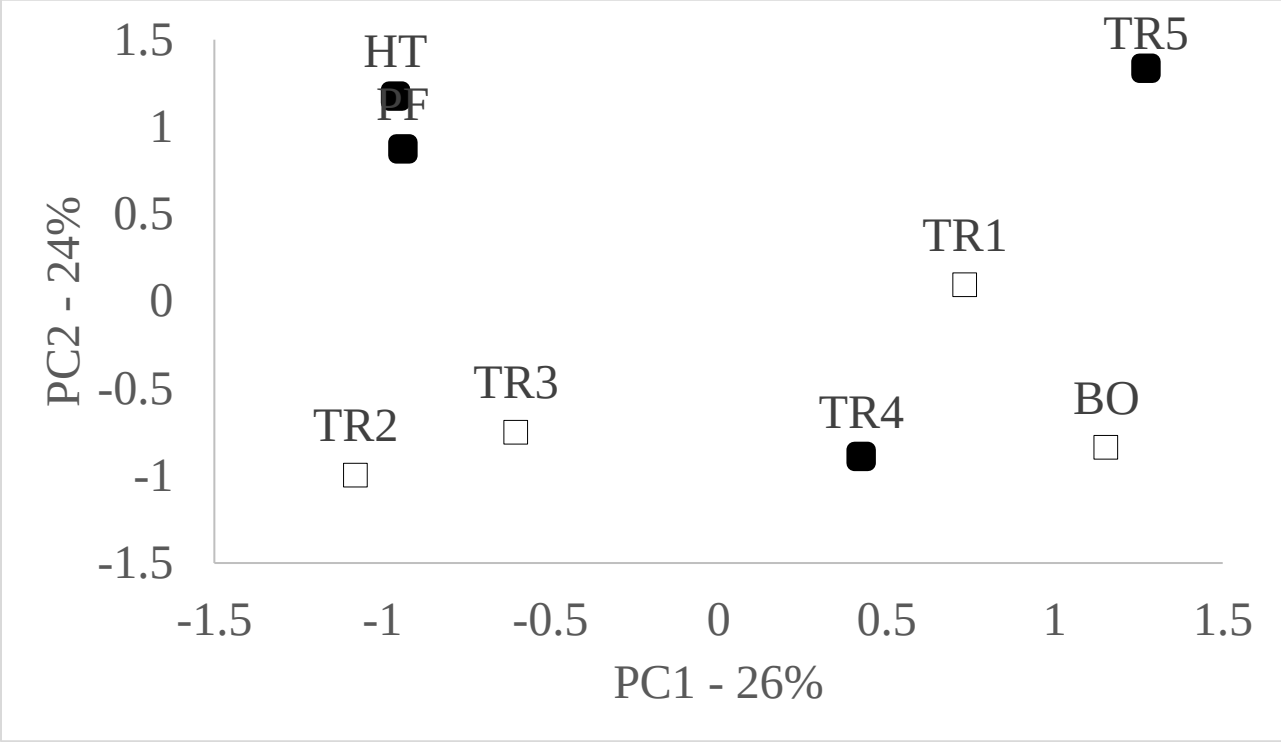

Figure A-4: Principal Component scatterplot of plant community composition among reference sites based on their plant base (Carex – open or Sphagnum – filled).

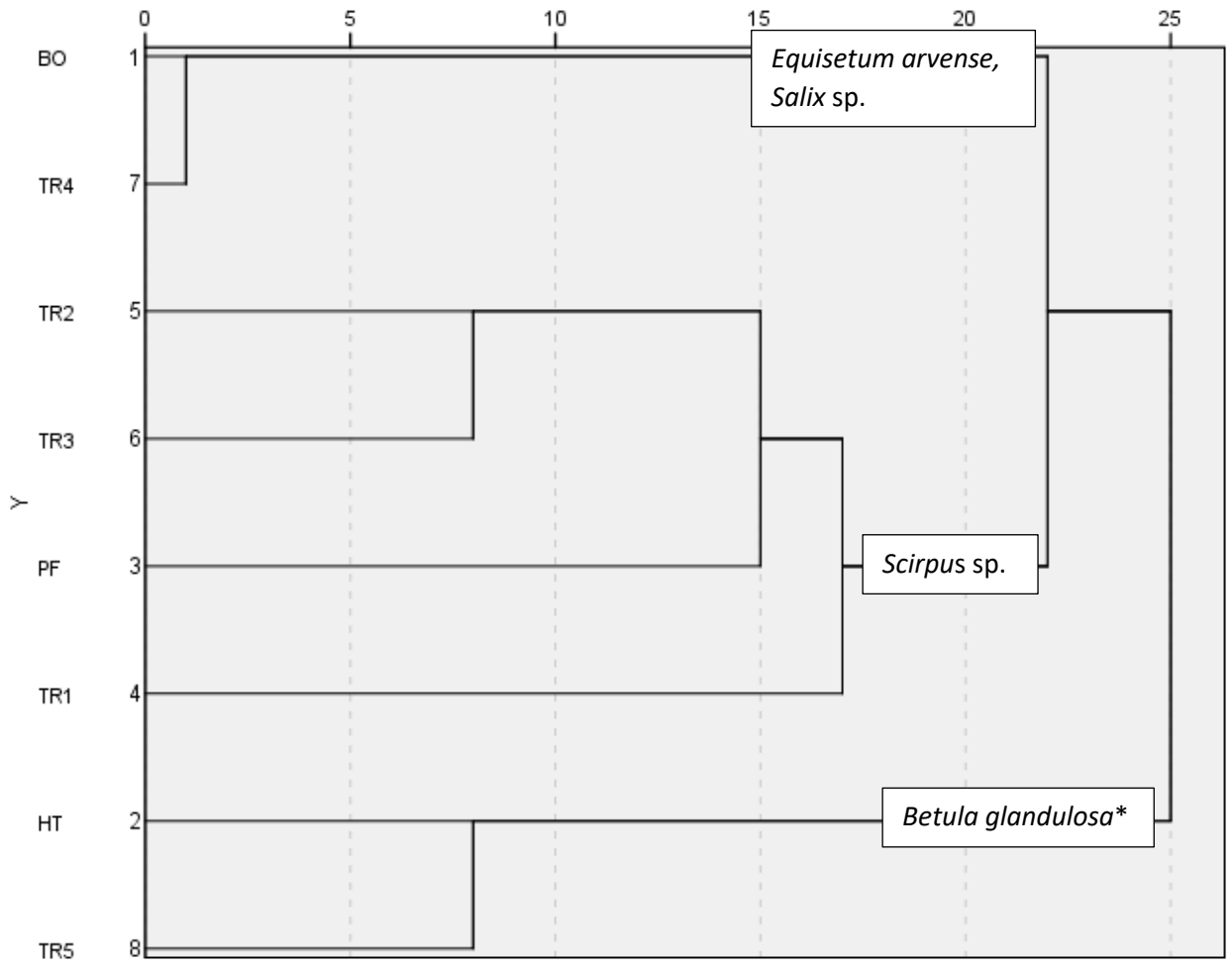

Figure A-5: Cluster analysis of plant communities based on reference sites (*p<0.05).

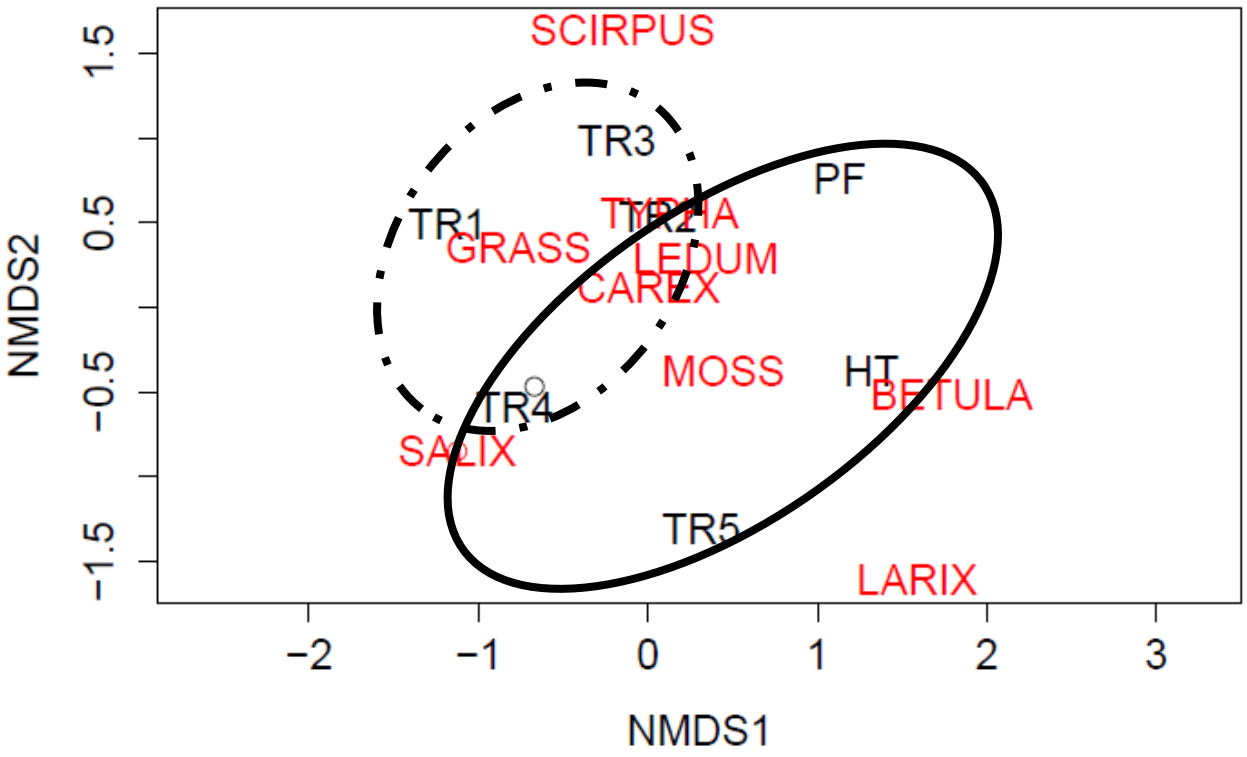

Figure A-6: nMDS ordination plot showing relationships among reference sites based on plant community composition. Stress = 0.08, dim=2. Dotted ellipse indicates *Carex* sites, and solid ellipse indicates *Sphagnum* sites.

Invertebrate Community

For each reference site, the abundance and richness of invertebrates were summarized in three ways – by combining data from all trap types used at a site ("whole site"), by pooling data from all traps of one type at a fen, and by summarizing data for each trap individually. Additionally, the arithmetic mean (±SE) number of invertebrates per trap per fen was calculated. Differences in invertebrate abundance between the two fen classes were measured overall and by trap type using T-tests. Relative abundance values were calculated and transformed into octaves for all further analyses of community composition. Variation in the composition of invertebrate communities was similarly analyzed using cluster analysis to identify biologically similar groups of wetlands, and then identifying the invertebrate taxa whose relative abundances differed most greatly between cluster groups identified using the ANOVA F method. Reference sites were then ordinated using NMDS of the relative abundances of invertebrate taxa to graphically illustrate relationships among the sites.

Results

Cluster analysis of invertebrate community relative composition among the reference sites identified two groups (Figure A-7). In order to be comparable to the NMDS only the 8 most abundant invertebrate taxa (Chironomidae, Chalicoidea, Cicadellidae, Sciaridae, Acari, Thripidae, Ephydridae, and Chloropidae) were used in the cluster analysis due to the small number of sites available for ordination Group 2 (sites PF+TR5) were distinguished from the other fens by their substantially greater relative proportions of Acari (mites) (ANOVA $F=4.47$, $p<0.079$). In contrast, fens in Group 1 had higher relative abundances of Chalicoidea (wasps), Chloropidae (Grass flies), and Sciaridae (Fungus

gnats) (ANOVA F = 23.72, $p<0.003$, F= 22.78, $p<0.003$, and F=9.997, $p<0.02$, respectively). Group 1 was further divided into three subgroups, Group 1A, 1B and 1C. Groups 1A and 1B were separated from Group 1C through a high relative abundance of Chalicoidea (ANOVA, F=38.5, $p<0.003$). Group 1A had a greater relative abundance of Cicadellidae (leafhoppers; ANOVA, F=11.67, $p<0.042$) whereas Group 1B had a higher abundance of Sciaridae (ANOVA, F=26.09, $p<0.015$). The NMDS conducted on the two-dimensional solution had a residual stress value of 0.03, indicating that the fit was acceptable. The ordination of fens and placement of invertebrates on the biplot (Figure A-8) was consistent with the representation of groups identified by the cluster analysis.

Discussion

Patterns in invertebrate abundance and richness between reference fen types were explored to determine whether there were differences. The greater abundance of invertebrates found in sweep samples in *Carex*-sites is most likely due to the plant community and associated invertebrates. Sanderson (1995) found that certain groups of plant-associated invertebrates (particularly hemipterans) were highly correlated with the plant species and plant cover. Since *Carex*-sites tend to have a higher abundance of herb and graminoid plant species with greater ground cover than *Sphagnum* fens, methods used to sample these types of plants would have a greater abundance and richness of invertebrates than sites that lack these plant characteristics. Additionally, pitfall traps in reference sites had a lower richness of invertebrates compared to Sandhill fen, regardless of whether they were *Carex*- or *Sphagnum* dominated. The lower richness of soil-dwelling invertebrates in established fens is consistent with findings of Bujen et al. (2015), who observed significantly higher invertebrate richness in early successional sites over that of

older fens, both rich and poor. This is most likely caused by a higher water table in established fens (Bujen et al., 2015).

