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Arthropod Diversity in Contrasting Ontario Peatlands

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Abstract

Peatlands are important wetland systems, but dominant macroarthropod groups endemic to peatlands and the environmental factors that affect them are poorly represented in the literature. I examined the richness, abundance, and community composition of soil and surface dwelling macroarthropods using emergence traps, peat sorting, and pitfall traps in two Ontario fens differing in water table, nutrient level, and vegetation. I found 218 arthropod morphospecies, with each site having a similar richness of emergent arthropods, but patterns of community composition differed between the two sites. The *Carex* (sedge) dominated site had twice as many emergent individuals, and total abundances declined dramatically over the growing season, whereas the *Sphagnum* (moss) dominated site had consistent arthropod abundances. Seasonal change in soil moisture was a significant correlate of arthropod abundance. Since Canadian peatlands face increasing climate warming, this study provides baseline information on the resident macroarthropod communities in different peatland types.

Keywords

Peatlands, Diptera, Araneae, biodiversity, macroarthropods, pitfall trapping, emergence traps, Chironomidae, Lycosidae, community composition.

Summary for Lay Audience

Soil organisms are hyperdiverse, have high biomass, and play important roles in both below-ground and above-ground food webs as both predators and as food source for other organisms. Yet despite soil arthropods having important ecological roles, they are not well understood because they are difficult to directly observe. Many soil-dwelling species only live in soil for part of their life cycle, emerging when they reach maturity. Along with predatory macroarthropods (mostly spiders) on the soil surface, these emergent macroarthropods (mainly the Nematocera or lower flies) connect the below-ground system to the above-ground food web. Peatlands are important wetland systems, but dominant macroarthropod groups endemic to peatlands lack records in the literature. I examined the diversity of soil and soil-surface dwelling macroarthropods in two adjacent peatlands that differ in water table, nutrient level, and vegetation. I collected these macroarthropods using insect emergence traps, peat sorting, and pitfall traps. Altogether I found 218 morphospecies (groups differentiated based on morphological traits), with each site having the same richness, but twice as many emergent individuals in the *Carex* (sedge) dominated site compared to a *Sphagnum* (moss) dominated site. At the *Carex* site, emergent arthropod abundances declined dramatically over the season, while the *Sphagnum* site had a much more stable emergent community, with no significant changes in abundance. The abundances of the surface ground-dwelling community were very similar between the two fens, but there was little overlap in the species present at each site. Seasonal changes in soil moisture were an important correlate for the overall abundance of emergent insects collected. Northern peatland ecosystems are expected to undergo significant changes in vegetation and soil moisture under ongoing climate warming with unknown consequences for peatland biodiversity. This study provides baseline information for the emergent insects and their ground-dwelling predators that are important components of peatland biodiversity.

Co-Authorship Statement

This manuscript was envisioned by Dr. Zoë Lindo and Grace Carscallen, Carscallen collected and analyzed the data; a subset of this data will be submitted for publication to a scientific journal in the future by Carscallen and Lindo.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1 Introduction

1.1 Arthropods of Boreal Peatlands

Peatlands are wetlands that contain a minimum 40 cm of partially decomposed organic matter (peat) (National Wetlands Working Group 1997) and are important ecosystems for global carbon storage (Gorham 1991; Frolking and Roulet 2007). In Canada, peatlands cover 13% of the land area and most peatlands occur in the Boreal zone (Tarnocai *et al.* 2011). Within the Boreal zone, peatlands form a gradient of habitat types from low-nutrient, ombrotrophic bogs that are dominated by *Sphagnum* spp. mosses to minerotrophic fens that range in nutrient status (low, intermediate, and high nutrient) and can be dominated by *Sphagnum* spp. mosses, or *Carex* spp. sedges and other vascular plants (Rydin and Jeglum 2013). Bogs are generally lower in pH and nutrient levels, and are hydrologically supplied by precipitation, while fens are higher in pH and nutrients and are hydrologically supplied by groundwater (Rydin and Jeglum 2013). Because peatlands are unique in their vegetation, hydrology and soil chemical properties, peatlands have unique arthropod communities (Spitzer and Danks 2006), yet are relatively understudied ecosystems in Canada (Spitzer and Danks 2006; but see Finnamore and Marshall 1994; Grégoire Taillefer and Wheeler, 2012, 2018) compared to other systems such as forests, grasslands, and other wetland types. That said, some previous studies indicate that >2000 arthropod species may inhabit or use peatlands as habitat (Finnamore 1994). These peatland arthropods can have many ecological roles, particularly macroarthropods, such as providing important food resources for higher trophic level organisms (Cristol *et al.* 2008), stabilizing predators (Paetzold and Tockner 2005), and as pollinators (Savage *et al.* 2019).

The majority of broad-scale peatland arthropod studies are of arthropod diversity assessed using non-target trapping and sampling methods such as aerial malaise traps (Finnamore 1994; Deans 2005; Grégoire Taillefer and Wheeler 2012), pan traps (Blades and Marshall 1994; Finnamore 1994; Grégoire Taillefer and Wheeler 2012, 2018) and/or sweep netting (Grégoire Taillefer and Wheeler 2012, 2018, 2019). However, these trapping methods can over-estimate arthropod diversity in peatlands by trapping members of the aerial community which complete most of their development in surrounding habitats, or even attract arthropods from adjacent habitats. In this context, larvae are much less mobile than adults, and therefore newly emerged adults may be more informative for peatland studies because they can be directly associated with the habitat in which they are found using emergence traps (Rosenberg *et al.* 1988). Similarly, pitfall traps that collect surface-dwelling (i.e., often non-flying) invertebrates would also represent resident peatland invertebrates as the presumed catchment area of collection is typically on the scale of meters (1-20 meters) (Zhao *et al.* 2013).

While several key studies of peatland arthropod diversity have been performed in Canada that compare the fauna of multiple peatland sites (see Blades and Marshall 1994; Aitchison-Benell 1994; Dondale and Redner 1994), studies where vegetation cover and soil moisture are quantified and analyzed alongside arthropod sampling are still lacking (but see Grégoire Taillefer and Wheeler 2012; 2018). The nature of peatlands with varied microtopography (a type of habitat heterogeneity) allows them to provide specific resources for the arthropods that live there. Hummocks (raised areas) can provide warm and dry habitats for overwintering arthropods (Främbs 1994), while within the moss layer moisture can remain constant and temperatures may fluctuate by only 5°C, creating a consistent refuge from other, more severe, environmental fluctuations (Gerson 1969). Moist hollows (low-lying depressions) provide food resources of abundant smaller arthropods in summer (Främbs 1994). Plants often structure arthropod habitats, and the plant community can impact arthropod communities. For instance, the spider community under the bark in the Boreal forest in Alberta differed between deciduous and coniferous trees (Pinzón and Spence 2010), while the surface-dwelling spider communities in German forests varied by dominant tree species (Ziesche and Roth 2008). Similarly, the abundance of emergent flies decreased over the course of plant succession of fallow farmlands, likely due to more dense and dry plant litter from a dominant grass species in later successional stages (Frouz 1999). So, excluding more specialized relationships, such as those between host plants and plant parasites, peatland plant communities likely influence peatland arthropods through overall habitat structure. Evidence for this is limited, yet Wrubleski (1987) found that the highest abundances of macroarthropods in both bogs and marshes were associated with areas of greater submerged vegetation (likely providing habitat for larvae), but at the same time, shade can also alter the emergence of some arthropods (Lammers 1977), such as that cast by vascular plants. Therefore, water table, alongside plant density and community composition are thought to be important factors affecting arthropod diversity and abundance in peatlands.

1.2 Ecology of Peatland Arthropods

Among the macroarthropods (i.e., insects and spiders), community composition within terrestrial habitats, including peatlands, is linked to food availability, temperature (Robinson *et al.* 2018), soil moisture (Ziesche and Roth 2008), and plant community composition, often with arthropod species composition related to specific vegetation types (Blades and Marshall 1994; Spitzer and Danks 2006; Glime 2017). For instance, in a study of peatlands in Belarus, Sushko (2017) found that insect species diversity increased with increasing cover of dwarf shrubs and decreasing cover of herbs. Previous studies in Canadian (Alberta) peatlands also suggest that peatlands with a higher variation in plant architecture have greater insect species richness (Finnamore 1994). So, while many peatlands are observed to have high local arthropod (alpha) diversity (Finnamore 1994), they also show high compositional variability among different peatland types (beta diversity) (Blades and Marshall 1994), and therefore are posited to contribute to high regional (gamma) diversity.

The larvae of many holometabolous insect groups (i.e., that undergo complete metamorphosis) are found within soils. For instance, Behan-Pelletier and Bissett (1992) report that larvae of Diptera (flies) may constitute up to 33% of all arthropod species found in soil. Several orders of holometabolous insects are abundant and diverse in Boreal peatlands, including Hymenoptera (ants, wasps, bees) (Finnamore 1994), Coleoptera (beetles) (Runtz and Peck 1994) and Diptera (Blades and Marshall 1994;

Grégoire Taillefer and Wheeler 2012); the nematocerous flies (which include mosquitos and black flies) are often the most abundant peatland macroarthropods (Wrubleski 1987). At the soil surface, spiders (Order Araneae) are some of the most prevalent peatland arthropod predators (Dondale and Redner 1994; Finnamore 1994). Araneae and Diptera are shown to have matching seasonal trends in abundance (Hodkinson *et al.* 2001) and form a large portion of the animal biomass in peatlands as well as many other terrestrial ecosystems (Hölldobler and Wilson 1990; Bar-On *et al.* 2018). Both Araneae and Diptera are extremely important food sources for birds (Hussell 1972; Cristol *et al.* 2008) and because of this ubiquity and high abundance, Diptera and Araneae play a vital role in food webs (Wiggins *et al.* 1991), and this suggests that peatland arthropods in general play an important role in terrestrial food webs.