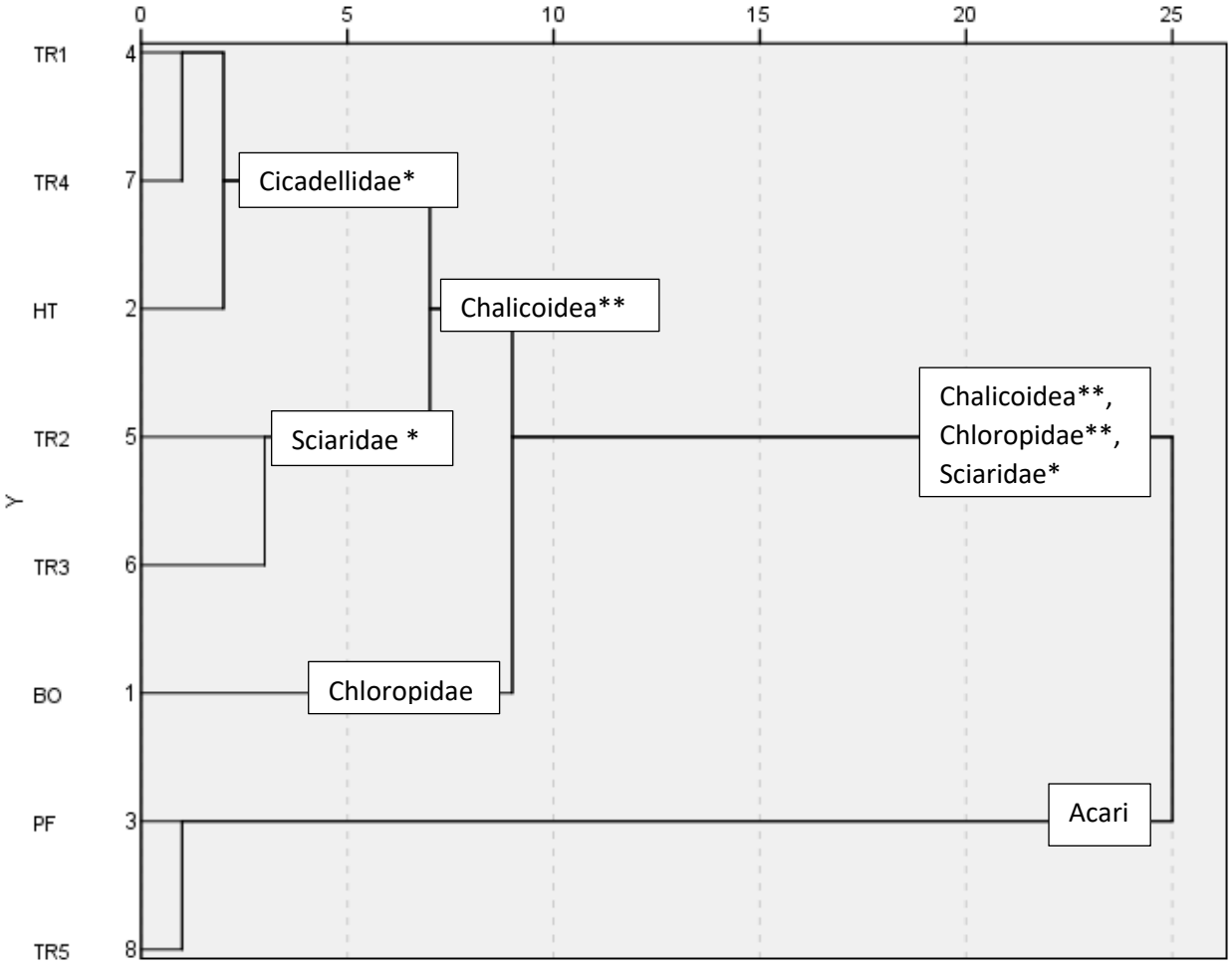

Figure A-7: Cluster analysis of reference fens based on invertebrate community composition (*p<0.05, **p<0.01).

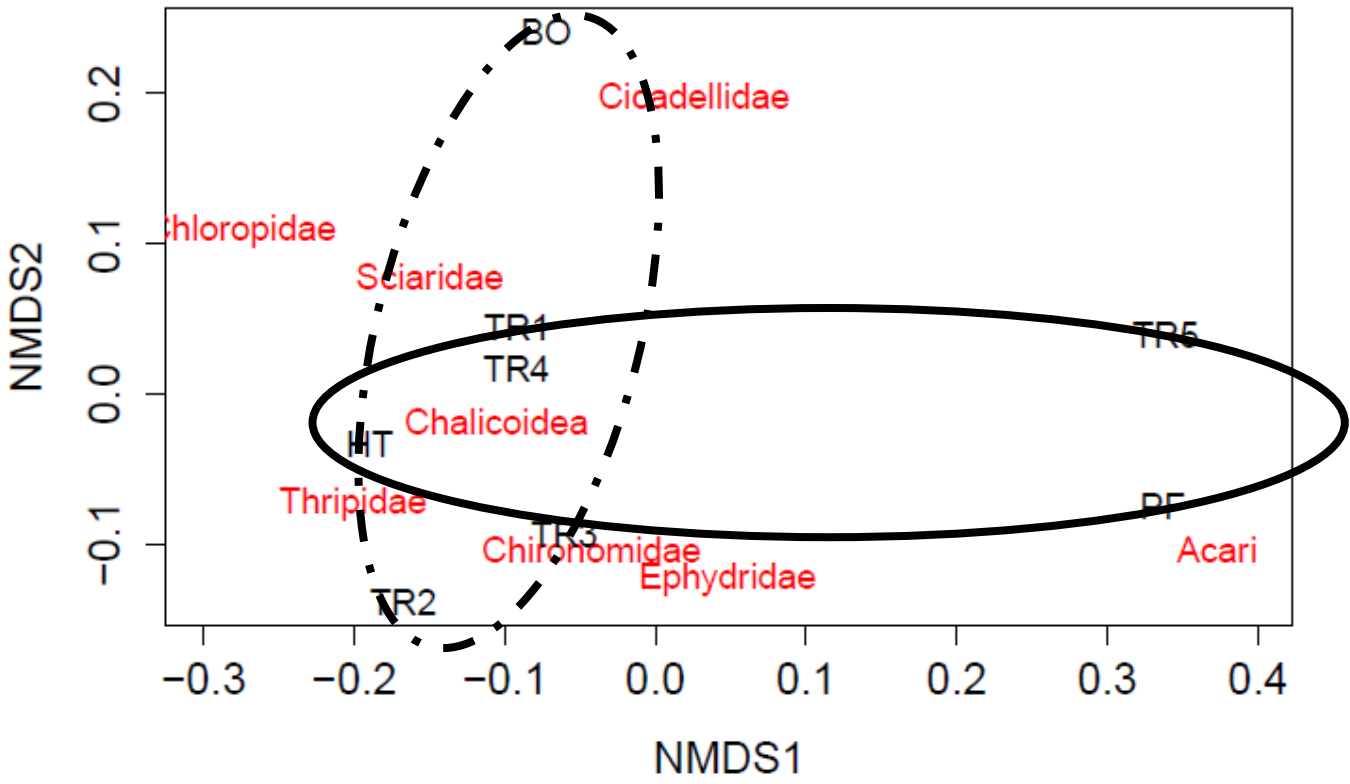

Figure A-8: nMDS ordination plot showing relationships among reference sites based on invertebrate community composition. Stress = 0.03, dim=2. Dotted ellipse indicates *Carex* sites and solid ellipse indicates *Sphagnum* sites.

Conclusion

The examination of soil, plant and invertebrate attributes of the reference fens indicate that there are chemical and plant community difference between and among fen sites. Though there were some differences in invertebrate abundance and family richness, some invertebrate taxa were more likely to be found in one type of fen over the other.

Appendix B: Summary Tables of Analyses

Chapter Two: Environmental Variable Principal Component Analysis

Table B-1: Site loadings of Principal Components 1 and 2 based on soil environmental variables. Italicized values load on the specified axis.

Site	PC1	PC2	Site	PC1	PC2
U27	*2.02*	-0.86	**U36**	-0.99	*2.09*
U32	*2.01*	-0.04	**U06**	-0.82	*1.85*
U28	*1.91*	0.01	**U07**	-0.18	*1.77*
U01	*1.67*	0.01	**U24**	0.50	*1.69*
U37	*1.55*	0.36	**U22**	-0.53	*1.52*
U31	*1.34*	-0.20	**U19**	-0.86	*1.49*
U26	*1.03*	0.80	**U05**	0.11	*0.55*
U29	*0.94*	0.63	**U38**	-0.21	*-0.43*
U02	*0.92*	0.32	**U34**	-0.50	*-0.85*
U25	*0.78*	-0.52	**U12**	-0.81	*-0.89*
U30	*0.54*	-0.36	**U21**	-0.81	*-1.11*
U33	*-0.18*	0.15	**U10**	-0.79	*-1.12*
U03	*-0.19*	-0.02	**U11**	-0.97	*-1.53*
U23	*-0.56*	0.22	**U39**	0.72	*-1.54*
U15	*-0.58*	-0.56	**U20**	-0.88	*-1.58*
U35	*-0.60*	0.47	**U40**	1.31	*-1.62*
U17	*-0.60*	0.47			
U14	*-0.61*	-0.49			
U04	*-0.81*	-0.55			
U16	*-0.88*	0.17			
U13	*-0.89*	-0.84			
U09	*-0.90*	0.77			
U08	*-0.92*	0.52			
U18	*-1.30*	-0.52			

Table B-2: Rotated component loadings of environmental variables (Varimax Rotation). Italicized values load on specified component.

Environmental Variable	Component 1	Component 2
Moisture Content	*0.844*	-0.067
EC	*0.807*	-0.281
Phosphorus (P)	*0.586*	0.009
pH	*-0.695*	-0.373
Potassium (K)	0.188	*0.778*
Nitrogen (N)	-0.302	*0.667*

Chapter Three: Tests of Equality of Means and Redundancy Analyses Loadings

Table B-3: Environmental variable site cluster analysis: Test of equality of group means

	Group 1 vs Group 2		**Group 1A vs Group 1B**	
Site Variable	**F**	**Sig.**	**F**	**Sig.**
Moisture	75.382	***	0.152	0.700
EC	49.38	***	2.57	0.122
pH	24.47	***	2.51	0.126
Phosphorus (P)	10.99	***	0.187	0.669
Nitrogen (N)	3.43	0.072	147.69	***
Potassium (K)	0.911	0.346	3.24	0.085

Table B-4: Tests of Equality of Group Means for Pitfall Traps. Significant values are bolded.

Invertebrate Taxa	F	Sig.
Muscidae	1.064	0.311
Silphidae	1.721	0.200
Latriidae	1.279	0.268
Cecidomyidae	1.276	0.268
Cicadellidae	2.565	0.120
Aphididae	1.700	0.203
Thripidae	1.096	0.304
Phoridae	1.579	0.219
Formicidae	0.451	0.507
Phalangidae	2.291	0.141
Platygastridae	0.144	0.708
Acari	9.264	**0.005**
Saldidae	5.106	**0.032**
Carabidae	1.764	0.195
Staphylinidae	1.299	0.264
Araneae	34.325	**0.000**

Table B-5: Table of Equality of Group Means for Sweep Samples. Significant values are bolded.

Invertebrate Taxa	F	Sig.
Muscidae	0.219	0.646
Cicadellidae	0.465	0.505
Thripidae	63.323	**0.000**
Aphid	0.293	0.596
Lygaeidae	0.322	0.578
Chrysomelidae	1.194	0.290
Chloropidae	0.991	0.334
Chironomidae	10.191	**0.005**
Ephydridae	0.013	0.909
Formicidae	1.316	0.267
Chalicoidea	2.243	0.153
Platygastridae	0.058	0.812
Ichneumonidae	1.182	0.292
Aranaea	0.937	0.347
Coccinellidae	0.022	0.883

Table B-6: Tests of Equality of Group Means for Site Totals. Significant values are bolded.

Invertebrate Taxa	F	**Sig.**
Acari	40.519	**0.000**
Acrididae	0.017	0.898
Aphididae	1.646	0.207
Araneae	0.902	0.348
Braconidae	15.018	**0.000**
Carabidae	0.139	0.712
Cecidomyidae	6.594	**0.014**
Ceratopogonidae	3.969	0.054
Cercopidae	0.385	0.539
Chalicoidea	1.321	0.258
Chironomidae	4.828	**0.034**
Chloropidae	3.042	0.089
Chrysididae	2.629	0.113
Chrysomelidae	1.216	0.277
Cicadellidae	7.848	**0.008**
Coccinellidae	11.329	**0.002**
Delphacidae	13.313	**0.001**
Ephydridae	0.680	0.415
Formicidae	2.774	0.104
Hybotidae	0.994	0.325
Ichneumonidae	5.358	**0.026**
Latrididae	0.842	0.365
Lepidoptera	0.099	0.754
Lygaeidae	0.643	0.428
Miridae	0.000	0.986
Muscidae	5.514	**0.024**
Mycetophilidae	1.029	0.317
Phalangidae	0.554	0.461
Phoridae	0.554	0.461
Platygastridae	3.251	0.079
Proctoruptidae	0.844	0.364
Saldidae	6.322	**0.016**
Sciaridae	0.020	0.888
Silphidae	0.242	0.625
Sphaeroceridae	3.634	0.064
Staphylinidae	4.558	**0.039**
Thripidae	21.473	**0.000**

Table B-7: Table of Equality of Group Means for Vacuum (Soil) Samples. Significant values are bolded.

Invertebrate Taxa	F	Sig.
Cicadellidae	3.798	0.059
Thripidae	5.472	**0.025**
Aphididae	0.084	0.774
Delphacidae	3.569	0.067
Cercopidae	2.389	0.131
Gastropoda	0.239	0.628
Phoridae	0.446	0.508
Acari	115.666	**0.000**
Saldidae	2.789	0.103
Reduviidae	4.463	**0.041**
Carabidae	2.500	0.122
Staphylinidae	0.118	0.734
Araneae	15.102	**0.000**
Carabidae	1.764	0.195
Staphylinidae	1.299	0.264

Table B-8: Table of Equality of Group Means for Vacuum (vegetation) Samples. Significant values are bolded.

	Group 1 vs Group 2		Group 1A vs Group 1B		Group 2A vs Group 2B	
Invertebrate Taxa	F	Sig.	F	Sig.	F	Sig.
Muscidae	0.031	0.861	1.23	0.282	1.01	0.328
Sciaridae	1.25	0.271	0.57	0.461	0.12	0.735
Cecidomyiidae	2.33	0.136	4.18	0.057	1.05	0.319
Cicadellidae	0.04	0.841	0.42	0.525	3.97	0.061
Thripidae	0.65	0.424	5.99	**0.026**	0.02	0.897
Aphididae	8.84	**0.005**	10.09	**0.006**	1.03	0.322
Delphacidae	1.04	0.315	2.64	0.122	9.66	**0.006**
Cercopidae	0.18	0.677	2.95	0.104	1.73	0.204
Lygaeidae	6.64	0.014	0.01	0.934	0.49	0.494
Chloropidae	2.25	0.142	1.25	0.279	7.83	**0.011**
Lepidoptera	1.07	0.308	1.25	0.279	1.67	0.211
Chironomidae	30.34	**0.0005**	0.18	0.675	5.30	**0.033**
Ephydridae	11.49	**0.002**	---	---	0.05	0.822
Phoridae	3.44	0.071	---	---	0.08	0.784
Miridae	0.13	0.723	2.44	0.137	0.21	0.655
Formicidae	6.67	**0.014**	1.79	0.199	4.99	**0.038**
Braconidae	1.27	0.267	0.01	0.922	0.87	0.362
Chalicoidea	7.83	**0.008**	0.14	0.715	0.04	0.853
Ichneumonidae	7.91	**0.008**	---	---	0.03	0.867
Platygastridae	0.08	0.777	3.08	0.097	1.05	0.317
Proctoruptidae	0.02	0.887	0.18	0.675	0.37	0.552
Acari	21.27	**0.0005**	0.72	0.409	0.41	0.531
Staphylinidae	3.06	0.088	0.72	0.409	9.46	**0.006**
Coccinellidae	3.96	0.054	0.57	0.461	62.77	**0.0005**
Carabidae	2.65	0.112	11.36	**0.004**	0.55	0.467
Araneae	0.002	0.967	21.42	**0.0005**	14.11	**0.001**

Table B-9: Table of Equality of Group Means for Sticky Trap Samples. Significant values are bolded.

	Group 1 vs Group 2		Group 1A vs Groups 1B/1C		Group 1B vs Group 1C	
Invertebrate Taxa	F	Sig.	F	Sig.	F	Sig.
Chironomidae	45.36	**0.0005**	0.31	0.581	1.33	0.262
Phoridae	1.88	0.178	12.65	**0.001**	1.67	0.211
Sciaridae	6.70	**0.014**	4.39	**0.045**	24.90	**0.0005**
Cecidomyiidae	7.88	**0.008**	1.26	0.271	6.98	**0.016**
Hybotidae	8.36	**0.006**	10.09	**0.004**	2.04	0.168
Mycetophilidae	0.003	0.957	0.68	0.416	1.06	0.315
Cicadellidae	4.59	**0.039**	18.93	**0.0005**	2.25	0.149
Thripidae	31.12	**0.0005**	11.19	**0.002**	1.05	0.318
Aphididae	0.58	0.450	0.68	0.415	0.07	0.788
Anthocoridae	2.24	0.143	0.26	0.617	36.44	**0.0005**
Chalicoidea	6.01	**0.019**	15.41	**0.001**	0.485	0.494
Braconidae	2.85	0.100	10.28	**0.003**	8.12	**0.010**
Platygastridae	4.80	**0.035**	0.06	0.807	3.04	0.097
Acari	0.47	0.497	0.70	0.411	0.03	0.868
Lepidoptera	1.13	0.294	0.62	0.437	1.7	0.209

Table B-10: Summary table of Site-based Redundancy Analysis Factors

		Eigenvalues					
Trap	Matrix	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Site	Plant	7.26	4.48	3.22	2.42	1.93	1.58
	Environmental	5.17	2.72	1.54	1.34	0.82	0.75
Pitfall	Plant	6.71	5.94	4.74	3.78	2.36	1.76
	Environmental	4.27	2.61	2.37	1.39		
Vacuum (Veg)	Plant	7.94	5.53	4.14	2.77	2.25	1.5
	Environmental	4.97	2.75	1.23	1.02	0.56	0.52
Vacuum (Soil)	Plant	10.47	4.13	2.78	1.52	1.33	1.21
	Environmental	5.72	2.03	1.53	0.5	0.29	0.16
Sweep	Plant	7.00	5.61	4.47	3.37	2.66	2.16
	Environmental	5.72	2.83	1.94	1.29	0.57	0.45
Sticky Trap	Plant	4.91	3.58	1.81	1.71	1.16	1.0
	Environmental	4.13	1.17	0.62	0.38	0.32	0.06

Table B-11: Summary table of Site-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Acari	**1.34**	0.48	0.15	-0.35	0.02	0.11
Cecidomyiidae	**0.35**	-0.21	-0.28	0.04	-0.09	-0.26
Latrididae	**0.34**	-0.28	0.07	-0.29	-0.29	-0.002
Phalangidae	**0.33**	-0.1	0.05	-0.15	-0.25	-0.07
Staphylinidae	**-0.2**	0.2	-0.05	-0.14	-0.13	-0.03
Braconidae	**-0.37**	0.26	0.04	-0.001	0.14	0.02
Lygaeidae	**-0.43**	0.24	-0.16	0.21	-0.21	**-0.43**
Saldidae	**-0.47**	-0.05	-0.21	-0.2	-0.29	-0.002
Coccinellidae	**-0.48**	0.04	0.17	0.02	0.32	-0.16
Chloropidae	**-0.56**	-0.003	-0.2	0.09	-0.08	-0.09
Ephydridae	**-0.68**	0.11	-0.1	-0.1	0.06	0.42
Delphacidae	**-0.73**	-0.01	-0.14	-0.12	0.005	-0.16
Cicadellidae	**-0.89**	0.61	-0.05	0.14	-0.13	0.2
Chironomidae	**-0.89**	-0.43	0.61	-0.01	-0.42	0.1
Aphididae	0.46	**0.82**	-0.57	0.5	-0.33	0.3
Phoridae	0.19	**0.26**	0.14	0.15	-0.17	-0.01
Araneae	0.19	**-0.6**	-0.19	0.14	0.07	-0.11
Chrysomelidae	-0.01	-0.01	**0.53**	-0.47	0.07	0.05
Chalicoidea	-0.11	0.01	**0.44**	-0.05	-0.26	-0.05
Membracidae	0.06	0.19	**0.42**	-0.24	0.04	0.06
Carabidae	0.06	0.19	**0.3**	0.27	-0.26	-0.06
Mycetophilidae	0.08	-0.002	**-0.14**	-0.04	-0.02	0.02
Thripidae	0.12	-1	**-0.74**	-0.17	-0.37	0.1
Formicidae	0.33	-0.64	0.58	**0.96**	0.06	0.15
Chrysididae	0.05	-0.08	-0.05	**-0.09**	0.05	0.06
Hybotidae	-0.12	0.04	-0.15	**-0.19**	0.11	0.13
Acrididae	-0.05	0.19	0.07	0.08	**-0.2**	0.03
Ceraphronidae	-0.002	-0.07	0.17	-0.004	**-0.2**	0.18
Proctoruptidae	-0.02	-0.03	-0.04	-0.09	**-0.21**	-0.15
Reduviidae	0.004	0.08	-0.08	0.03	**-0.22**	0.14
Lepidoptera	-0.01	0.1	-0.04	0.1	**-0.26**	-0.02
Sciaridae	0.05	0.12	0.08	-0.26	**-0.38**	0.16
Platygastridae	0.09	0.07	-0.11	-0.07	**-0.54**	-0.15
Muscidae	0.2	0.04	-0.17	-0.02	0.15	**0.39**
Ichneumonidae	-0.3	-0.02	0.03	0.1	-0.06	**0.34**
Ceratopogonidae	-0.17	-0.31	-0.27	-0.18	0.14	**0.33**
Miridae	0.02	-0.21	-0.04	0.17	-0.003	**0.24**
Cercopidae	-0.09	0.3	-0.1	-0.17	0.11	**-0.37**

CAREX	**-0.84**	-0.1	-0.32	-0.07	-0.02	-0.07
TYPHLAT	**-0.45**	-0.01	-0.34	0.01	-0.22	0.27
SONCARV	**0.41**	-0.33	0.05	0.41	0.02	-0.12
MOSS	**-0.31**	-0.23	0.06	0.22	0.09	0.19
LATHOCH	**0.36**	-0.08	-0.28	-0.11	0.26	-0.27
HIERUMB	**0.33**	-0.02	-0.21	-0.07	0.08	-0.07
MEDISAT	0.4	**-0.47**	0.21	-0.3	0.01	-0.18
EQUIARV	0.13	**0.15**	0.05	-0.02	-0.03	-0.04
CORNSER	0.05	**-0.33**	0.001	0.13	0.18	0.32
FRAGVES	0.27	-0.15	**0.51**	-0.32	-0.12	0.07
CICEMIL	0.04	0.06	**0.45**	0.12	-0.21	0.25
PICEGLA	-0.05	-0.06	**0.39**	0.12	-0.13	0.19
LOTUCOR	0.04	0.05	**0.21**	0.03	0.13	0.04
EPILANG	-0.07	0.15	**0.37**	-0.13	0.03	0.08
SALIX	-0.19	0.04	0.22	**0.26**	0.21	0.09
PRUNPEN	-0.09	-0.07	0.23	**0.25**	-0.22	-0.21
RUBUIDA	0.19	0.05	0.34	-0.15	**0.49**	-0.12
MELIOFF	0.13	-0.11	0.13	0.04	**0.16**	-0.02
HORDJUB	0.09	-0.002	-0.08	0.17	**-0.3**	0.11
MELIALB	0.05	-0.12	-0.07	-0.11	**0.18**	0.16
TARAOFF	0.13	-0.05	0.31	0.09	**0.4**	0.08
SCIRPUS	-0.32	-0.02	-0.07	0.15	-0.11	**-0.53**

Table B-12: Summary table of Site-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Acari	**1.08**	-0.07	0.51	-0.06	-0.02	-0.02
Formicidae	**0.54**	-0.17	-0.5	-0.17	-0.06	-0.32
Muscidae	**0.35**	-0.18	0.04	0.04	0.14	-0.09
Araneae	**0.27**	-0.3	-0.11	-0.07	0.02	0.25
Carabidae	**0.18**	0.06	0.14	-0.15	0.06	-0.11
Ichneumonidae	**-0.22**	-0.17	0.03	-0.01	0.15	0.09
Saldidae	**-0.27**	-0.22	0.1	0.05	0.05	-0.04
Staphylinidae	**-0.29**	-0.05	0.08	-0.13	-0.05	0.08
Chloropidae	**-0.53**	-0.23	-0.09	-0.05	0.06	0.06
Ephydridae	**-0.55**	-0.16	0.13	0.07	0.4	-0.005
Delphacidae	**-0.58**	-0.02	0.01	0.06	-0.09	0.01
Coccinellidae	**-0.63**	0.15	-0.24	0.02	-0.1	-0.08
Chironomidae	**-0.64**	-0.58	0.11	0.27	-0.22	-0.12