1.2.1 Diptera Taxonomy, Life History, and Ecology

The Diptera are an order of holometabolous insects, and therefore undergo a life cycle which includes an egg, larval, pupal, and adult stage, and are more evolutionarily derived relative to the non-holometabolous insects (Grimaldi and Engel 2005). The Diptera are divided into two groups, the monophyletic (i.e., including all descendants of a common ancestor) and more derived Suborder Brachycera, and the less derived nematocerous flies. The nematocerous flies that include the most basal Diptera taxa are often functionally grouped together, but are not considered a true suborder because they are not monophyletic (Grimaldi and Engel 2005). The Suborder Brachycera represents ~120 families in the literature, and is a very large and diverse group with respect to morphology and life history (Yeates 2002). While specific brachyceran taxa are often less abundant in biodiversity studies (Ryan and Hilchie 1981), their taxonomy is better understood than that of the nematocerous flies (Grimaldi and Engel 2005).

Adult Diptera are mostly non-feeding or are fluid feeders (i.e., needing to dissolve solid food with saliva before they can consume it) (Grimaldi and Engel 2005; Marshall 2012). Besides plant community impacting litter decomposition (Palozzi and Lindo 2017) thus influencing the food resources for detritivorous or root-feeding Dipteran larvae

(McAlpine *et al.* 1981), some flies are nectar feeders as adults and influenced by herb diversity, likely related to floral food resources (Scherber *et al.* 2014). Due at least in part to their holometabolous lifestyle and their varied diets, Grimaldi and Engel (2005) call the Diptera 'the most ecologically diverse insect group'. This applies spatially as well, as they are present in many 'harsh' habitats globally including both the Arctic (Danks and Oliver 1972) and the Antarctic (Allegrucci *et al.* 2006). Different substrates (litter, rocks, or submerged riparian vegetation) have been shown to influence Diptera community composition in Brazil (Figueiró *et al.* 2012), with large latitudinal effects (likely due to temperature) (Patitucci *et al.* 2011), as well as soil moisture (De Bruyn *et al.* 2001).

In Canadian peatlands, vegetation also has been shown to influence Diptera community composition (Grégoire Taillefer and Wheeler 2012). The *Sphagnum* mosses present in peatlands modify their environments extensively by releasing acidic compounds (National Wetlands Working Group 1997), potentially limiting which organisms can survive there (Glime 2017), and yet many Diptera species are found in peat (Ryan and Hilchie 1981) and peatlands (Blades and Marshall 1994) composed of *Sphagnum* mosses. In relation to these wetland habitats, many Diptera species also maintain the ancestral characteristic of a simple larval form which is adapted to aquatic habitats (Chapman *et al.* 2006; Marshall 2012), and often respire through their cuticle (Int Panis *et al.* 1995; Urbanek *et al.* 2011). Some are capable of surviving in even ephemerally moist environments because they can enter desiccation-resistant diapause in response to drying (Danks 1971). Diptera adults are fast flyers, capable of taking advantage of otherwise ephemeral food and habitat resources for their offspring, further allowing them to live otherwise difficult to exploit resources such as fresh dung (Parker 1970). At the ecoregion scale peatland Diptera communities also appear to be structured by highly stochastic processes such as dispersal (Grégoire Taillefer and Wheeler 2019).

1.2.2 Araneae Taxonomy, Life History, and Ecology

The Order Araneae (i.e., the spiders) undergo a life cycle that includes multiple developmental stages within three phases: egg, juvenile spiderlings (including subadults that are morphologically similar to adults but without functional genitalia), and adults (Ubick *et al.* 2017). Worldwide, spider species richness includes over 45,000 described species in 114 families, according to the World Spider Catalog (2015). In Canada, it is estimated that there are around 1500 species in 45 families (Bennett *et al.* 2019), although new Canadian species are still being added with broader spider taxonomy based on morphology being supported and supplemented by recent developments in DNA work (Bennett *et al.* 2019). Compared to dipteran diversity, spider diversity in Canada is quite well known (Coddington and Levi 1991), making them a reliable taxon for biodiversity studies.

Spiders are effective predators in many habitats, and nearly all spiders are opportunistic and solitary predators, found in all terrestrial ecosystems except the Antarctic (Ubick *et al.* 2017). Many spiders are ground-dwelling and have been shown to impact the abundances of their prey, such as of emergent aquatic insects around riparian areas (Paetzold and Tockner 2005). Spiders are prevalent in forests and their biodiversity has been well studied (Pinzón and Spence 2008, 2010; Ziesche and Roth 2008) where community composition is shown to be habitat specific (Bergeron *et al.* 2013). Peatland spider communities are also known to be different from forest communities (Rėlys and Dapkus 2000), although the factors that affect peatland spider communities are less well known than for forest communities. In forest systems, plant species richness is positively correlated with spider species richness (Buddle *et al.* 2000), and spider communities are more varied when conditions favour higher variability of microhabitats, such as after fire (Buddle *et al.* 2000). As well, having varied local habitats can allow for habitat segregation such that spider species with similar hunting methods may coexist by occupying different niches (Greenstone 1980) thereby increasing spider species richness.

Because peatlands often occur in isolated patches (Tarnocai *et al.* 2011), this may inhibit dispersal of spider groups that are less mobile between peatlands. At the same time, peatlands can be ‘island-like’ refuges for the specific species that occupy them (Poulin *et al.* 2004). Some spiders, such as *Pirata piraticus* are sensitive to low humidity and rely on a moist humid habitat (Maelfait *et al.* 1995) such as that which is found in peatlands, and peatlands with high water tables can even be habitat to spiders that hunt on the surface of open water such as *Dolomedes* sp. (Dondale and Redner 1994), this is however not common among spiders in general. In more open habitats, the highly mobile hunting spiders (including wolf spiders, Family Lycosidae) are abundant (Coyle 1981), which may also facilitate lycosid dispersal into peatlands (Glime and Lissner 2017). Indeed, wolf spiders are present in all Canadian ecoregions (Bennett *et al.* 2019) and are often a dominant spider group in peatlands (Dondale and Redner 1994; Koponen 1994). Other life history factors may contribute to this such as the maternal care lycosid females provide by carrying their juveniles on their backs, enabling this otherwise vulnerable stage better survival under wetter environments (as postulated by Platen 2003), whereas other groups of spiders may be more vulnerable to the frequent flooding events that occur in some peatlands (Glime and Lissner 2017). Despite the challenges associated with living in peatlands, there also can be benefits for peatland spider communities, such as during the winter when spiders can remain mobile despite freezing temperatures by living within the moss layer (Maelfait *et al.* 1995). Because of their high specificity to these habitats, spiders can be used as indicators for peatland sites (Scott *et al.* 2006).

1.3 Objectives

Many Canadian peatland arthropod studies are now more than twenty years old (but see the work of Grégoire Taillefer and Wheeler 2012; 2013; 2018; 2019; Deans *et al.* 2005; Hammond *et al.* 2018b), and of these recent studies, only the work of Deans *et al.* (2005) and Grégoire Taillefer and Wheeler (2013) provide abundance data for the nematocerous flies (Order Diptera); a dominant taxonomic group. The Boreal zone (forest and peatlands) is predicted to undergo substantial climate warming (IPCC 2013). Therefore, regarding Boreal peatland-endemic arthropods (such as surface-dwelling spiders and emergent flies), it is critical to update the scientific records on their biodiversity and seasonal changes in their abundances, and the overall goal of my thesis is to serve as an important baseline metric for future monitoring efforts.

Here I characterize the diversity of the peat-dwelling (mostly larvae), emergent (mostly Diptera), and surface-dwelling (mostly Araneae) arthropods at two Boreal peatland sites that differ in vegetation, hydrology and nutrient status; a *Sphagnum* moss-dominated fen and a *Carex* sedge-dominated fen. At both these sites, my objectives were to:

1) describe patterns in morphospecies richness, total abundance, and overall community composition across one growing season using three different trapping methods, and
2) link emergent arthropod morphospecies and community composition to peat soil and vegetation properties to help explain variation in arthropod diversity among different peatland types.

As this is an observational study that is mostly descriptive, I use univariate and multivariate statistics to quantify patterns, rather than test specific hypotheses about these communities. That said, I predict that seasonality will affect the emergent arthropods due to fluctuations in moisture levels and changes in plant biomass related to increased shade on emergent insects, but also that seasonal effects will be related to daily temperature conditions that are important for development and activity. For the ground dwelling-arthropods, I predict that the dominant groups will be arachnid predators whose abundances will positively correlate with those of their prey (i.e., other arthropods), and which will vary seasonally and between the two fen habitats. I predict that abundances will be highest at the *Sphagnum* fen because of the greater availability of dry hummock habitat. As the two fen sites differ substantially in the number of plant species and corresponding habitat heterogeneity, I predict that the sites will differ in richness due to the greater environmental heterogeneity (more plant species and more varied microhabitat) to be found at the *Sphagnum* fen (Palozzi and Lindo 2017), which will provide more niches. I also predict that a higher water table (i.e., at or near surface level), as is seasonally observed at the *Carex* site, will be correlated with higher abundances of emergent arthropods.

Chapter 2

2 Methods

2.1 Study Area

The study area is near White River, Ontario, Canada, in two Boreal peatlands located at 48°21'N, 85°21'W and 48°21'N, 85°20'W. Both sites are considered fen habitat (i.e., hydrologically supplied by groundwater with greater nutrients and higher pH than bog habitats), but these two sites differ in nutrient status, water table, and dominant vegetation. One fen is 4.5 ha in size, is nutrient poor, has a water table approximately 10-15 cm below the peat surface, and is semi-forested with a dominant ground cover of *Sphagnum* mosses (henceforth the *Sphagnum* fen). The other fen, located 2 km west of the *Sphagnum* fen, is approximately 10 ha in size, has slightly more nutrient availability (considered an intermediate nutrient fen) and a water table 0-5 cm below the peat surface, and is dominated by *Carex* sedges (henceforth the *Carex* fen). Both sites are used as long-term environmental monitoring sites by the Ontario Ministry of Natural Resources and Forestry (OMNRF). Further information on the two sites, such as climate, full vegetation descriptions, and geology is available in McLaughlin and Webster (2010), and Palozzi and Lindo (2017).