Cicadellidae	**-0.7**	-0.12	0.27	-0.36	0.08	-0.11
Braconidae	-0.17	**0.24**	0.03	0.12	0.03	-0.15
Miridae	0.08	**0.11**	-0.01	-0.03	-0.06	-0.09
Chrysididae	0.15	**-0.19**	-0.1	-0.1	0.08	-0.11
Reduviidae	-0.05	**-0.25**	0.05	-0.16	0.1	0.15
Acrididae	-0.06	**-0.3**	0.08	0.05	-0.12	-0.06
Ceratopogonidae	0.005	**-0.35**	-0.04	0.07	0.29	-0.05
Sciaridae	0.03	**-0.36**	0.29	0.31	-0.06	-0.1
Thripidae	0.13	**-0.5**	-0.41	0.01	0.03	0.22
Hybotidae	-0.004	**-0.52**	0.25	-0.06	0.16	-0.07
Cecidomyiidae	0.36	**-0.57**	-0.05	-0.01	-0.17	0.09
Cercopidae	-0.08	0.14	**0.38**	-0.36	-0.32	0.14
Membracidae	0.03	0.05	**0.25**	0.19	-0.02	-0.17
Platygastridae	0.05	-0.03	**0.06**	0.001	0.003	0.04
Mycetophilidae	0.07	-0.09	**-0.15**	-0.01	0.06	0.06
Chrysomelidae	-0.05	0.2	0.2	**0.34**	0.02	0.18
Latrididae	0.26	-0.24	0.08	**0.31**	-0.11	0.09
Phoridae	0.13	-0.16	-0.06	**0.25**	-0.15	-0.21
Phalangidae	0.2	-0.06	0.02	**0.22**	0.04	0.17
Ceraphronidae	0.08	0.09	-0.04	**0.17**	0.06	0.04
Chalicoidea	0.1	0.09	-0.05	**0.14**	-0.03	-0.08
Aphididae	0.25	-0.22	0.13	**-0.35**	0.14	-0.04
Lygaeidae	-0.28	-0.4	-0.01	-0.28	**-0.29**	0.01
Proctoruptidae	-0.09	-0.004	-0.04	0.07	-0.12	**0.25**
Lepidoptera	-0.03	0.13	0.01	-0.0004	0.08	**0.21**
Moisture	**-0.97**	0.12	-0.05	-0.15	-0.13	0.05
EC	**-0.68**	-0.5	-0.07	-0.28	0.06	0.46
K	-0.12	-0.05	**0.96**	0.2	-0.11	-0.04
N	0.35	0.43	0.36	**-0.74**	-0.12	-0.04
P	-0.41	0.05	0.16	-0.06	**0.89**	0.09
pH	0.55	0.37	-0.21	0.23	-0.05	**0.64**

Table B-13: Summary table of Pitfall-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Acari	**1.71**	-0.98	0.25	0.51	0.48	0.09
Phoridae	**0.42**	0.23	-0.19	-0.08	0.05	-0.12
Staphylinidae	**0.25**	-0.02	-0.06	-0.02	-0.17	0.14
Thripidae	0.03	**-0.16**	-0.05	-0.07	-0.13	0.02
Silphidae	0.13	**-0.26**	0.24	-0.15	0.03	-0.04
Latrididae	-0.01	**-0.3**	0.02	-0.1	-0.16	0.01
Aphididae	0.36	**-0.45**	0.05	-0.34	-0.28	-0.25
Carabidae	0.81	1.03	**1.24**	-0.14	-0.52	-0.25
Cecidiomyiidae	0.28	0.25	**-0.42**	0.14	-0.13	0.17
Formicidae	0.68	1.08	**-1.09**	0.61	0.01	-0.27
Saldidae	-0.15	-0.26	-0.17	**-0.47**	-0.04	-0.01
Platygastridae	0.51	-0.6	-0.47	**-0.57**	-0.48	0.01
Cicadellidae	0.28	0.06	-0.65	**-0.69**	-0.14	-0.22
Phalangidae	0.38	0.23	-0.18	0.06	**-0.61**	0.9
Arachnida	-0.54	-0.75	-0.01	1.07	**-0.75**	-0.29
Muscidae	0.33	-0.18	-0.2	-0.17	-0.27	**-0.45**
CAREX	**-0.65**	-0.24	-0.04	-0.24	-0.06	0.12
SONCARV	0.17	**0.42**	-0.29	0.37	-0.14	-0.26
TYPHLAT	-0.15	**-0.24**	0.08	-0.39	-0.16	0.01
PRUNPEN	0.22	0.11	**0.34**	-0.06	0.23	-0.08
MOSS	-0.11	0.09	**0.32**	0.08	0.32	-0.05
FRAGVES	0.1	0.27	0.22	**0.55**	-0.25	0.07
MEDISAT	0.03	0.22	-0.07	**0.37**	-0.12	0.13
MEFIOFF	-0.05	0.23	-0.07	**0.32**	0.23	-0.24
SCIRPUS	-0.28	-0.01	-0.29	**-0.57**	0.14	0.03
RUBUIDA	0.1	0.02	-0.17	0.22	**0.49**	-0.1
LOTUCOR	-0.01	0.29	-0.01	0.06	**0.37**	-0.05
MELIALB	-0.25	0.09	-0.03	-0.11	**0.27**	0.1
CICEMIL	-0.18	0.36	0.39	0.04	**-0.47**	0.15
EQUIARV	0.28	0.06	-0.01	0.2	-0.24	**0.43**
PICEGLA	-0.21	0.31	0.17	-0.17	-0.01	**0.41**
TARAOFF	0.04	0.13	-0.24	0.21	0.2	**-0.25**

Table B-14: Summary table of Pitfall-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis

	RDA1	RDA2	RDA3	RDA4
Arachnida	**0.54**	0.03	0.3	0.52
Muscidae	**-0.35**	-0.19	-0.29	-0.07
Silphidae	**-0.46**	-0.13	0.31	-0.45
Carabidae	**-0.63**	0.7	-0.21	-0.18
Acari	**-1.32**	0.31	0.35	0.4
Latrididae	-0.22	**-0.35**	0.26	-0.26
Aphididae	-0.35	**-0.44**	-0.05	0.16
Thripidae	-0.46	**-0.54**	0.14	-0.07
Cicadellidae	-0.32	**-0.62**	-0.37	-0.02
Cecidomyiidae	0.01	0.06	**-0.28**	0.16
Phoridae	-0.01	0.14	**-0.34**	0.02
Phalangidae	-0.004	-0.52	**-0.57**	-0.04
Formicidae	-0.15	0.34	**-0.83**	0.04
Platygastridae	-0.35	-0.29	-0.14	**0.48**
Saldidae	0.19	-0.22	0.04	**0.26**
Staphylinidae	-0.09	-0.08	-0.12	**0.14**
N	**-0.48**	0.41	0.1	0.04
EC	0.29	**-0.8**	0.31	-0.3
K	-0.39	0.02	**0.68**	0.48
MOISTURE	0.66	-0.21	**0.67**	-0.09
pH	0.16	0.26	**-0.64**	0.25
P	0.06	0.1	0.45	**-0.78**

Table B-15: Summary table of Vacuum (Vegetation)-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Chironomidae	**1.12**	0.58	0.28	-0.47	-0.19	0.22
Cicadellidae	**0.73**	-1.13	-0.39	-0.14	-0.54	0.31
Braconidae	**0.68**	-0.34	0.26	-0.35	0.11	-0.67
Ephydridae	**0.66**	-0.34	0.01	-0.46	0.38	0.11
Delphacidae	**0.39**	-0.37	-0.28	-0.02	0.27	0.04
Chloropidae	**0.35**	-0.2	-0.21	0.03	0.34	-0.06
Staphylinidae	**0.35**	-0.24	-0.26	0.23	-0.04	0.17
Aphididae	**-0.77**	-0.22	-0.37	-0.21	-0.62	-0.35
Acari	**-1.31**	-0.67	0.92	-0.5	0.02	0.3
Formicidae	0.32	**1**	0.33	0.03	-0.28	0.03
Araneae	-0.38	**0.94**	-0.69	-0.28	-0.14	0.17
Phoridae	0.15	**0.22**	0.07	0.13	0.03	0.04
Muscidae	0.02	-0.09	**0.19**	-0.13	-0.18	-0.11
Proctoruptidae	-0.07	-0.08	**-0.18**	0.03	-0.11	-0.18
Cecidomyiidae	-0.2	0.02	**-0.34**	-0.06	0.13	0.17
Thripidae	-0.81	-0.06	**-0.83**	-0.38	0.02	0.11
Carabidae	-0.11	-0.23	0.36	**0.7**	-0.05	0.07
Cercopidae	0.14	-0.08	-0.22	**0.46**	-0.013	0.28
Sciaridae	0.11	-0.03	-0.03	**-0.29**	-0.13	-0.06
Miridae	-0.12	0.26	-0.19	**-0.37**	0.21	0.04
Ichneumonidae	0.38	-0.03	0.15	**-0.46**	-0.18	0.02
Coccinellidae	-0.26	-0.26	-0.3	-0.04	**0.42**	0.11
Lepidoptera	0.09	0.06	-0.08	-0.16	**-0.21**	-0.05
Chalicoidea	0.49	-0.1	0.1	0.01	**-0.53**	0.23
Platygastridae	-0.01	-0.03	0.15	-0.06	-0.09	**0.25**
Lygaeidae	0.05	-0.22	-0.3	0.22	-0.33	**-0.35**
MOSS	**0.45**	0.17	0.03	-0.2	0.05	-0.03
SALIX	**0.31**	0.05	0.08	0.12	0.04	0.12
HIERUMB	**-0.38**	0.08	-0.02	-0.14	-0.01	-0.15
LATHOCH	**-0.45**	0.08	-0.09	-0.13	0.05	0.1
CORNSER	0.05	**0.51**	0.11	-0.03	0.1	-0.04
SONCARV	-0.28	**0.47**	-0.13	-0.13	-0.02	0.04
FRAGVES	-0.04	-0.05	**0.55**	-0.04	0.01	0.23
EQUIARV	-0.11	-0.12	**0.43**	0.35	0.26	-0.32
TARAOFF	0.07	0.28	**0.32**	-0.08	0.14	-0.16
MELIALB	-0.11	-0.13	**0.21**	-0.18	-0.04	0.15
RUDUIDA	0.04	0.18	**0.2**	0.06	0.02	0.2

TYPHLAT	0.29	-0.23	**-0.44**	-0.17	0.18	0.1
CAREX	0.52	-0.28	**-0.56**	-0.05	0.39	-0.13
HORDJUB	-0.27	-0.05	-0.14	**-0.34**	-0.29	-0.06
LOTUCOR	-0.1	-0.05	0.16	**-0.34**	-0.11	0.2
PRUNPEN	0.23	0.17	0.11	-0.06	**-0.24**	-0.01
CICEMIL	0.25	0.06	0.27	-0.18	**-0.45**	0.14
PICEGLA	0.1	0.04	0.15	-0.29	-0.32	**0.4**
MEDISAT	-0.33	0.23	0.17	-0.27	0.21	**0.36**
EPILANG	0.18	-0.07	-0.01	-0.01	-0.3	**0.33**
MELIOFF	-0.23	-0.07	0.08	-0.31	0.06	**0.32**
SCIRPUS	0.09	0.07	-0.24	-0.02	-0.17	**-0.38**

Table B-16: Summary table of Vacuum (Vegetation)-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Araneae	**0.78**	0.58	-0.17	-0.05	-0.06	-0.17
Acari	**0.75**	-0.65	0.29	-0.25	-0.24	0.01
Formicidae	**0.39**	-0.1	-0.002	0.22	-0.2	-0.07
Chironomidae	**-0.18**	-0.05	-0.14	-0.12	0.11	0.1
Chalicoidea	**-0.18**	-0.05	0.05	0.04	0.16	-0.08
Staphylinidae	**-0.49**	0.05	0.24	-0.06	-0.11	0.01
Braconidae	**-0.51**	-0.31	0.01	0.25	0.16	0.07
Delphacidae	**-0.55**	0.09	-0.05	0.1	0.12	-0.11
Ephydridae	**-0.57**	-0.37	-0.1	-0.46	-0.01	-0.14
Coccinellidae	**-0.63**	-0.16	-0.14	0.1	-0.21	0.02
Chloropidae	**-0.65**	0.38	-0.23	-0.24	-0.19	0.15
Cicadellidae	**-0.78**	0.31	0.36	-0.18	-0.13	-0.28
Cecidomyiidae	0.22	**0.65**	-0.11	-0.13	0.13	-0.03
Lygaeidae	0.13	**0.51**	0.21	0.02	-0.01	-0.001
Platygastridae	0.09	**-0.12**	0.01	-0.04	0.11	-0.004
Miridae	0.11	**-0.14**	-0.14	0.12	0.07	-0.04
Phoridae	-0.02	**-0.16**	-0.09	0.07	-0.01	-0.09
Sciaridae	-0.02	**-0.2**	-0.06	-0.02	0.04	0.03
Ichneumonidae	-0.17	**-0.23**	-0.14	-0.21	0.06	0.02
Cercopidae	-0.21	0.43	**0.46**	0.05	0.02	0.3
Carabidae	0.19	-0.16	**0.31**	-0.21	0.06	0.22
Thripidae	0.07	0.08	**-0.43**	-0.13	-0.11	0.2

Aphididae	0.38	0.12	0.01	**-0.46**	0.12	-0.06
Lepidoptera	-0.04	-0.05	-0.06	-0.08	**0.29**	-0.05
Muscidae	0.08	-0.07	0.08	-0.12	**0.2**	0.13
Proctoruptidae	-0.1	0.14	-0.22	-0.06	-0.1	**0.22**
MOISTURE	**-0.93**	0.12	-0.14	0.09	-0.3	0.11
EC	-0.55	**0.58**	-0.37	-0.41	-0.25	-0.04
N	0.27	0.03	**0.79**	-0.02	-0.5	0.22
P	-0.49	-0.31	0.11	**-0.66**	-0.03	-0.46
K	-0.3	0.25	0.61	-0.11	**0.63**	0.24
PH	0.55	-0.4	-0.29	-0.31	0.04	**0.6**

Table B-17: Summary table of Vacuum (Soil)-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis.

	RDA	RDA2	RDA3	RDA4	RDA5	RDA6
Cicadellidae	**-1.51**	1.49	-0.59	-0.03	0.07	-0.17
Delphacidae	**-0.59**	-0.05	0.2	-0.08	0.31	0.39
Acari	**2.04**	0.24	-0.86	0.1	0.55	0.17
Saldidae	**-0.91**	0.11	0.3	0.22	0.27	0.61
Araneae	**1.47**	1.12	0.97	-0.25	-0.15	0.12
Reduviidae	0.07	**0.35**	-0.15	-0.01	0.04	-0.06
Staphylinidae	-0.09	**0.22**	-0.02	-0.05	-0.13	0.12
Thripidae	0.34	0.42	0.16	**1.01**	-0.2	0.007
Gastropoda	-0.09	0.09	0.18	**-0.41**	0.35	0.07
Aphididae	0.32	0.14	-0.62	-0.35	**-0.68**	0.5
Phoridae	0.03	0.24	0.09	-0.13	**0.29**	-0.14
Cercopidae	-0.11	-0.09	-0.21	0.13	-0.05	**0.37**
Carabidae	-0.28	-0.01	0.11	-0.06	-0.02	**0.38**
CAREX	**-0.62**	0.16	0.23	-0.02	0.08	0.53
SONCARV	**0.42**	-0.3	0.26	0.31	-0.33	0.04
MOSS	**-0.37**	-0.2	0.17	0.33	0.01	-0.07
CICEMIL	**0.26**	0.21	-0.02	0.14	0.25	-0.11
SALIX	**-0.28**	-0.17	0.16	-0.14	0.24	0.04
TYPHLAT	-0.33	**0.44**	0.1	0.06	0.01	0.39
RUBUIDA	0.05	**-0.33**	0.16	-0.2	-0.31	-0.12
PRUNPEN	-0.07	**-0.29**	0.11	-0.02	-0.14	-0.23
MEDISAT	0.44	0.09	**0.46**	0.04	-0.07	-0.14
HORDJUB	-0.01	-0.19	**-0.4**	0.06	-0.16	0.01

TARAOFF	0.24	0.04	**0.3**	-0.28	-0.26	0.26
MELIOFF	0.08	-0.01	-0.07	**0.37**	0.1	-0.26
EQUIARV	0.05	0.18	0.14	**-0.32**	0.26	-0.27
HIERUMB	0.24	0.04	0.03	**-0.28**	-0.25	0.26
FRAGVES	0.51	0.08	0.11	0.2	**0.54**	-0.13
CORNSER	0.14	-0.23	-0.23	0.05	**0.32**	-0.08
PICEGLA	-0.09	0.27	-0.17	-0.11	0.1	**-0.4**
LOTUCOR	-0.06	-0.07	-0.24	0.11	0.15	**-0.33**
MELIALB	-0.004	0.05	-0.07	-0.08	0.1	**-0.29**
EPILANG	-0.22	-0.13	-0.01	-0.05	-0.16	**-0.45**
SCIRPUS	-0.32	-0.18	0.1	0.06	0.11	**0.47**

Table B-18: Summary table of Vacuum (Soil)-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Cicadellidae	**-0.82**	0.68	0.66	-0.01	0.05	0.05
Thripidae	**0.32**	-0.22	0.22	-0.11	0.04	0.16
Delphacidae	**-0.42**	0.07	0.03	-0.24	0.04	-0.18
Gastropoda	**-0.28**	0.17	0.04	-0.27	0.02	-0.16
Acari	**1.88**	0.41	0.08	-0.14	0.14	0.02
Saldidae	**-0.44**	0.18	0.11	-0.37	0.13	0.12
Carabidae	**-0.47**	-0.21	0.09	0.06	0.01	-0.01
Aphididae	0.32	**0.75**	0.07	0.06	-0.37	-0.03
Cercopidae	0.14	**0.32**	0.04	0.32	0.28	-0.13
Phoridae	-0.05	**-0.26**	0.02	0.01	-0.06	0.1
Reduviidae	0.09	0.09	**0.16**	-0.07	-0.03	0.04
Staphylinidae	-0.26	0.11	**0.4**	0.26	0.06	0.1
Araneae	0.56	-0.64	**0.88**	-0.01	-0.09	-0.12
PH	**0.77**	0.05	-0.23	-0.22	0.47	-0.3
MOISTURE	**-0.9**	-0.09	0.01	0.01	0.41	-0.09
P	-0.47	**0.6**	0.26	-0.33	-0.21	-0.45
N	0.08	0.38	**-0.71**	0.55	-0.2	-0.02
EC	-0.52	0.37	0.5	0.11	**0.54**	0.18
K	-0.27	0.27	-0.43	-0.45	-0.2	**0.66**

Table B-19: Summary table of Sweep Net-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Chrysomelidae	**1**	0.53	-0.61	-0.08	-0.48	0.06
Araneae	**0.77**	-0.72	-0.35	0.14	0.16	-0.34
Chironomidae	**0.72**	0.33	0.12	0.11	0.34	-0.03
Chalicoidea	**0.51**	-0.13	0.24	-0.47	-0.09	-0.06
Coccinellidae	**-0.43**	0.38	0.11	0.1	0.12	-0.4
Cicadellidae	**-0.86**	0.44	-0.07	0.68	0.12	0.49
Formicidae	0.49	**-0.92**	0.6	-0.03	0.12	0.59
Thripidae	-0.8	**-1.18**	-0.82	-0.26	-0.06	-0.01
Aphididae	-0.05	-0.46	**0.98**	0.59	-0.05	-0.45
Ephydridae	-0.2	-0.28	-0.18	**0.45**	-0.24	-0.09
Lygaeidae	-0.8	0.23	0.33	**-0.84**	0.34	-0.41
Chloropidae	0.05	-0.01	0.51	-0.31	**0.72**	0.13
Platygastridae	-0.02	0.15	0.11	-0.39	**0.48**	-0.42
Muscidae	0.07	0.001	-0.25	0.18	**0.45**	0.16
Ichneumonidae	0.03	0.2	-0.24	0.1	**0.24**	-0.24
FRAGVES	**0.73**	-0.22	-0.17	-0.01	-0.42	-0.13
MELIOFF	**0.49**	0.18	0.19	-0.13	0.13	0.26
MEDISAT	**0.47**	0.05	-0.4	-0.07	-0.27	0.16
SCIRPUS	**-0.59**	0.15	-0.03	-0.39	-0.38	0.25
TYPHLAT	**-0.63**	-0.27	-0.4	0.05	-0.08	-0.09
CAREX	**-0.74**	0.15	-0.42	0.07	0.26	-0.29
RUBUIDA	0.31	**0.35**	-0.35	0.06	-0.32	0.23
CICEMIL	0.35	**-0.41**	0.14	0.22	-0.23	0.03
SONCARV	0.15	**-0.62**	0.34	0.36	-0.22	0.06
EQUIARV	-0.1	0.2	**0.6**	0.16	-0.22	-0.28
MOSS	-0.02	-0.51	-0.09	-0.06	**0.51**	0.09
HORDJUB	0.13	0.14	0.34	0.02	0.39	**0.6**

Table B-20: Summary table of Sweep Net-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Cicadellidae	**0.85**	0.08	0.2	-0.33	0.02	0.01
Lygaeidae	**0.76**	-0.34	-0.02	-0.4	-0.2	0.14
Coccinellidae	**0.54**	-0.01	0.03	0.18	-0.05	-0.13
Ephydridae	**0.22**	0.18	0.02	0.12	-0.17	-0.3
Muscidae	**-0.33**	0.22	-0.06	0.14	-0.16	0.13
Chalicoidea	**-0.56**	-0.08	0.2	-0.2	-0.29	-0.13
Araneae	**-0.89**	-0.01	0.0004	-0.16	0.14	-0.24
Chrysomelidae	-0.63	**0.67**	0.25	-0.31	-0.09	0.16
Ichneumonidae	0.08	**0.44**	-0.1	0.03	0.09	0.1
Platygastridae	0.3	**0.34**	0.02	0.23	0.1	0.1
Aphididae	0.22	**-0.43**	0.36	0.22	0.18	-0.01
Formicidae	-0.65	**-0.82**	0.14	-0.16	0.1	0.13
Thripidae	-0.17	-0.02	**-0.93**	-0.09	0.01	0.03
Chironomidae	-0.32	0.11	0.35	**0.36**	0.03	0.13
Chloropidae	-0.18	-0.36	-0.24	**0.38**	-0.35	0.1
MOISTURE	**0.81**	0.39	-0.08	0.09	0.36	0.21
EC	0.61	0.17	**-0.71**	-0.28	0.11	0.06
P	-0.22	0.44	**-0.64**	0.56	-0.11	0.15
PH	-0.53	0.06	-0.09	**-0.66**	-0.21	0.47
N	-0.39	-0.31	0.21	-0.15	**0.81**	-0.17
K	-0.24	0.61	0.46	0.06	-0.002	**-0.59**

Table B-21: Summary table of Sticky Trap-based RDA loadings of the invertebrate community constrained by the plant community. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Thripidae	**1.59**	-0.24	-0.22	0.14	-0.25	-0.07
Phoridae	**-0.65**	-0.45	-0.59	-0.01	-0.1	-0.14
Braconidae	**-0.68**	0.01	0.52	0.11	-0.25	0.49
Cicadellidae	**-1.08**	-0.1	0.39	0.3	-0.27	-0.18
Chalicoidea	0.39	**1.4**	0.02	-0.23	-0.16	0.28
Lepidoptera	0.02	**0.58**	-0.51	0.01	-0.31	-0.03
Acari	-0.05	**-0.68**	-0.21	-0.18	-0.17	-0.29
Mycetophilidae	0.01	-0.04	**0.4**	0.23	0.19	-0.14
Sciaridae	-0.61	-0.07	**-0.81**	0.21	0.2	0.31
Anthocoridae	-0.33	-0.19	0.03	**-0.56**	-0.15	0.22
Platygastridae	0.39	-0.67	0.25	**-0.7**	0.4	0.15
Chironomidae	-0.64	0.46	-0.29	**-0.74**	0.17	-0.13
Hybotidae	-0.11	0.54	-0.01	0.36	**0.82**	-0.21
Cecidomyiidae	0.16	-0.46	-0.25	0.43	0.16	**0.63**
Aphididae	-0.1	0.19	-0.04	0.25	-0.2	**-0.3**
SONCARV	**0.59**	0.05	0.04	-0.21	0.16	0.11
MEDISAT	**0.49**	-0.16	-0.29	-0.37	0.17	0.04
MELIALB	**0.35**	0.16	0.28	0.23	-0.03	0.12
MELIOFF	**0.22**	-0.02	0.06	-0.1	-0.16	-0.06
TYPHLAT	**-0.49**	0.04	0.36	-0.26	0.13	-0.25
CAREX	**-0.68**	0.11	0.49	-0.23	-0.07	0.04
MOSS	-0.15	**0.35**	0.02	-0.22	-0.02	0.09
CICEMIL	0.08	**0.31**	-0.06	0.09	0.11	-0.03
PICEGLA	0.14	**0.3**	-0.15	-0.07	0.004	-0.14
PRUNPEN	0.15	**0.28**	-0.09	-0.02	0.07	-0.07
LOTUCOR	0.08	**0.26**	-0.06	-0.05	-0.22	0.1
HIERUMB	0.19	**0.25**	-0.02	-0.09	-0.005	-0.19
FRAGVES	0.16	**-0.26**	-0.21	-0.19	-0.15	0.07
EQUIARV	-0.06	**-0.36**	-0.09	-0.01	0.25	0.41
EPILANG	0.02	0.12	**-0.2**	-0.11	-0.16	-0.01
RUBUIDA	0.08	0.14	**-0.32**	-0.11	0.08	0.01
TARAOFF	0.14	0.2	**-0.33**	-0.04	-0.11	-0.04
SCIRPUS	-0.2	0.13	0.12	**-0.22**	-0.3	0.12
LATHOCH	0.21	0.22	0.06	-0.2	**0.34**	-0.16
SALIX	-0.16	0.005	0.17	-0.22	**0.33**	0.03
HORDJUB	0.28	0.05	0.14	-0.07	**-0.36**	-0.12
CORNSER	0.24	-0.13	0.24	0.12	-0.2	**-0.29**

Table B-22: Summary table of Sticky Trap-based RDA loadings of the invertebrate community constrained by the environmental variables. Bolded values load on identified axis.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
Thripidae	**1.48**	0.02	-0.11	-0.11	-0.11	0.0001
Cecidomyiidae	**0.36**	-0.17	-0.27	-0.02	0.1	-0.11
Chironomidae	**-0.61**	-0.4	0.19	-0.09	0.03	0.09
Sciaridae	**-0.76**	-0.43	-0.56	-0.05	-0.04	0.02
Braconidae	**-0.79**	0.39	-0.02	0.04	-0.19	-0.12
Cicadellidae	**-0.94**	0.3	0.1	-0.11	-0.001	0.03
Phoridae	-0.22	**-0.4**	-0.09	-0.11	0.14	-0.02
Mycetophilidae	-0.05	**0.35**	0.2	-0.07	0.14	-0.01
Acari	0.12	**-0.55**	0.37	-0.14	-0.33	-0.01
Chalicoidea	0.17	0.3	**-0.22**	-0.11	-0.13	0.06
Hybotidae	0.03	-0.002	0.08	**-0.32**	0.28	-0.07
Aphididae	0.003	-0.11	0.1	**-0.17**	0.03	-0.1
Platygastridae	0.11	0.03	-0.1	**0.17**	-0.04	0.04
Lepidoptera	0.05	0.28	-0.15	**-0.43**	-0.07	0.1
Anthocoridae	-0.23	0.08	-0.08	-0.13	**-0.25**	-0.1
MOISTURE	**-0.86**	0.25	0.02	0.38	0.12	-0.17
EC	**-0.61**	0.15	0.59	0.29	0.24	0.34
K	-0.5	**-0.74**	-0.15	-0.41	-0.11	0.04
P	-0.43	0.35	**0.59**	-0.45	-0.23	-0.31
N	0.01	0.22	-0.55	**-0.59**	0.51	0.2
PH	0.42	0.24	-0.25	-0.07	**-0.62**	0.56

Table B-23: Principal Component loadings of reference fen and plant community

	PC1	PC2	PC3	PC4
TR2	**-1.08**	-1	0.832	-0.85
BO	**1.15**	-0.8	0.74	-0.02
TR5	1.27	**1.34**	0.626	-0.12
HT	-0.96	**1.18**	0.717	-0.95
TR1	0.73	0.09	**-1.83**	-0.9
TR3	-0.6	-0.8	**-1.03**	-0.13
TR4	0.42	-0.9	0.445	**1.25**
PF	-0.94	0.87	-0.5	**1.72**
CAREX	**-0.75**	-0.2	-0.42	0.04
EQUI	**0.96**	-0.1	-0.01	0.06
SALIX	**0.96**	-0.1	-0.01	0.06
GRASS	-0.03	**-0.9**	0.264	0.07
BETULA	-0.17	**0.94**	0.232	0.18
LARIX	0.1	**0.78**	0.415	-0.33
SCIRPUS	-0.22	0.06	**-0.93**	0.19
MOSS	-0.04	0.2	**0.882**	0.32
TYPHA	-0.36	0.08	-0.08	**-0.75**
LEDUM	-0.16	-0	-0.02	**0.92**

Table B-24: Principal component loadings of reference fens and environmental variables.