2.2 Sample Design and Field Collection

All data and samples were collected during three sampling periods (June, July, and August) during the growing season of 2018. Each sampling period lasted five days and samples were collected from emergence traps, pitfall traps, and peat samples daily. All sampling was performed within an undisturbed 25 m × 25 m site at each fen location.

Emergent peat arthropods were collected using tent-like emergence traps (BioQuip®) that were 110 cm × 110 cm × 110 cm in size and open at the base. One trap per fen was placed at a different, randomly selected plot each day within each 25 m × 25 m site (Fig.

2.1). Plots were not resampled, and plots with pitfall traps in them were also excluded. Any open water or trees were avoided, such that trap edges were fully flush with the ground on all sides. Temperature on the peat surface was measured during emergence trap deployment using Hobo® data loggers placed 1 m north of each plot. Data loggers measured temperature and relative humidity every 10 min for the full 24 hours of emergence trap sampling. Arthropods were collected from the emergence traps daily using a vacuum aspirator and placed into a jar containing the killing agent ammonium carbonate (5 trapping days × 3 sampling periods × 2 sites = 30 emergence samples total). Arthropods were kept at 4°C for up to 8 hours after sampling, until they were transferred into 75% ethanol for longer-term storage and processing.

Peat-dwelling arthropods were sampled by excavating 10 × 10 cm × 5-10 cm deep peat cores using a peat saw. Two peat cores were collected from each emergence trap plot after the emergence trap was sampled (5 plots × 2 cores × 3 sampling periods × 2 sites = 60 peat samples). Peat samples were kept at 4°C until processed for arthropods in the lab two to three weeks after sampling.

Surface-dwelling arthropods were collected in the field using pitfall traps (11 cm in diameter × 13 cm deep) that were partially covered with a plastic roof to prevent rain and debris from collecting in the trap. Attempts were made to ensure traps were flush with the peat surface; however, due to the higher water table at the *Carex* fen, some traps were approximately 1 cm above the peat. Six pitfall traps were deployed per site, one along each border of the 25 m × 25 m grid and two at central locations within the grid, such that all traps were at least 8 m apart (Fig. 2.1). Pitfall traps contained approximately 100 ml soapy water (approximately 2.5 mL of soap per litre of water) which acted as the collection liquid and killing agent. Surface-dwelling arthropods were collected from pitfall traps daily (5 trapping days × 6 pitfalls × 2 sites × 3 sampling periods = 180 pitfall samples). Arthropods were strained from the soapy water using cheesecloth, stored in Ziploc bags in a cooler in the field, and kept at 4°C until they were enumerated and transferred into 75% ethanol for longer-term storage and processing.

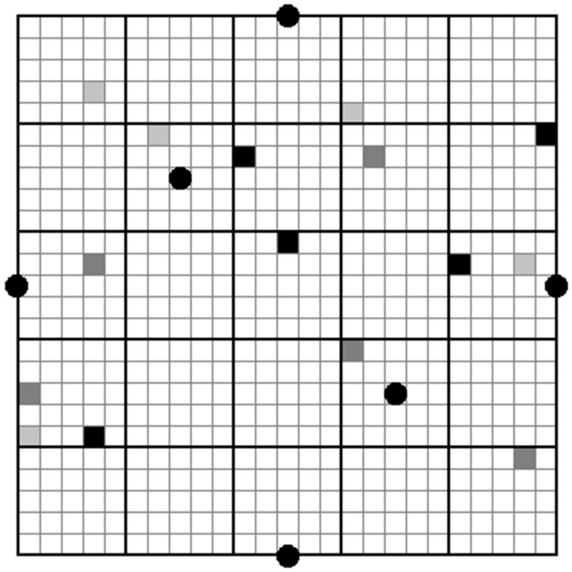

Figure 2.1 The sampling scheme for emergence traps (randomly selected quadrats are shown as squares; light gray for June, dark gray for July, and black for August) and the pitfall traps (black circles, not to scale; locations constant throughout the study) within the 25 m × 25 m site at each peatland. Each small square represents 1 m × 1 m. Pitfall traps were at least 8 m apart.

In addition to arthropod samples, peat moisture content, leaf area index (LAI), plant species richness, and relative plant species abundance were measured at each peat-emergence trap plot in the field to determine whether these environmental variables explain arthropod richness and abundance. Peat moisture was an average of six measurements as a volumetric water content percentage (m^3 H_2O / m^3 soil) using a WET Sensor and an HH2 Moisture Meter (Delta-T Devices Ltd) immediately after the emergence trap was sampled. Leaf area index (LAI) was measured using an AccuPAR PAR/LAI Ceptometer Model LP-80 (METER Group Inc.), which calculates the difference between above and below-canopy photosynthetically active radiation. LAI effectively estimates the amount of light obstructed by the plant canopy and is used as an estimate of above-ground plant biomass. Due to the greater variation in canopy cover at the *Sphagnum* fen, LAI was recorded as the average of ten measurements, while LAI was recorded as the average of five measurements at the *Carex* fen. Plant richness and relative plant species abundance were measured using the point intercept method (Bråthen and Hagberg 2004) for 100 intersecting points within 1 m × 1 m at the centre of each plot. At each point intercept the nearest plant was identified using Newmaster *et al.* (1997).

2.3 Sample Processing

For each sampling type a target group of individuals was selected, and other individuals found in those traps were considered bycatch and were not included in further analyses. For instance, in emergence traps the target group was holometabolous adult insects that could reasonably inhabit and emerge from either the peat or vegetation as larvae. For example, Simuliidae (i.e., black flies) were excluded from the analyses of emergent arthropods as they inhabit lotic habitats (i.e., running water) as larvae (McAlpine *et al.* 1981), and therefore were likely only caught accidentally in emergence traps at a time when their densities were high.

For pitfall traps the target groups were surface-dwelling arthropods, which included spiders and some Orthoptera (i.e., grasshoppers), Hymenoptera (i.e., ants), and

Coleoptera (beetles primarily in the family Staphylinidae). Organisms not considered surface-dwelling arthropods (such as Hemiptera (true bugs) that live on foliage) or that are not targeted invertebrates using pitfall traps (such as Diptera), as well as non-adult specimens were considered ‘bycatch’ and excluded from these totals, and not analyzed further. In the peat sampling, the target taxonomic groups were any holometabolous larvae. For all trapping methods, any extensively damaged, broken, or partial specimens that could not be sufficiently morphotyped were similarly excluded from analyses but are included in the relevant appendices.

The nematocerous flies (Order Diptera) collected in the emergence traps and peat samples, and spiders and insects collected in the pitfall traps were identified to a minimum of family level and assigned to a morphotype representing species level. Other groups were identified to order or suborder level, but all intact individuals of the study were assigned a morphotype representing species level (hereafter referred to as ‘morphospecies’, even though some individuals were identified to species). Several groups (e.g., Ceratopogonidae (biting midges) and Sciaridae (fungus gnats)) are known to display strong sexual dimorphism and could not be confidently grouped into species; for this reason males and females were considered separate morphospecies. Emergent nematocerous flies were identified to family and, where possible, genus level using McAlpine *et al.* (1981) and species using Langton and Pinder 2007, with diagrams in Marshall (2012) and Jewiss-Gaines (2018) used as further reference. Similarly, peat arthropods, primarily larvae from the Order Diptera, were identified to family using McAlpine *et al.* (1981) with diagrams from Marshall (2016) used as further reference. Chironomid larvae were further identified to genus using Oliver and Roussel (1983), with diagrams in Epler (2001) used as further reference. Finally, surface-dwelling Araneae were identified to genus using Ubick *et al.* (2017), and to species using Dondale and Redner (1990), with the diagrams in Paquin and Dupérre (2003) used as a further reference, while any surface-dwelling insects (including ants) were identified using Marshall (2006), with staphylinid beetles identified to subfamily using Brunke *et al.* (2011). Voucher arthropods will be deposited at the Zoological Collections at Western University as either slide mounted or ethanol-preserved specimens.

Total abundance and species richness for emergent arthropods were standardized based on sampling area and time (abundance: # individuals / m^2 / day; richness: # species / m^2 / day). Peat-dwelling arthropods, hand-picked from approx. 230 ml subsample of peat were standardized based on a per 10 g dry weight (abundance: # individuals / 10 g peat; richness: # species / 10 g peat) after the sorted peat subsample was subsequently dried at 60°C to obtain the dry weight value. Total abundance and species richness for surface-dwelling arthropods were standardized by trapping time (abundance: # individuals / day; richness: # species / day).

The remainder of each peat sample was used to calculate gravimetric moisture content and measure pH. Soil moisture was calculated on approx. 4 cm × 4 cm × 5 cm peat subsample using the following equation:

$$\text{Moisture content (ratio)} = ((\text{wet weight} - \text{dry weight}_{60^\circ C}) / \text{dry weight}_{60^\circ C}) \times 100.$$

pH was measured from approx. 4 cm × 4 cm × 5 cm peat in distilled H_2O at a ratio of 5.5 ml to 0.5 g dry weight equivalent peat. Water was squeezed from the peat sample and the pH of this liquid was measured using a calibrated glass pH probe. Plant species richness was standardized to species per m^2 and LAI is expressed as leaf area per m^2 of terrain surface.