	PC1	PC2
TR3	**1.95**	-0.96
TR5	**-1.41**	-1.25
TR2	**0.64**	0.27
TR4	**-0.59**	0.12
HT	**-0.15**	0.12
TR1	-0.26	**1.92**
PF	-0.50	**-0.70**
BO	0.32	**0.47**
Moisture	-0.05	**0.97**
EC	**0.67**	-0.17
K	**0.67**	0.15
N	**0.90**	-0.32
P	**0.85**	0.03

Table B-25: Summary table of test of equality of group means from reference fen cluster group comparisons (environmental variables, plant community, and invertebrate community). Bolded terms indicate significance.

Factor	F	Sig.
EC	2.136	0.182
K	0.721	0.421
N	0.564	0.474
P	0.002	0.962
Moisture	15.497	**0.004**
GRASS	0.071	0.798
BETULA	3.036	0.125
LARIX	3.889	0.089
MOSS	2.074	0.193
LEDUM	0.025	0.879
EQUI	3.036	0.125
TYPHA	0.977	0.356
SCIRPUS	4.667	0.068
SALIX	3.036	0.125
Acari	8.898	**0.018**
Aphididae	1.678	0.231
Braconidae	5.381	**0.049**
Chalicoidea	3.669	0.092
Chironomidae	1.543	0.249
Chloropidae	16.451	**0.004**
Cicadellidae	2.344	0.164
Delphacidae	6.667	**0.033**
Dolichopodidae	14.673	**0.005**
Ephydridae	3.118	0.115
Phoridae	4.908	0.058
Sciaridae	15.652	**0.004**
Thripidae	0.944	0.360
Chrysomelidae	0.661	0.440

Table B-26: Summary table of reference fen NMDS loadings based on plant communities. Bolded terms indicate values loadings on identified axis.

	MDS1	**MDS2**
BO	**-0.67**	-0.47
HT	**1.32**	-0.37
PF	**1.13**	0.75
TR1	**-1.18**	0.49
TR4	**-0.78**	-0.59
TR2	0.06	**0.53**
TR3	-0.18	**0.98**
TR5	0.31	**-1.32**
EQUI	**-1.13**	-0.85
SALIX	**-1.13**	-0.85
GRASS	**-0.76**	0.35
BETULA	**1.79**	-0.52
MOSS	**0.45**	-0.38
LEDUM	**0.34**	0.28
CAREX	0.003	**0.12**
TYPHA	0.13	**0.56**
SCIRPUS	-0.15	**1.63**
LARIX	1.59	**-1.61**
Stress	**0.075**	

Table B-27: Summary table of reference fen NMDS loadings based on environmental variables. Bolded terms indicate values loading on identified axis.

	MDS1	MDS2
BO	**-0.16**	0.07
PF	**-0.33**	0.23
TR2	**0.15**	0.02
TR3	**0.41**	0.15
HT	0.19	**-0.22**
TR1	-0.20	**-0.32**
TR4	-0.05	**-0.11**
TR5	-0.03	**0.19**
EC	**0.30**	-0.05
K	**-0.13**	0.06
N	**0.69**	0.33
P	-0.08	**0.09**
Moisture	-0.14	**-0.43**
Stress	**0.068**	

Table B-28: Summary table of reference fen NMDS loadings based on invertebrate community. Bolded terms indicate values loading on identified axis.

	MDS1	MDS2
HT	**-0.19**	-0.03
PF	**0.34**	-0.08
TR1	**-0.09**	0.04
TR2	**-0.17**	-0.14
TR4	**-0.09**	0.02
TR5	**0.34**	0.04
BO	-0.07	**0.24**
TR3	-0.06	**-0.09**
Acari	**0.37**	-0.10
Chalicoidea	**-0.11**	-0.02
Chloropidae	**-0.27**	0.11
Sciaridae	**-0.15**	0.08
Thripidae	**-0.20**	-0.07
Chironomidae	-0.04	**-0.10**
Cicadellidae	0.03	**0.19**
Ephydridae	0.05	**-0.12**
Stress	**0.029**	

Table B-29: Summary table of reference fen and Sandhill Fen NMDS loadings based on plant communities. Bolded terms indicate value loadings on identified axis.

	MDS1	MDS2	MDS3
CAREX	**0.24**	-0.05	-0.0011
EQUI	**-0.62**	0.14	-0.011
TYPHA	**0.41**	-0.05	0.173
SALIX	**-0.62**	0.14	-0.011
MOSS	**0.28**	0.16	0.242
MEDISAT	**-1.80**	-0.12	-0.034
FRAGVES	**-1.80**	-0.12	-0.034
PICEGLA	**-1.80**	-0.12	-0.034
SONCARV	**-1.80**	-0.12	-0.034
GRASS	-0.14	**-0.49**	0.271
BETULA	0.52	**0.84**	-0.181
LARIX	0.36	**1.00**	0.315
SCIRPUS	0.32	-0.31	**-0.955**
LEDUM	0.23	0.16	**-0.389**
BO	**-0.30**	-0.05	0.227
HT	**0.62**	0.49	0.197
PF	**0.60**	0.30	-0.525
TR2	**0.41**	-0.26	0.314
TR4	**-0.30**	-0.09	0.183
SF-P	**0.41**	-0.26	0.314
SF-L	**-1.36**	-0.04	-0.014
TR3	0.36	**-0.75**	-0.275
TR5	-0.14	**0.63**	0.105
TR1	-0.31	0.02	**-0.508**

Table B-30: Summary table of reference fen and Sandhill Fen NMDS loadings based on environmental variables. Bolded terms indicate value loadings on identified axis.

	MDS1	MDS2	MDS3
EC	**0.61**	0.21	-0.28
K	**-0.11**	-0.10	-0.03
P	-0.001	**-0.06**	-0.02
Moisture	-0.32	**0.41**	0.07
N	0.43	-0.25	**0.56**
HT	**-0.30**	0.06	-0.09
TR4	**-0.16**	0.07	-0.01
SF-P	**0.39**	0.16	-0.30
SF-L	**0.44**	0.02	0.03
PF	-0.18	**-0.34**	-0.13
TR1	-0.26	**0.35**	0.09
TR5	-0.09	**-0.20**	-0.16
BO	-0.10	-0.02	**0.14**
TR2	0.05	0.09	**0.10**
TR3	0.22	-0.19	**0.32**

Table B-31: Summary table of reference fen and Sandhill Fen NMDS loadings based on invertebrate community. Bolded terms indicate value loadings on identified axis.

	MDS1	MDS2
HT	**-0.11**	-0.04
PF	**0.33**	-0.01
TR1	**-0.04**	0.01
TR2	**-0.21**	-0.10
TR4	**-0.13**	0.03
TR5	**0.31**	0.09
BO	-0.14	**0.24**
TR3	-0.08	**-0.10**
SF-P	-0.01	**0.10**
SF-L	0.08	**-0.21**
Acari	**0.32**	-0.11
Ephydridae	**-0.02**	0.02
Sciaridae	**-0.18**	0.11
Chloropidae	**-0.33**	0.14
Cicadellidae	0.03	**0.17**
Chironomidae	0.01	**-0.09**
Chalicoidea	-0.07	**-0.08**
Thripidae	-0.11	**-0.16**

Table B-32: Summary table of Distance-based redundancy analysis loadings based on environmental variables. Bray-Curtis distances used.

	CAP1	**CAP2**	**CAP3**	**CAP4**	**CAP5**
Eigenvalue	0.072	0.025	0.014	0.004	0.001
Proportion	0.32	0.11	0.06	0.02	0.01
P	**-0.64**	0.49	0.02	-0.59	-0.03
Moisture	**-0.70**	-0.38	-0.06	0.44	0.41
N	-0.31	**0.67**	0.56	-0.16	-0.35
EC	0.02	-0.50	0.12	**-0.82**	-0.27
K	-0.52	0.39	-0.23	0.40	**-0.60**
TR1	**-0.48**	-0.40	0.16	0.39	0.26
TR5	**0.61**	0.06	0.19	0.10	0.37
TR3	-0.24	**0.55**	0.52	-0.06	-0.40
BO	-0.24	0.21	**-0.32**	0.13	-0.16
PF	0.29	0.24	**-0.57**	0.10	-0.22
SF-L	0.31	-0.17	**0.43**	-0.20	-0.10
HT	0.06	-0.32	-0.04	**0.41**	-0.38
SF-P	-0.09	-0.45	-0.17	**-0.71**	-0.19
TR2	-0.29	0.30	-0.13	-0.28	**0.54**
TR4	0.07	-0.01	-0.08	0.12	**0.27**
Chloropidae	**-0.48**	0.34	-0.21	0.33	0.22
Acari	0.30	**0.35**	0.31	-0.27	0.01
Cicadellidae	-0.14	**-0.48**	-0.34	0.01	-0.06
Chalicoidea	-0.31	0.08	**0.56**	0.43	0.25
Thripidae	-0.27	0.09	**0.57**	-0.36	-0.31
Sciaridae	-0.56	0.30	0.12	**-0.59**	0.36
Chironomidae	-0.28	-0.44	0.09	-0.39	**0.55**
Ephydridae	-0.30	0.48	-0.31	0.00	**0.59**

Table B-33: Summary table of Distance-based redundancy analysis loadings based on plant community. Bray-Curtis distances used.

	CAP1	CAP2	CAP3	CAP4	CAP5	CAP6	CAP7
Eigenvalue	**0.08**	**0.04**	**0.03**	**0.01**	**0.01**	**0.001**	**0.0001**
Proportion	**0.36**	**0.19**	**0.13**	**0.06**	**0.02**	**0.004**	**0.0002**
TYPHA	**-0.57**	0.33	0.07	0.53	0.41	-0.28	-0.15
GRASS	**-0.59**	-0.01	-0.04	-0.58	-0.05	0.41	0.38
CAREX	-0.24	**-0.57**	-0.49	0.32	0.17	-0.18	-0.46
SCIRPUS	0.32	0.08	**-0.66**	0.01	-0.09	-0.63	0.20
LEDUM	0.38	-0.11	**-0.60**	0.32	-0.26	0.55	0.12
EQUI	0.12	-0.34	0.55	0.11	**-0.67**	-0.01	0.33
LARIX	0.28	-0.01	0.44	0.15	0.03	-0.06	**-0.84**
PF	**0.68**	-0.02	-0.50	0.20	0.32	0.13	0.19
TR2	**-0.40**	0.06	-0.02	0.05	0.38	0.12	0.06
SF-P	**-0.40**	0.06	-0.02	0.05	0.38	0.12	0.06
BO	-0.07	**-0.65**	0.24	-0.20	0.13	0.02	0.26
SF-L	0.23	**0.54**	0.47	-0.31	-0.16	0.17	0.43
TR3	-0.10	0.09	-0.47	**-0.69**	-0.17	-0.36	-0.19
TR4	-0.19	-0.11	-0.25	0.21	**-0.65**	0.56	-0.03
TR1	-0.11	0.05	0.01	0.51	-0.27	**-0.69**	0.28
HT	0.02	0.35	0.15	0.22	0.14	0.01	**-0.63**
TR5	0.34	-0.36	0.41	-0.03	-0.11	-0.09	**-0.43**
Sciaridae	**-0.59**	-0.24	-0.10	-0.44	0.24	-0.35	0.23
Chironomidae	-0.36	**0.63**	-0.08	0.51	0.47	0.14	-0.38
Thripidae	-0.32	**0.53**	0.26	-0.53	0.39	0.17	0.00
Ephydridae	-0.21	-0.08	**-0.76**	0.16	0.17	-0.09	-0.70
Acari	0.29	0.25	-0.24	**-0.37**	-0.09	0.27	0.19
Chalicoidea	-0.27	0.30	-0.09	-0.08	**-0.62**	-0.23	-0.41
Chloropidae	-0.41	-0.24	-0.35	-0.03	-0.38	**0.43**	-0.05
Cicadellidae	-0.24	-0.21	0.38	0.31	-0.06	**0.71**	0.33