2.4 Statistical Analyses

Low abundances and high number of morphospecies singletons (taxa represented by a single specimen) prevented a comprehensive analysis of the peat-dwelling arthropods; data are thus summarized and presented descriptively. For the emergence and pitfall trap data, I performed sample-based rarefaction (species accumulation) curves based on 1000 permutations of randomized resampling without replacement using the vegan package in R (R Development Core Team, version 3.5.1). Rarefaction curves were used to assess cumulative (total) species richness collected with respect to sampling effort and were performed for each site separately as well as both fen sites together. To compare total richness values with the potential number of species occurring, I calculated four richness estimators (Chao, Jackknife 1, Jackknife 2, and Bootstrap) to calculate the estimated species richness based on all emergence trap and pitfall trap arthropods sampled across both fens and separately for each fen site. Estimators were calculated using the vegan package in R (R Development Core Team, version 3.5.1). In addition to measures of species richness and total species abundance, three diversity indices were calculated for each emergent trap and pitfall sample: Shannon's diversity (H'), the inverse of Simpson's diversity (1/D), and Pielou's evenness (J) using the following equations in R (R Development Core Team, version 3.5.1):

$$H' = -\Sigma(p_i) \times (\ln (p_i))$$

$$1/D = 1/ \Sigma(p_i^2)$$

$$J = H'/\ln(S)$$

where p_i is the proportional abundance of the i^{th} species.

I used the following statistical methods to help quantify overarching patterns of arthropod communities at my two peatland sites over the growing season. Average species richness, total abundance, and the three diversity indices for the emergent and surface-dwelling arthropods were examined separately using one-way repeated measures ANOVA (RM-ANOVA) to compare between the two peatland sites and across the three sample periods using the statistical package Statistica v7 (StatSoft Inc., 2004). Because some pitfall trapping days yielded zero abundance, the diversity index analyses were based on four replicates for pitfall traps. Tukey's post hoc tests were used to determine differences between the sites and sampling times. I also ran a Pearson correlation on the abundance of emergent arthropods and spiders across all sampling times, again in Statistica v7 (StatSoft Inc., 2004).

To examine and compare the overall community composition for both emergence and pitfall trap collection methods between sites and across the growing season, I used Bray-Curtis dissimilarity on the abundances for each morphospecies, and visualize this using non-metric multidimensional scaling ordination biplots (NMDS) with 95% confidence interval ovals for both sites and seasons using the vegan package in R. I tested the significance of site and seasonal effects using a permutational ANOVA (PERM-ANOVA) with 999 permutations in the vegan package in R. To further visualize the emergent and ground-dwelling arthropod communities, I performed two principal components analysis (PCA) using the dominant arthropod groups from each trapping method. For the emergence traps this was seven species that had standardized abundances of >20 individuals and for the pitfall traps, this was six species where I collected >10 individuals in total.

To attempt to understand factors affecting the species composition of my peatland arthropods, I extracted PC axis scores from my PCA and used them as response variables in a main effect ANOVA to determine whether fen site and/or month were related to dominant species composition. Additionally, I used the first two PC axis scores in separate backward stepwise multiple regressions with the following environmental variables included in the initial model: minimum air temperature, maximum air temperature, soil pH, field soil moisture content, and plant LAI to help find variables that could explain arthropod composition.

Further to this, I used Bray-Curtis similarity matrices of my emergent arthropods and the plant data (individual plant species abundances collected at each emergence trap site) (see Appendix D), and a Euclidean distance similarity matrix of the environmental variables (minimum air temperature, maximum air temperature, soil pH, field soil moisture content, and plant LAI) created using Euclidean distance, in Mantel and partial Mantel tests separately for each fen site. Mantel tests examine whether variation in two similarity matrices are correlated, whereas the partial Mantel test examines whether variation in two similarity matrices are correlated while accounting for variation in a third matrix. Functionally, the Mantel tests ask: '*does arthropod species composition change when there is a corresponding change in plant community composition?*', and '*does arthropod species composition change with a corresponding change in soil variables?*'. Finally, I used Pearson's correlation coefficients to explain results of significant Mantel tests.

Chapter 3

3 Results

I collected 1814 macroarthropod individuals using the different trapping methods of this study across a total of 218 morphospecies (hereafter referred to as morphospecies); 87 species were identified belonging to 20 families across all target taxa. These numbers do not include the non-target individuals (i.e., non-macroarthropods or accidental captures for the trapping method) and partial specimens that were unidentifiable, which were also collected during sampling. Emergence traps yielded the highest number of species and total number of individuals (1562), with overall richness and abundance decreasing over the sampling period for all sampling methods. A total of 160 species were collected from emergence traps (Appendix A), 27 species in the peat samples (Appendix B), and 31 species from pitfall traps (Appendix C). Diptera were the dominant arthropod group in the emergence trap and peat samples, whereas Araneae was the dominant order in the pitfall traps.

3.1 Emergent Arthropods

A total of 1562 holometabolous adult insects across 160 species were collected using the emergence traps. Although total observed species richness was the same at both the *Sphagnum* and *Carex* fen sites (99 species), the two sites shared only 37 species in common. However, more than twice the number of individuals were collected at the *Carex* site (N=1077) compared to the *Sphagnum* site (N=485). The total estimated species richness across both sites was between 198-321 species, and richness estimators were similar for each site individually (estimated richness values *Sphagnum*: 124-240 species; *Carex*: 124-244 species). The sample-based accumulation and rarefaction curves produced for each site (Fig. 3.1 a, b) as well as both sites together (Fig. 3.1 c) show similar trends where the cumulative species richness does not approach an asymptote at the maximum sampling effort, suggesting more sampling would reveal considerably more species.

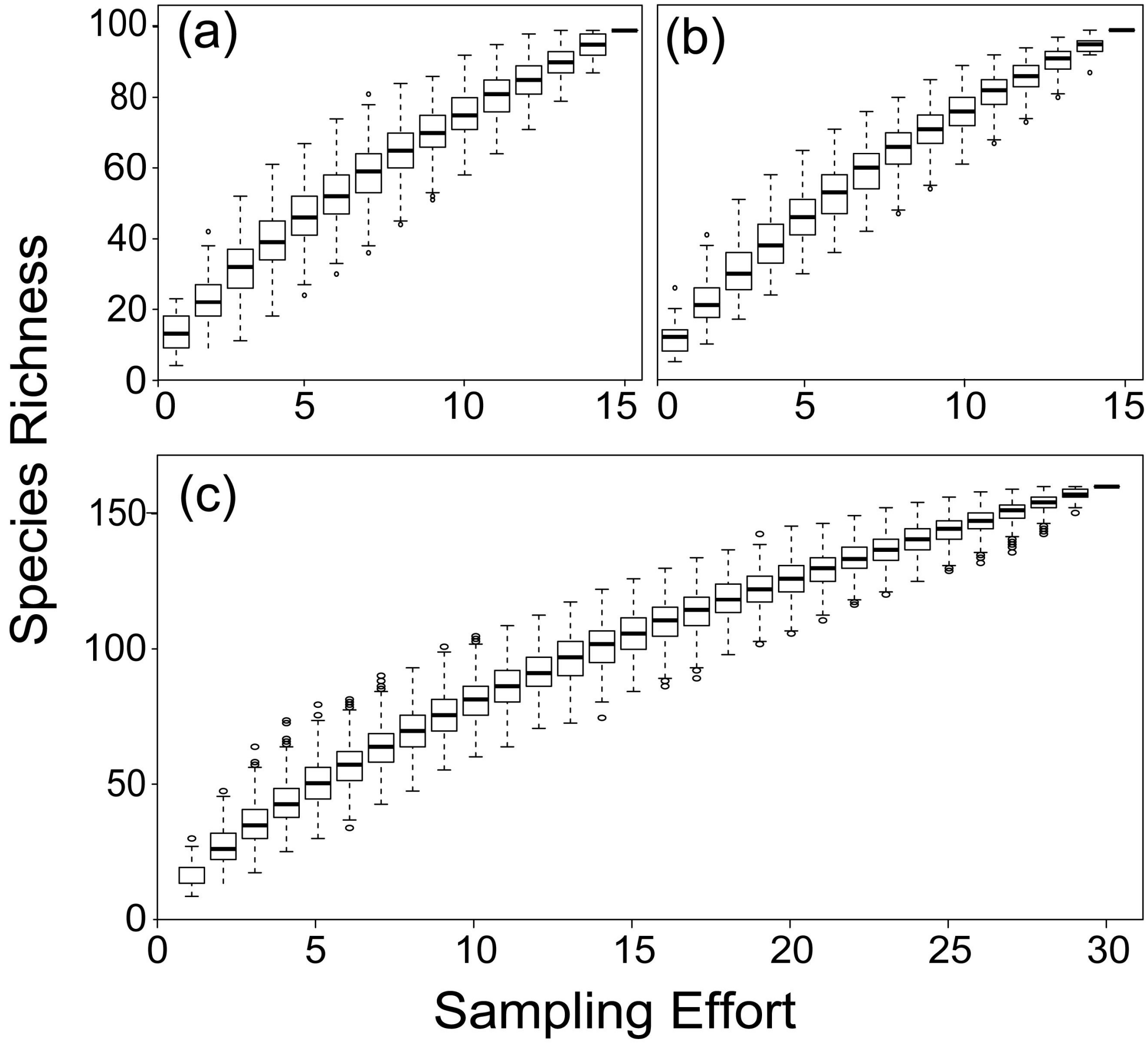

Figure 3.1 Sample-based rarefaction of cumulative species richness of holometabolous adult insects in two fen habitats collected with emergence traps: (a) Rarefaction curve using data from the *Carex* fen; (b) Rarefaction curve using data from the *Sphagnum* fen; (c) Rarefaction curve of data from both fens together.

The mean standardized richness (# species / m^2 / day) was similar at the two fens ($F_{1,8}$=0.30, p=0.599) and across the three sampling times ($F_{2,16}$=2.22, p=0.141), although the *Carex* site had higher standardized richness values in June compared to the *Sphagnum* site, and both sites had slightly lower species emergence in August sampling, but there was no significant fen-by-month interaction (Fig. 3.2 a). The mean standardized abundance of total arthropods collected (# individuals / m^2 / day) was significantly greater in the *Carex* fen compared to the *Sphagnum* fen ($F_{1,8}$ =13.92, p=0.006) in June and July when abundances were greatest at both sites, but total abundance did not differ between the two sites in August leading to a significant fen-by-month interaction (Month: $F_{2,16}$=14.60, p<0.001, Interaction: $F_{2,16}$=7.01, p=0.007) (Fig. 3.2 b).