Appendix C – Invertebrate and Plant Species Lists

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
HEXAPODA																		
	INSECTA																	
		COLEOPTERA																
			ADEPHAGA															
				Carabidae														Predator
					Bembidiini													
						Bembidion												
							quadrimaculatum		x									
							versicolor	x	x									
							transparens		x								x	
							patruele		x									
							punctatostriatum		x									
					Carabini													
						Calosoma												
							scruator		x									
						Carabus												
							vinctus	x	x									
					Cicindellini													
						Cicindela												
							repanda		x									
							duodecimguatta		x									
					Dyschiriini													
						Dyschirius			x									

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Elaphrinae												
					Elaphrus			x			x						
					Harpalini												
					Harpalus		x	x									
					Agonoleptus		x	x									
					Anisodactylus												
						interpunctatus		x									
					Amphasia		x	x									
					Licini												
					Dicaelus			x									
					Platynini												
					Platynus		x	x									
					Pterostichini												
					Poecilius												
						lucublandus		x									
					Pterostichus												
						melanius	x	x	x	x			x	x	x		
					Chlaenini												
					Chlaenius			x									
					Zabrini												
					Amara												
						latior		x									
					Nebriini												
					Nebria			x								x	
					Omophronini												
					Omophron												
						tessellatum		x									

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Other									x		x		
				Dytiscidae														Predator
					Agabinae													
						Ilybius												
							Biguttulus		x									
					Dytiscinae													
							Prodaticus								x			
				Gyrinidae														Predator
					Gyrininae													
						Gyrinus												
							minutus		x									
				Haliplidae								x				x		Predator
			HYDROPHILOIDEA															
				Hydrophilidae								x			x			Predator
				Histeridae														Predator
					Histerini													
						Hister												
							interruptus		x									
			BYRRHOIDEA															
				Heteroceridae														Predator
						Augyles			x									
				Byrrhidae				x										Herbivore
					Byrrhini													
						Byrrus		x										
			BOSTRICHOIDEA															
				Bostrichidae														Herbivore
						Stephanopachys			x									

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
			CHRYSOMELOIDEA															
				Chrysomelidae														Herbivore
					Bruchinae													
					Chrysomelini													
						Calligrapha										x		
					Alticini													
						Phyllotreta												
							striolata	x	x	x	x	x						
						Other		x	x	x	x			x				
					Galerucini													
						Erynephala				x			x					
					Luperini													
						Acalymma					x							
						Phyllobroica												
							decorata			x								
					Plateumarini													
						Plateunaris			x									
					Eumolpini													
						Brachynoea							x					
					Adoxini													
						Bromius												
							obscurus	x	x									
					Other			x	x		x		x			x		
				Cerambycidae														Herbivore
					Monochamini													
						Monochamus												
							scutellatas		x									

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Callidiini													
						Callidelium		x										
				Buprestidae														Herbivore
						Anthaxia			x									
						Other							x	x				
				Cantharidae								x						Omnivore
			COCCINELLOIDEA															
				Coccinellidae														Predator
						Anisostricta												
							strigata	x		x			x	x		x		
						Coccinella												
							monticola								x			
						Hippodamia												
							tredecimpunctata		x		x							
							americana							x				
				Latridiidae														Fungivore
						Corticaria		x	x	x		x	x	x	x			
			CUCUJOIDEA					x										
				Nitidulidae														Fungivore
				Phalacridae														Fungivore
						Phalacrus		x	x	x	x	x	x			x		
						Olibrus			x									
						Stilbus		x	x			x		x				
			CURCULIONOIDEA															
				Curculionidae														Herbivore
					Sitonini													
						Sitona												

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
							cylindricollis		x									
						Anthomini												
						Anthonomus							x				x	
						Tychiini												
						Tychius												
							griseus	x	x									
						Rhynchophorini												
						Sphenophorus			x									
						Petenomus			x									
						Ceutorhynchini												
						Glocianus		x	x			x						
						Other			x									
					Anthribidae													Detritivore
						Anthribinae												
						Trigonorhinus		x	x	x	x		x					
			ELATEROIDEA															
					Elateridae													Herbivore
						Dendrometrinae			x									
						Elaterinae												
						Ampedus												
							nigricollis		x									
						Other		x	x									
			STAPHYLINOIDEA															
					Leiodidae													Fungivore
						Agathidiini												
						Anistoma		x	x									
						Leiodini												

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
						Leiodes			x									
				Ptiliidae														Fungivore
					Ptiliini													
						Ptenidium			x									
				Silphidae				x	x				x					Detritivore
						Nicrophorus												
							defodiens		x									
							investigator		x									
							obscurus	x										
							vespilloides						x					
						Heterosilpha												
							ramosa	x	x									
				Staphylinidae														Predator
					Aleocharinae													
						Myllaena			x									
						Other			x								x	
					Oxypodini			x	x		x							
					Staphylinini													
						Philonthus			x									
						Ontholestes												
							cingulatus		x									
					Scaphisomatini													
						Sterus		x								x		
						Scaphisoma			x									
					Other			x	x	x	x							
				Derodontidae					x									Omnivore
				Meloididae														Herbivore

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Epicautini												
					Epicauta					x							
				Mordellidae													Herbivore
					Mordellistenini												
					Mordellistena			x	x	x		x					
				LARVA			x	x	x	x	x	x	x	x	x	x	
				OTHER			x	x									
		DIPTERA															
				Other			x	x		x	x	x	x	x	x		
			ACALYPTRATE														
				Agromyzidae			x	x		x	x	x			x	x	Nectarivore
				Clusiidae			x	x	x	x	x	x	x	x	x	x	Detritivore
				Canacidae													Detritivore
						Pelomylinae	x	x	x	x	x		x	x	x	x	
						Other	x	x	x	x	x	x	x	x	x	x	
				Chloropidae													Nectarivore
					Chloropinae												
					Chlorops		x	x	x	x	x	x	x	x	x	x	
					Menomyza		x		x	x	x	x	x	x		x	
					Oscillinae												
					Chaetochlorops		x		x						x		
					Other		x	x	x	x	x	x		x	x		
				Chyromyidae				x									Nectarivore
				Heleomyzidae													Fungivore
					Heleomyzinae												
					Orbellia		x										
					Other		x	x	x	x	x			x	x		

						Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
Psilidae																Nectarivore
	Psila			x	x	x		x		x						
Scatopsidae									x							Detritivore
Sepsidae									x							Detritivore
Sphaecoceridae																Detritivore
Limosininae																
	Leptocera															
		fontinalis		x	x	x	x		x							
Other				x	x			x	x		x					
Drosophilidae				x	x	x										Fungivore
Ephydridae																Omnivore
Ephydrinae																
	Scetella			x	x	x	x	x	x	x	x	x				
	Ephydra			x	x	x	x							x		
Hydrellinae																
		Hydrellia		x	x	x		x	x		x					
		Notiphila		x	x	x	x	x	x	x	x	x	x	x	x	
Gymnomyzinae																
		Ochthera		x												
Chamaemyiidae																Herbivore
	Pseudodinia													x		
Lauxaniidae								x	x				x			
Dryomyzidae																Herbivore
	Drymoza															
		anilis		x	x	x	x	x					x	x		
	Other			x	x							x	x	x	x	
Sciomyzidae																Nectarivore

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
						Sepedon		x		x	x							
						Tetanocera		x			x	x				x		
						Other		x	x		x		x		x	x		
				Tanypezidae														Unknown
						Tanypeza		x			x							
						Other					x	x						
				Tephritidae														Herbivore
						Neotephritis		x		x	x				x	x		
						Camipiglossa									x			
				Ulidiidae														Herbivore
						Chaetopsis		x	x	x	x			x		x		
			ASCHIZA															
				Syrphidae														Nectarivore
					Bacchini													
						Platycherus							x					
						Bacca				x		x				x		
						Pyrophaena		x				x						
					Syrphini													
						Sphaerophoria			x				x					
						Didea										x		
					Eristalini													
						Helophilus			x							x		
						Other		x	x	x			x				x	
				Pipunculidae														Herbivore
					Pipunculinae													
						Eudorylas		x							x			
					Other				x			x			x			

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
				Lonchopteridae			x	x	x	x	x	x	x			x	Nectarivore
				Phoridae													Omnivore
						Chaetopleurophora	x	x	x	x	x	x	x	x	x	x	
						Conicera	x	x					x		x		
						Other	x	x			x	x	x	x		x	
				Platypezidae			x	x		x	x		x	x	x		Fungivore
			CALYPTRATE														
				Anthomyidae			x	x	x	x	x			x	x	x	Nectarivore
				Fannidae													Detritivore
						Fannia		x									
				Muscidae													Detritivore
					Azeliini												
						Hydrotaea		x	x		x				x		
					Muscini												
						Musca	x	x									
						Eudasyphora		x			x						
					Other		x	x	x	x	x	x	x	x	x	x	
				Scathophagidae													Herbivore
					Delininae		x	x	x	x		x	x	x	x	x	
					Scathophaginae												
								Scathphaga			x						
								Cordilura			x						
				Calliphoridae													Detritivore
					Calliphorinae												
						Calliphora											
								vicina		x							
						Lucilia				x							

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Other			x									
				Sarcophagidae				x						x	x		Nectarivore
				Tachinidae													Nectarivore
					Exoristinae					x	x					x	
					Other		x	x	x	x	x		x	x	x	x	
			NEMATOCERA														
				Ptychopteridae			x										Non-Feeding
				Tipulidae			x	x	x	x	x		x	x		x	Nectarivore
				Trichoceridae			x	x									Non-Feeding
				Cecidiomyiidae			x	x	x	x	x	x		x	x	x	Nectarivore
				Sciaridae													Fungivore
					Bradysia		x	x			x		x		x		
					Epidapus		x	x		x	x	x	x	x	x		
					Other		x	x	x	x	x	x	x	x	x	x	
				Cathyloscelidae						x		x			x	x	Fungivore
				Biblionidae				x									Herbivore
				Mycetophilidae			x	x	x	x	x	x	x	x	x		Fungivore
				Chironomidae			x	x	x	x	x	x	x	x	x	x	Non-Feeding
				Culicidae													Parasite
					Aedes									x			
					Other		x	x		x							
				Ceratopogonidae			x	x	x		x	x	x	x	x	x	Parasite
				Dixidae				x							x		Non-Feeding
				Simuliidae						x		x	x	x	x		Parasite
				Psychodidae													Fungivore

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
			ORTHORRHAPHA														
				Asilidae				x						x			Predator
				Dolichopodidae													Omnivore
					Dolichopodinae												
						Dolichopus		x	x	x	x	x	x		x	x	x	
						Tachytrechus		x	x	x						x		
					Other			x	x	x	x	x		x	x	x		
				Hybotidae													Predator
					Hybotinae													
						Hybos		x										
					Tachydromiinae													
						Crossopalpus		x	x	x	x				x	x		
					Other			x	x			x		x	x	x		
				Empididae													Predator
					Empidinae													
						Rhamphomyia				x				x				
				LARVA				x	x	x	x	x	x		x		x	
				OTHER							x		x		x	x		
			HEMIPTERA														
				Aphid				x	x	x	x	x	x	x	x	x		Herbivore
							Juv.	x	x				x					
							Adult	x	x	x	x	x	x	x	x	x		
			PSYLLOIDEA														
				Psyllidae				x	x			x	x		x	x		Herbivore
				Liviidae														Herbivore
						Livia		x			x							
				Calophyidae														Herbivore

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
						Calophya						x						
			CERCOPOIDEA															
				Cercopidae														Herbivore
						Aphrophora		x	x	x	x	x	x					
						Lepyronia		x			x							
						Juv.		x		x	x		x			x		
			CICADOIDEA															
				Cicadellidae														Herbivore
					Megophthalminae			x	x	x	x		x	x	x	x		
						Agallia		x								x		
					Deltocephalinae			x	x	x	x	x	x		x		x	
					Cicadellini			x	x	x	x	x	x	x	x	x	x	
						Draeculacephala												
							inscripta	x	x	x	x		x	x	x	x	x	
						Helochara		x		x		x		x				
					Juv.			x	x	x	x	x	x	x	x	x	x	
				Membracidae														Herbivore
					Centrotinae													
							Gargara	x										
			FULGOROIDEA															
				Delphacidae				x	x	x	x	x	x	x	x	x	x	Herbivore
					Delphacinae													
						Delphacodes		x	x	x	x	x	x	x	x	x	x	
						Javesella		x	x			x			x	x	x	
						Juvenile		x	x	x	x		x		x	x	x	
				Cixiidae														Herbivore
					Cixiini													

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
							Cixius								x			
			CIMICOMORPHA															
				Miridae														Omnivore
					Mirinae													
						Prepops							x					
						Phytocoris		x		x								
					Deraeocorinae			x		x	x							
						Eurychilopterella				x								
					Other			x				x				x		
				Reduviidae				x										Predator
				Nabidae				x										Predator
				Tingidae				x	x				x					Herbivore
					Tingini													
						Corythucha		x	x				x					
				Anthocoridae				x	x			x						Predator
			NEPOIDEA															
				Belostomatidae														Predator
						Belastoma		x	x									
			LEPTOMOMORPHA															
				Saldidae														Predator
					Saldinae													
						Saluda		x	x	x		x			x			
						Salda		x			x							
			COREOIDEA															
				Alydidae														Predator
				Coreidae				x										Predator
			LYGAEOIDEA															