Shannon's diversity was significantly higher at the *Sphagnum* fen ($F_{1,8}$=13.69, p=0.006) (Table 3.1), but was not significantly different between the months ($F_{2,16}$=0.78, p=0.480) or for the interaction between month and fen. Simpson's diversity showed the same pattern being significantly higher at the *Sphagnum* fen ($F_{1,8}$=10.04, p=0.013), with no differences in Simpson's diversity between sampling months, nor was there a significant interaction between fen and month (Table 3.1). However, Simpson's diversity was highest at the *Sphagnum* site in July and August, and lower at the *Carex* site in June and July. Pielou's evenness values were significantly greater in the *Sphagnum* fen ($F_{1,8}$=10.67, p=0.011) and significantly higher in August at both sites ($F_{2,16}$=9.96, p=0.002), but there was no statistically significant fen-by-month interaction (Table 3.1).

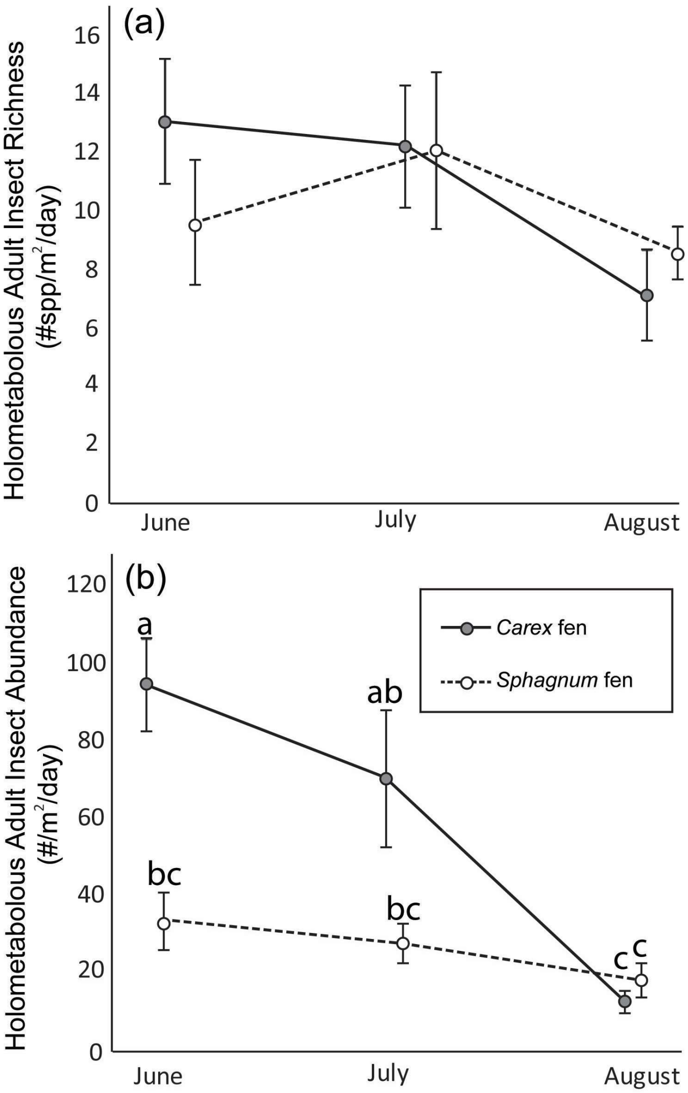

Figure 3.2 (a) Standardized species richness, and (b) total abundance of holometabolous adult insects collected using emergence traps at two fens that differ in dominant vegetation near White River, Ontario. Values are means and error bars are standard error, values with different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test.

Table 3.1 Diversity indices for the emergence trap arthropods collected from a Carex and Sphagnum fen in central Ontario over the 2018 growing season. Indices were calculated in the vegan package of R, and values are means ± standard error; different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test run in Statistica.

Month	Site	Shannon's Diversity	Simpson's Diversity	Pielou's Evenness
June	*Carex* fen	1.48 ± 0.1^{ab}	2.59 ± 0.3	0.55 ± 0.0^{b}
	Sphagnum fen	1.65 ± 0.3^{ab}	3.99 ± 1.0	0.70 ± 0.1^{ab}
July	*Carex* fen	1.26 ± 0.2^{b}	2.18 ± 0.5	0.49 ± 0.1^{b}
	Sphagnum fen	2.04 ± 0.4^{a}	6.41 ± 2.1	0.76 ± 0.1^{ab}
August	*Carex* fen	1.84 ± 0.2^{ab}	5.52 ± 1.1	0.90 ± 0.0^{a}
	Sphagnum fen	2.09 ± 0.1^{a}	6.81 ± 0.6	0.90 ± 0.0^{a}

The two most abundant families collected from the emergence traps were Chironomidae (*Carex* fen: 68%, *Sphagnum* fen: 51% of individuals respectively) and the Ceratopogonidae (*Carex* fen: 12%, *Sphagnum* fen: 10% of individuals respectively). Not surprisingly, trends in Chironomidae abundance closely match trends for overall emergent arthropod abundances. Peak abundances of both families occurred in June; for the *Carex* fen 53% of Chironomidae emerged in June, whereas in the *Sphagnum* fen 49% of Chironomidae emerged in June. The mean standardized abundance of chironomids collected (# individuals / m^2 / day) was significantly greater in the *Carex* fen compared to the *Sphagnum* fen ($F_{1,8}$ =16.24, p=0.004) in June and July when abundances were greatest at both sites, but abundances did not differ between the two sites in August leading to a significant fen-by-month interaction (Month: $F_{2,16}$=11.99, p<0.001, Interaction: $F_{2,16}$=5.58, p=0.015) (Fig. 3.3 a). The ceratopogonids displayed a different pattern of seasonality from the chironomids: 93% and 83% of individuals emerged in June in the *Carex* and *Sphagnum* fens, respectively, with only the *Carex* fen June abundance differing from the other mean abundances. This trend drove significant differences among the two fens ($F_{1,8}$ =8.49, p=0.019) across sampling times (Month: $F_{2,16}$=26.49, p<0.001) as well as a strong fen-by-month interaction ($F_{2,16}$=7.27, p=0.006) (Fig. 3.3 b).

The overall community composition of the emergence trap insects was significantly different across the three sampling times ($F_{2,27}$=5.06, p=0.001). Fens were also significantly different from one another in terms of species composition ($F_{1,28}$=2.67, p=0.015), but the composition of the two fens was more similar in June and became increasingly dissimilar in July and August leading to a significant fen-by-month interaction based on PERMANOVA ($F_{2,24}$=2.36, p=0.007) (Fig. 3.4).

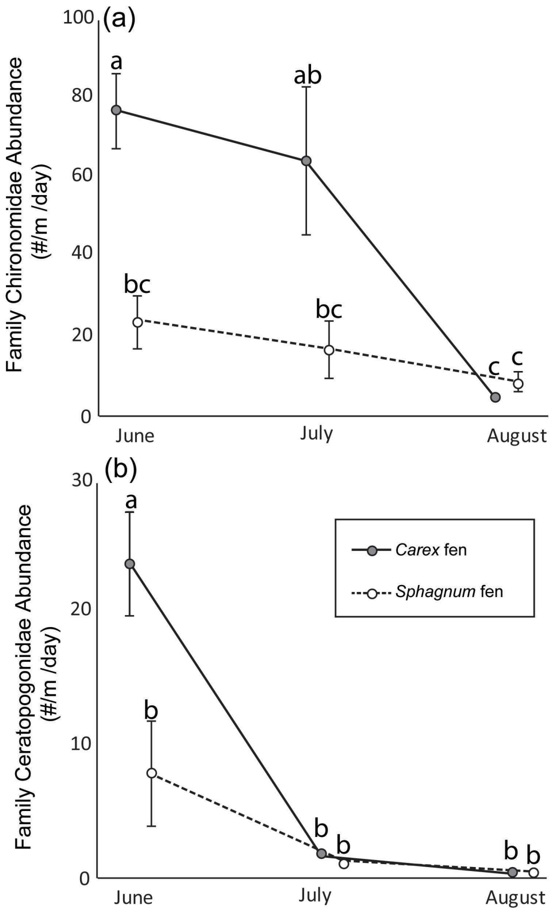

Figure 3.3 (a) Total abundance of individuals belonging to the Chironomidae, and (b) total abundance of individuals belonging to the Ceratopogonidae collected using emergence traps at two fens that differ in dominant vegetation near White River, Ontario.

Values are means and error bars are standard error, values with different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test.

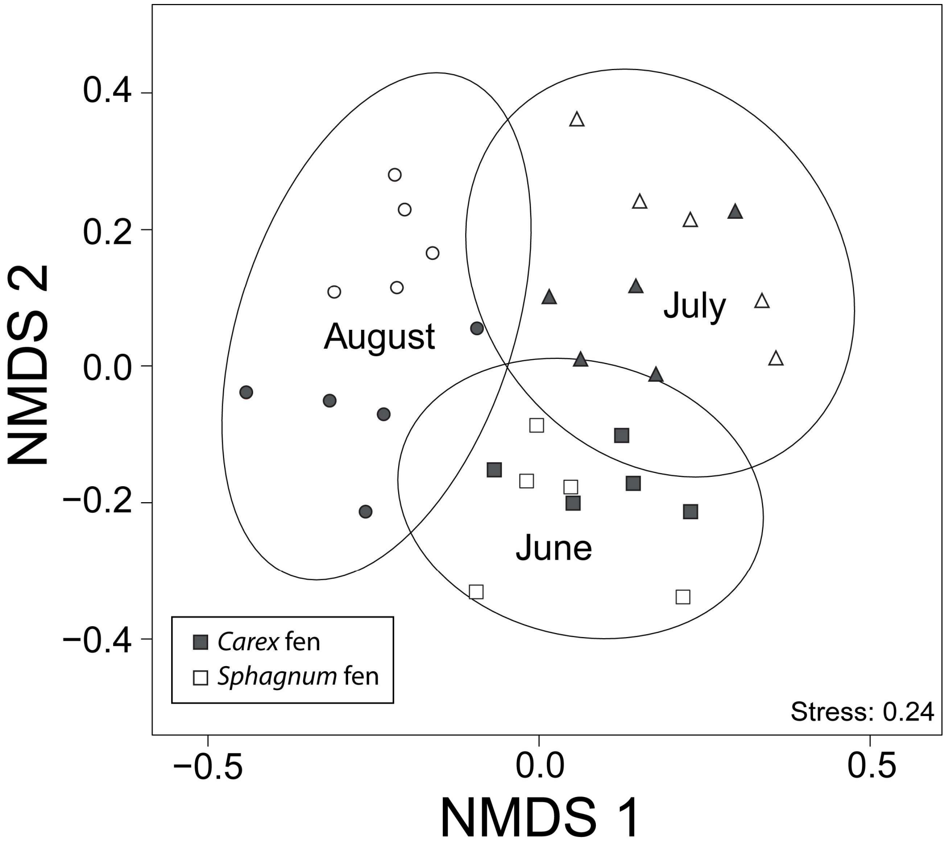

Figure 3.4 The community composition of adult holometabolous insects collected in emergence traps visualized by non-metric multidimensional scaling ordination using a Bray-Curtis dissimilarity matrix. Data points represent separate samples across the three sampling periods (squares = June, triangles = July, circles = August) and fen types (shaded = *Carex*, open = *Sphagnum*).

Data points that are plotted closer together represent communities that are more compositionally similar than data points that are plotted further apart. Ellipses denote 95% confidence intervals.

Looking closer at the most abundant species (the seven species with abundances that were greater than 20 individuals) in the emergence trap samples, the Principal Components Analysis (PCA) also suggests that community composition was significantly structured by variation in sampling month and fen type. The PC axis 1 explained 42% of the variation in species composition, and was significantly related to both month ($F_{2,27}$=10.74, p<0.001) and fen type ($F_{1,28}$=7.25, p=0.012). The second PC axis explained an additional 23% of the variation in species composition and was also significantly related to month ($F_{2,27}$=13.94, p<0.001) (Fig. 3.5). Species found along the positive side of axis 1 were mostly collected in June at the *Carex* site, whereas species plotted on the positive of axis 2 were collected in July from both sites, and species plotted with negative values along either axis 1 and/or axis 2 were species collected from both sites in June or August (Fig. 3.5). Species associated with the positive side of PC axis 1 were four species, two chironomids and two ceratopogonids that were highly abundant in the *Carex* fen in June. The regression of PC axis 1 scores with environmental variables was significant (adjusted R^2=0.700, $F_{2,27}$=34.89, p<0.001) and retained minimum air temperature and field peat moisture content as significant explanatory variables and suggest that cool, wet conditions are associated with abundances of these four species as field moisture content was greatest in the *Carex* fen in June and minimum daily temperatures were still low at both sites during this time. None of the environmental variables were retained in the multiple regression for PC axis 2 scores.

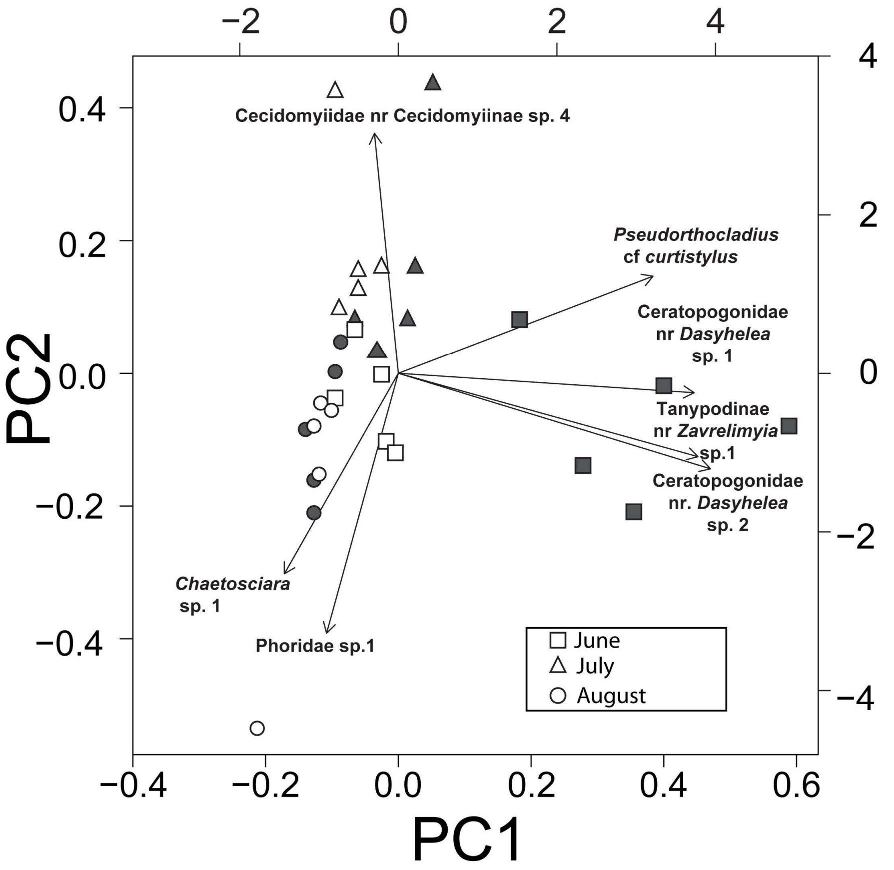

Figure 3.5 The community composition of seven selected adult holometabolous insects collected in emergence traps visualized by principal components analysis of species with standardized abundances of >20 shown as arrows (see Appendix A for full species codes). Data points represent separate samples across the three sampling periods (squares = June, triangles = July, circles = August) and fen types (shaded = *Carex*, open = *Sphagnum*).

3.2 Peat-dwelling Arthropods

A total of 66 holometabolous larvae were extracted from the peat samples (approx. 128 individuals per 10 g dry weight (dw) peat), belonging to the orders Diptera, Coleoptera, Lepidoptera (moths and butterflies), and Trichoptera (the caddisflies) (see Appendix B). Overall abundances were low, and the majority of the individuals were found in the *Carex* fen (N=57; 86%); only nine individuals were observed from samples collected from the *Sphagnum* fen, and all of these were singletons (i.e., only a single individual of a species observed). A total of 27 different morphs were found, 19 of them being dipterans, and many were singletons. The majority of individuals collected in both fen habitats were dipterans (88%) with these mostly belonging to Chironomidae (only found as larvae at the *Carex* fen) and Ceratopogonidae. The highest abundance at both sites was observed in July, which corresponded to the highest species richness at the *Sphagnum* fen, but higher species richness was observed in June in the *Carex* fen (Appendix B).

3.3 Surface-dwelling Arthropods

A total of 186 surface-dwelling macroarthropods were collected over the three sampling periods using pitfall traps. A similar number of individuals were collected from each site (*Sphagnum* = 103; *Carex* = 83). Thirty-one morphospecies were observed in total across both sites and all sampling times, and total richness was nearly twice as high in the *Sphagnum* fen (26 species) than the *Carex* fen (13 species). Richness estimators for pitfall traps suggest a total of 37-61 species across these two fen types. That said, most of the potential richness is coming from the richness estimated at the *Sphagnum* fen, where estimated richness values at the *Sphagnum* site are 31-46 species in contrast to only 15-29 species estimated at the *Carex* site. Like the accumulation and rarefaction curves from the emergence trap data, ground-dwelling sampling of macroarthropods did not approach an asymptotic trend given the sampling effort suggesting more sampling would reveal considerably more species (Fig. 3.6).