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
				Blissidae			x										Herbivore
				Lygaeidae													Herbivore
					Other		x			x		x					
					Ischnorhynchinae												
						Kleidocerys	x		x	x	x			x	x		
					Orsillinae												
						Nysius	x				x	x					
				Rhyparochromidae													Herbivore
						Sphragisticus	x		x	x					x		
						Other		x						x			
				Geocoridae													Predator
								x	x	x	x						
			PYRRHOCOROIDEA														
				Largidae			x			x							Herbivore
			PENTATOMOIDEA														
				Acanthosomatidae													Herbivore
						Juvenile	x			x				x			
				Scutelleridae													Herbivore
						Eurygaster	x		x				x				
						Juvenile	x		x	x	x	x		x			
			GERROMORPHA														
				Mesoveliidae													Predator
						Mesovelia		x									
			GERROIDEA														
				Gerridae													Predator
						Gerris		x			x				x		
					Juvenile		x	x	x	x	x	x	x	x	x	x	

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Other		x	x				x					
		HYMENOPTERA															
			APOIDEA														
				Andrenidae				x									Nectarivore
					Andrena			x									
				Apidae			x	x					x				Nectarivore
					Apinae												
					Bombus		x	x									
					Apis								x				
				Crabronidae			x	x	x								Nectarivore
					Trypoxylini												
					Trypoxylon		x		x								
					Crabronini												
					Ectemnius			x									
					Other		x										
				Colletidae			x	x									Nectarivore
						Colletini		x									
						Unknown	x										
				Halicitdae				x	x						x		Nectarivore
					Halictini												
					Sphaecodes				x								
					Halictus			x							x		
					Augochlorini												
					Augochlorella			x									
					Rophitinae												
					Dufourea			x							x		
				Megachilidae													Nectarivore

								Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
						Megachile		x	x									
				Spechidae					x		x		x				x	Nectarivore
					Ammophilinae													
						Ammophila			x									
					Sphecinae													
						Palmodes			x									
					Other				x		x		x				x	
			CHRYSIDOIDEA															
				Bethylidae							x	x		x				Parasite
				Chrysididae														Nectarivore
						Omalus		x	x									
						Other		x	x	x	x	x	x			x		
				Dryinidae				x	x						x	x		Predator
			FORMICOIDEA															
				Formicidae														Omnivore
							Myrmicinae		x									
							Formicinae	x	x	x	x	x	x	x			x	
			POMPILOIDEA															
				Pompilidae														Predator
					Pompilini													
						Evagetes			x									
						Arachnospila			x									
			VESPOIDEA															
				Vespidae														Nectarivore
						Other		x										
						Vespula												
							alascensis										x	

					Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
			CERAPHRONOIDEA												
			Ceraphronidae												Parasite
			Ceraphron		x	x	x	x	x	x	x		x		
			CHALCIDOIDEA												
			Encrytidae		x	x	x	x	x	x	x			x	Parasite
			Chalicidae		x	x	x	x	x	x	x		x		Parasite
			General		x	x	x	x	x	x	x	x	x	x	Parasite
			Diapridae		x	x	x	x	x		x			x	Parasite
			Eupelmidae			x				x			x		Parasite
			Eulophidae		x		x	x	x	x	x		x		Parasite
			Eurytomidae		x					x			x	x	Parasite
			Mymaridae		x	x	x	x	x	x	x	x	x	x	Parasite
			Pteromalidae		x	x	x	x	x	x	x	x	x	x	Parasite
			Perilampidae				x	x		x			x		Parasite
			CYNIPOIDEA												
			Cynipidae		x			x		x	x		x		Parasite
			ICHNEUMONOIDEA												
			Braconidae		x	x	x	x	x	x	x	x	x	x	Parasite
			Opiinae												
			Utetes		x	x	x	x	x	x	x	x			
			Orginlinae												
			Orgilus		x		x	x	x					x	
			Exothecinae			x		x					x	x	
			Alysiinae												
			Chorebus		x			x	x	x		x	x		
			Other		x	x	x	x	x	x	x	x	x	x	
			Ichneumonidae												Parasite

							Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
					Campopleginae												
					Casinaria		x	x				x			x		
					Other		x	x	x	x	x	x	x	x	x	x	
			PLATYGASTROIDEA														
				Platygastridae			x	x	x	x	x	x	x		x	x	Parasite
					Platygastrinae												
						Platygaster	x	x	x	x	x	x			x	x	
					Telenominae												
						Telenomus		x			x				x		
					Teleasinae												
						Trimorus	x	x		x		x			x	x	
					Scelioninae		x	x		x							
					Other		x	x		x	x	x	x		x	x	
			PROCTORUPOIDEA														
				Proctorupidae			x	x	x	x	x	x	x	x	x	x	Parasite
			SYMPHYTA														
				Tenthredinindae				x			x						Herbivore
			OTHER				x	x		x				x	x		
			LARVA						x		x		x				
		ORTHOPTERA															
				Acrididae													Herbivore
					Oedipodinae		x	x	x			x					
					Acrininae		x	x		x							
		TRICHOPTERA															
				Phyganeidae				x						x			Nectarivore
				Limnephilidae			x	x	x				x				Nectarivore
				Pupa			x										

				Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
PSOCOPTERA														
Psocidae				x	x	x	x		x	x	x			Detritivore
LEPIDOPTERA														
Gelechinidae				x	x	x	x	x	x	x	x	x		Nectarivore
Larvae				x	x	x	x		x	x		x	x	
Pupa											x			
ODONATA														
ANISOPTERA														
Libellulidae				x	x									Predator
ZYGOPTERA														
Coenagrionidae				x		x	x				x			Predator
Other														
Nehalemia				x		x	x				x			
EPHEMEROPTERA														
Siphlonuridae														Non-Feeding
Siphlonurus						x								
Larva					x				x					
NEUROPTERA														
Larva				x	x		x							
Hemerobiidae					x							x	x	Predator
Chrysopidae				x										Predator
THYSANOPTERA														
Thripidae				x	x	x	x	x	x	x	x	x	x	Herbivore
SIPHONAPTERA														
Pulicidae									x					Parasite
COLLEMBOLA														
Entomobryomorpha				x	x	x	x	x	x	x	x		x	Fungivore

	Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
Symphypleona	x	x	x	x	x		x		x		Fungivore
CHELICERATA											
ARACHNIDA											
ACARI											
Other	x	x	x	x	x	x	x	x	x	x	Parasite
Mesostigmata		x		x	x	x	x				Parasite
Orbatida											Parasite
Ceratozetodea	x	x	x	x	x	x	x	x		x	
Prostigmata	x	x	x		x	x			x	x	Parasite
Ixodidae				x			x				Parasite
ARANEAE											
Agelenidae	x	x					x				Predator
Araneidae	x	x	x	x	x		x		x	x	Predator
Gnaphosidae	x	x	x	x	x	x	x	x	x		Predator
Juvenile	x	x	x	x	x	x	x	x			Predator
Linyphiidae	x	x	x	x		x	x	x	x		Predator
Lycosidae	x	x	x	x	x	x		x		x	Predator
Other	x	x	x	x				x			Predator
Oxyopidae	x	x									Predator
Salticidae	x	x			x	x		x			Predator
Tetragnathidae	x		x	x			x	x		x	Predator
Thomisidae	x			x		x	x	x	x		Predator
OPILIONES											
Phalangidae	x	x									Omnivore
MYRIAPODA											
CHILOPODA											
Lithobiomorpha	x	x									Predator

		Sandhill	Island	TR1	TR2	TR3	TR4	TR5	HT	BO	PF	Functional Group
CRUSTACEA												
OSTRACODA		x										
BRANCHIOPODA												
Cladocera			x									Herbivore
GASTROPODA		x		x	x	x			x			
OLIGOCHAETA			x			x	x					Detritivore
NEMATODA		x		x	x							Parasite

Plant Species List 2014-2015

Name	Code	Common Names	SF-P	SF-L	TR1	TR2	TR3	TR4	TR5	BO	HT	PF
Carex	CAREX	Sedges	X		X	X	X	X	X		X	X
Typha latifolia	TYPHLAT	Cattail	X		X	X					X	
Sonchus arvensis	SONCARV	Sow thistle		X								
Medicago sativa	MEDISAT	Alfalfa		X								
Fragaria vesca	FRAGVES	Wild Strawberry		X								
Rubus idaeus	RUBUIDA	Wild Raspberry		X								
Moss	MOSS	Moss	X			X		X	X	X	X	X
Melilotus officinalis	MELIOFF	Yellow Sweet Clover		X								
Melilotus albus	MELIALB	White Sweet Clover		X								
Hordium jubatum	HORDJUB	Foxtail Barley		X								
Astragalus cicer	CICEMIL	Cicer Milkvetch		X								
Picea glauca	PICEGLA	White Spruce		X								
Lotus cornicularis	LOTUCOR	Bird's-Foot Trefoil		X								
Populus tremuloides	POPUTRE	Trembling Aspen		X								
Taraxacum offiniale	TARAOFF	Dandilion	X	X								
Epilobium angustifolium	EPILANG	Fireweed		X								
Equisetum arvense	EQUIARV	Common Horsetail	X	X	X			X	X	X		
Salix	SALIX	Willow	X		X				X	X		
Scirpus	SCIRPUS	Bulrush	X		X		X					X
Lathyrus ochroleucus	LATHOCH	Cream pea plant		X								
Prunus pensylvanica	PRUNPEN	Pin Cherry		X								
Cornus sericea	CORNSER	Red Osier Dogwood		X								
Rosa acicularis	ROSAACI	Wild Rose		X								

Name	Code	Common Names	SF-P	SF-L	TR1	TR2	TR3	TR4	TR5	BO	HT	PF
Hieracium umbellutam	HIERUMB	Narrowleaf Hawkweed		X								
Betula glandulosa	BETULA	American Dwarf Birch							X		X	X
Larix larIcina	LARIX	Tamarack							X		X	
Rhododendron groenlandicum	LEDUM	Labrador Tea						X				X

Measure of Invertebrate Presence in Each Trap Type in Sandhill Fen Watershed

	Pitfall Trap	Vacuum Soil	Sticky Trap	Sweep Net	Vacuum - Veg
Acari	102	117	56	7	202
Aranea	56	33	9	26	121
Phalangidae	15	1	2		
Anthribidae		4			
Byrrhidae	1				
Carabidae	30	4			9
Cerambycidae				1	
Chrysomelidae			10	25	
Coccinellidae		1	3	10	9
Curculionidae				1	
Elateridae			13		
Latriidae	6	3	11		
Meloidae	3	1			
Mycetophagidae			2		
Phalacridae		1			
Silphidae	12				
Staphylinidae	4	7	2	1	10
Agromyzidae			4	1	
Anthomyidae	3		1	1	
Canacidae			14	5	
Cecidiomyidae	4	3	150		13
Ceratopogonidae			28		
Chironomidae		1	821	148	65
Chloropidae	2		25	12	15
Chyromyidae			2		
Clusiidae			16		
Culicidae				1	
Dixidae			2		
Dolichopodidae		2	17	4	
Drosophilidae			11		
Dryomyzidae		1	11	6	
Empididae		1	11		
Ephydridae	1	3	44	14	23
Fannidae	3				
Heleomyzidae			10	13	
Hybotidae			72	1	
Lauxanidae			2		

	Pitfall Trap	Vacuum – Soil	Sticky Trap	Sweep Net	Vacuum - Veg
Lonchopoidae			2		
Muscidae	15		15	6	4
Mycetophilidae		1	89		
Phoridae	5	3	89	2	4
Pipunculidae			1		
Platypezidae			2	1	
Psilidae			5	1	
Psyllidae			1		
Scathophagidae			3		
Scatopsidae	1		5		
Sciaridae	1	1	360	3	5
Sciomyzidae			6	1	
Sphaecoceridae	1	3	7		
Syrphidae			1	1	
Tachnidae	1		1		
Tanyderidae			1		
Tanypezidae				6	
Tephritidae		1	1		
Tipulidae			1	2	
Ulidiidae			9	1	
Gastropoda	4	4			
Anthocoridae			56		
Aphididae	12	25	30	23	51
Cercopidae		4	4	3	17
Cicadellidae	13	44	261	85	265
Delphacidae		4	35	7	22
Liviidae	1				
Lygaeidae			1	20	15
Membracidae			4	8	
Miridae		2	4	2	13
Nabidae		1		3	
Reduviidae	1	3		3	
Rhyparochromidae				2	
Saldidae	6	9	6		
Scutelleridae				3	
Thripidae	10	19	383	96	50
Tingidae			2	1	
Apidae	2				
Bethylidae			1		
Braconidae	1	2	55	0	20

	Pitfall Trap	Vacuum – Soil	Sticky Trap	Sweep Net	Vacuum - Veg
Ceraphronidae			1	2	
Chalicoidea		2	246	6	16
Chrysididae			10	1	
Colletidae				1	
Crabronidae	1		3		
Cynipoidea			2		
Dryinidae			1	1	
Encrytidae				4	
Formicidae	84	3	7	16	13
Ichneumonidae			22	5	17
Megachilidae				1	
Platygastridae	23	3	41	7	6
Proctorupidae			32		5
Scelionidae				2	
Vespidae				1	
Lepidoptera	1	1	62	3	11
Centipede	2				
Neuroptera	2			1	
Odonata			1	1	
Acrididae	3	1	1	3	0
Pscoptera	2		3	1	
Trichoptera		1	3		
Oligochaeta		1			

Vita Auctoris

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