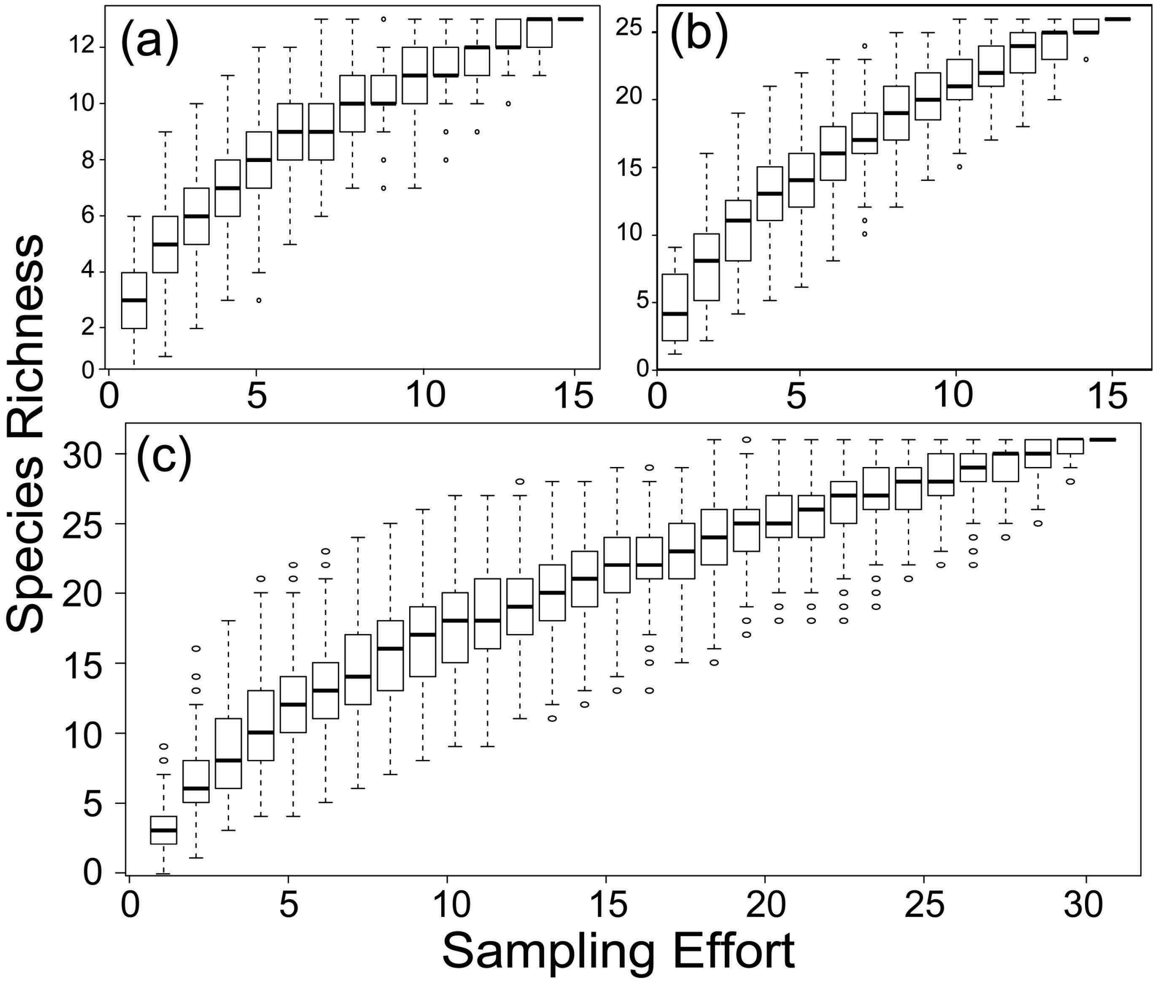

Figure 3.6 Sample-based rarefaction of cumulative species richness for surface-dwelling arthropods in two fen habitats collected with pitfall traps: (a). Rarefaction curve using data from the *Carex* fen; (b). Rarefaction curve using data from the *Sphagnum* fen; (c). Rarefaction curve of data from both fens together.

Standardized richness (# species / trapping day) was not significantly different between the *Carex* and *Sphagnum* fen sites ($F_{1,8}$=2.22, p=0.174), but species richness significantly decreased over the course of the growing season ($F_{2,16}$=15.89, p<0.001), with June having greater species richness than traps set in August across both sites (Fig. 3.7 a). The seasonal trend in species richness was mirrored in the standardized arthropod abundance data, where both fen sites showed highest abundances collected in June, and declining over the growing season ($F_{2,16}$=17.85, p<0.001), but there was no difference in abundance based on fen type (Fig. 3.7 b).

Shannon's diversity was not significantly different between the *Carex* and *Sphagnum* sites, but both sites showed decreasing diversity over the sampling period ($F_{2,12}$=6.84, p=0.010). Simpson's diversity followed a similar trend, with diversity decreasing over the sampling period at both sites ($F_{2,12}$=4.54, p=0.034). Pielou's evenness (J) index was high (near 1.0) and not significantly different between sites or among different sampling times (Table 3.2).

Of the collected arthropods 107 individuals belonged to the Order Araneae, with an average of three individuals per day being collected in the *Sphagnum* fen and four individuals per day in the *Carex* fen. Overall abundance data was thus largely driven by the abundances of spiders (Order Araneae) as they were the dominant Order at both fens (79% *Carex*; 40% *Sphagnum*). However, there were greater abundances of non-spider arthropods at the *Sphagnum* fen ($F_{2,16}$=9.80, p=0.014) (Fig. 3.7 c) including greater abundances of ants (Family Formicidae) and beetles (mostly Family Staphylinidae) ($F_{2,16}$=11.18, p=0.010). Correspondingly, there was a significantly consistent higher abundance of spiders at the *Carex* fen (Fen: $F_{2,16}$=13.30, p=0.007) (Fig 3.7 d), and spider abundance significantly declined over the growing season at both sites ($F_{2,16}$=16.49, p<0.001); ergo the non-Araneae groups show a different seasonal trend compared to the Araneae.

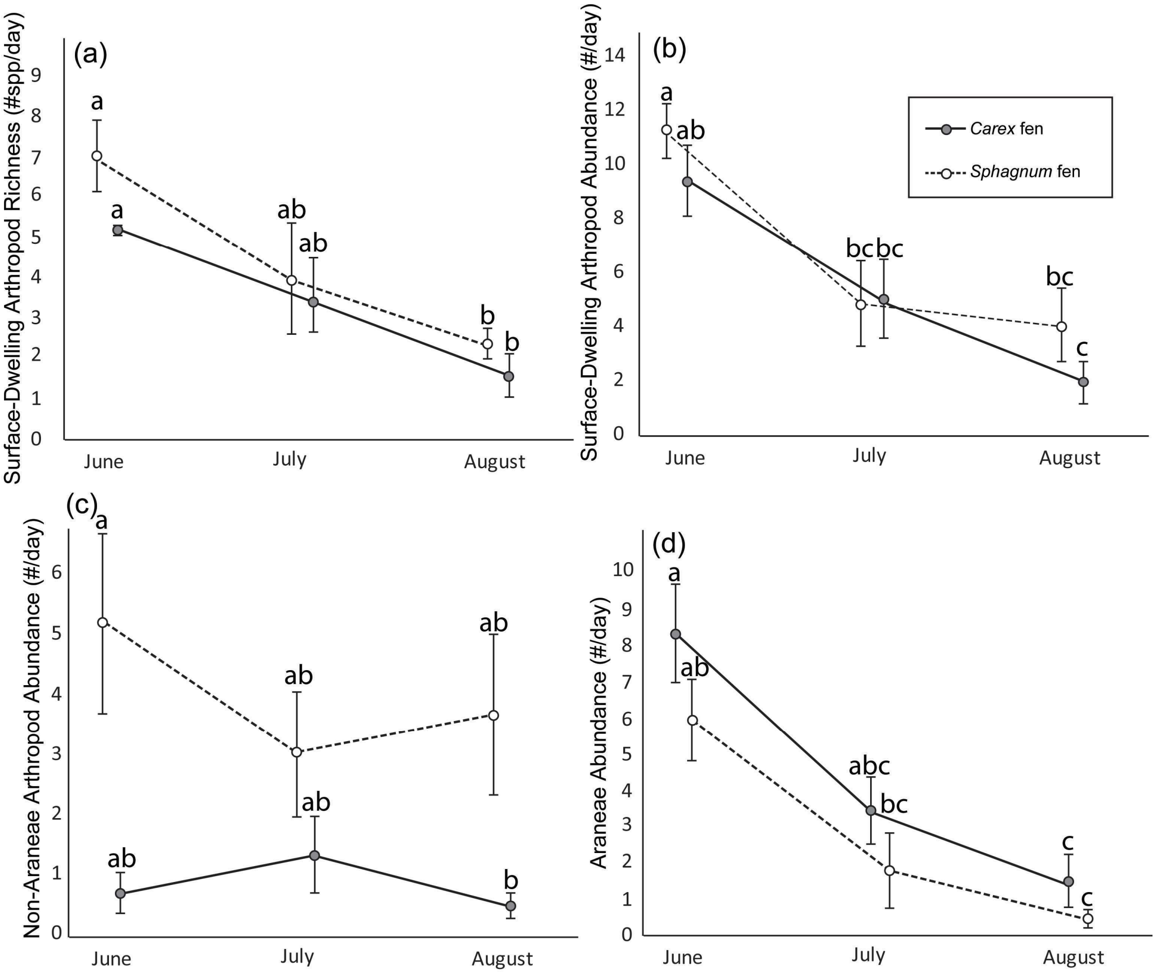

Figure 3.7 Surface-dwelling arthropod communities examined using pitfall traps at two fens that differ in dominant vegetation near White River, Ontario: (a) overall average species richness, (b) overall average abundance, (c) average non-spider arthropod abundance and (d) average Araneae (spider) abundance.

Values are means with standard error as bars. Different letters denote statistically different groups based on a repeated measures ANOVA and Tukey's post hoc test.

Table 3.2 Diversity indices (Shannon's, Simpson's and Pielou's) calculated using the vegan package in R for of arthropods collected by pitfall traps from a *Carex* and *Sphagnum* fen in central Ontario over the 2018 growing season. Values are means, errors are standard error; different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test.

Month	Site	Shannon's Diversity	Simpson's Diversity	Pielou's Evenness
June	*Carex* fen	1.22 ± 0.1^{a}	3.08 ± 0.3^{ab}	0.89 ± 0.04
	Sphagnum fen	1.73 ± 0.2^{ab}	5.18 ± 0.9^{a}	0.92 ± 0.03
July	*Carex* fen	0.98 ± 0.2^{ab}	2.55 ± 0.4^{b}	0.93 ± 0.03
	Sphagnum fen	1.23 ± 0.3^{ab}	3.86 ± 1.2^{ab}	0.96 ± 0.02
August	*Carex* fen	0.57 ± 0.2^{b}	1.77 ± 0.3^{b}	0.93 ± 0.04
	Sphagnum fen	0.73 ± 0.2^{ab}	2.11 ± 0.3^{b}	0.92 ± 0.03

The most common spider at both sites, *Pardosa moesta* Banks, 1892 (48 individuals), was only collected in June at the *Sphagnum* fen site (Appendix C) but was collected at all three sampling times in the *Carex* fen, albeit with greatest abundance also during June sampling. The second most abundant group (41 individuals) was the Family Formicidae (Order: Hymenoptera), with an average of two individuals collected per day at the *Sphagnum* fen and one individual per day at the *Carex* fen. Beetles (Order: Coleoptera) were only collected at the *Sphagnum* fen, mostly belonging to the subfamily Pselaphinae (Order: Coleoptera, Family: Staphylinidae) (18 individuals) which were collected at a rate of approximately one individual per day. The remaining orders of arthropods collected included: Opiliones (Class: Araneae); Orthoptera, other Coleoptera, and other Hymenoptera (Class: Ectognatha), although Diptera, Acari, and Collembola were also collected as bycatch. Spider abundances were correlated with emergent arthropod abundances (r^2=0.297, p=0.002).

The community composition of the pitfall arthropods as examined using PERMANOVA and visualized using NMDS ordination was significantly different across the three sampling times ($F_{2,26}$=2.88, p=0.002), as well as the two fens being significantly different from one another ($F_{1,27}$=5.40, p<0.001). At the *Carex* fen, there was a clear season shift in community composition, likely driven by declining abundances of spiders, whereas the *Sphagnum* fen also had a seasonal pattern, but likely driven by changes in the abundance of ants and beetles, such that the PERMANOVA also reported a significant fen × month interaction ($F_{1,23}$=1.72, p=0.045) (Fig. 3.8).

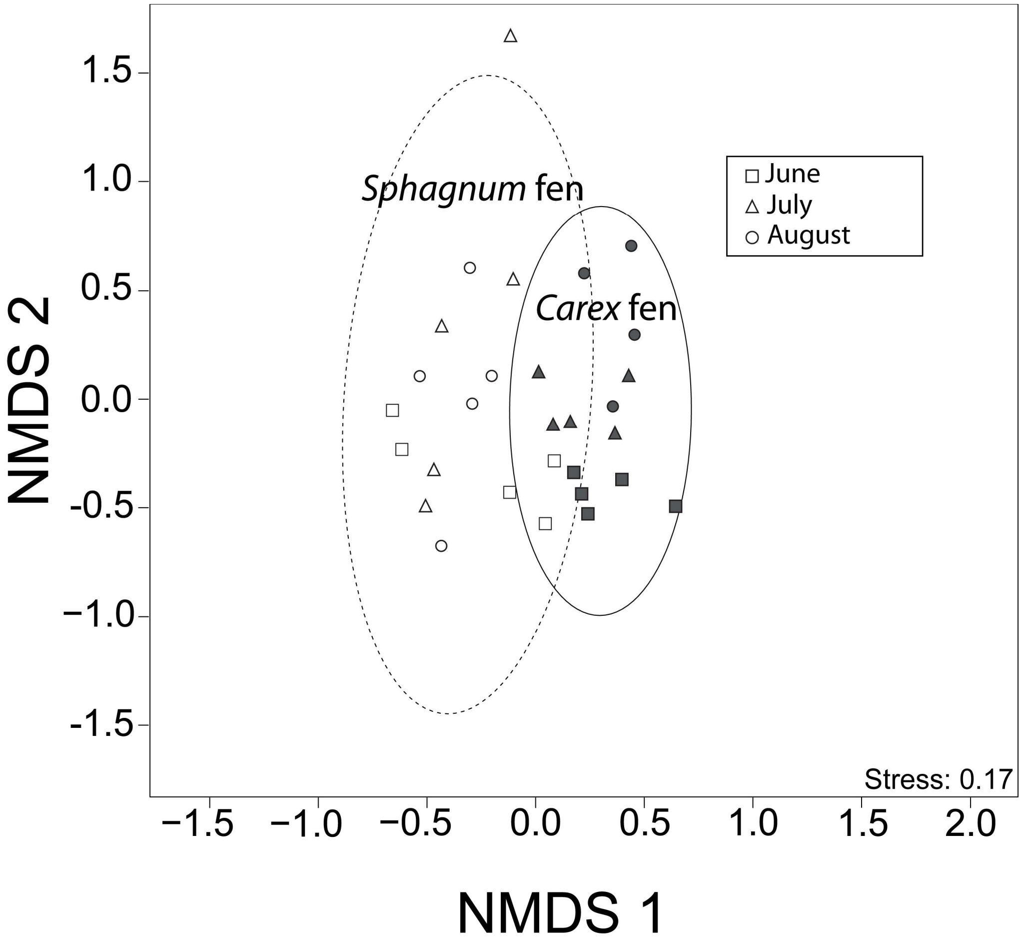

Figure 3.8 The community composition of surface-dwelling arthropods collected in pitfall traps visualized by non-metric multidimensional scaling ordination using a Bray-Curtis dissimilarity matrix. Data points represent separate samples across the three sampling periods (squares = June, triangles = July, circles = August) and fen types (shaded = *Carex*, open = *Sphagnum*).

Data points that are plotted closer together represent communities that are more compositionally similar than data points that are plotted further apart. Ellipses denote 95% confidence intervals.

For the principal components analysis of the six most abundant species collected in pitfall traps, the first PC axis (PC1) explained 32% of the variation in species composition and was significantly related to both sampling month ($F_{2,28}=3.56$, $p=0.044$) and fen type ($F_{1,27}=16.78$, $p<0.001$) (Fig. 3.9). This was mostly driven by species on the positive side of PC axis 1 (*P. moesta* and *Arctosa raptor*) that were most abundant at the *Carex* fen in June, whereas ant species on the negative side of PC axis 1 were most abundant in the *Sphagnum* fen. The second PC axis explained an additional 19% of the variation in species composition, but the axis scores were not significantly related to any known variable (i.e., fen site or sampling month) (Fig. 3.9).

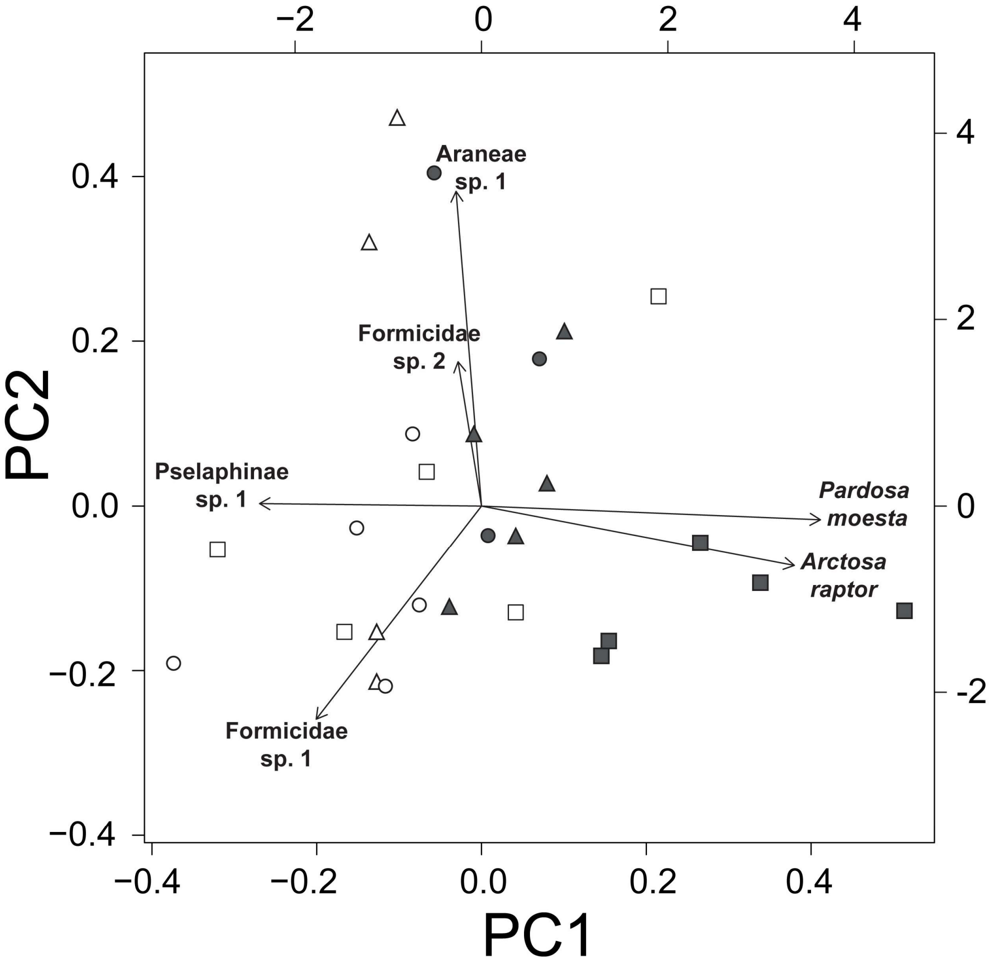

Figure 3.9 Principal components analysis biplot of the most abundant surface-dwelling arthropods (abundances of >10 indiv. total) collected in pitfall traps (shown as arrows; see Appendix A for further species information). Data points represent separate samples across the three sampling periods (squares = June, triangles = July, circles = August) and two fen types (shaded = *Carex*, open = *Sphagnum*).

3.4 Environmental Variables

Several abiotic variables were measured at the two peatland sites that may be important factors in the activity, and therefore sampling of macroarthropods. Not surprisingly, the temperature (minimum, maximum, and mean temperature) changed significantly over the sampling seasons (min: $F_{2,16}=22.74$, $p<0.001$; max: $F_{2,16}=6.26$, $p<0.001$; mean: $F_{2,16}=8.55$, $p=0.003$), with the minimum temperatures being lowest (Table 3.3) and maximum temperatures highest (Fig. 3.10 a) in June at both sites. The *Sphagnum* and *Carex* sites did not significantly differ in the temperatures recorded, although the *Carex* site recorded greater maximum daily temperatures in June and July compared to the *Sphagnum* site (Fig. 3.10 a).

Volumetric peat moisture content as measured in the field was significantly higher in the *Carex* fen ($F_{1,8}=86.82$, $p<0.001$). This was especially true at the beginning of the sampling season when moisture content was twice as high in the *Carex* site in June, compared to the other two sampling times (month: $F_{2,16}=5.70$, $p=0.014$), whereas the *Sphagnum* fen site had consistent moisture content (~ 20%) over the sampling seasons leading to a significant interaction between fen type and sampling period ($F_{2,16}=4.31$, $p=0.032$) (Fig. 3.10 b). Gravimetric moisture as measured directly on collected peat samples in the laboratory followed a similar trend of being highest in June ($F_{2,16}=3.75$, $p=0.046$), but moisture content was not significantly different between the two peatland sites. In contrast, the pH of the peat samples did not vary over the sampling season but did significantly differ between the two fen sites ($F_{1,8}=421.2$, $p<0.001$) (Table 3.3).

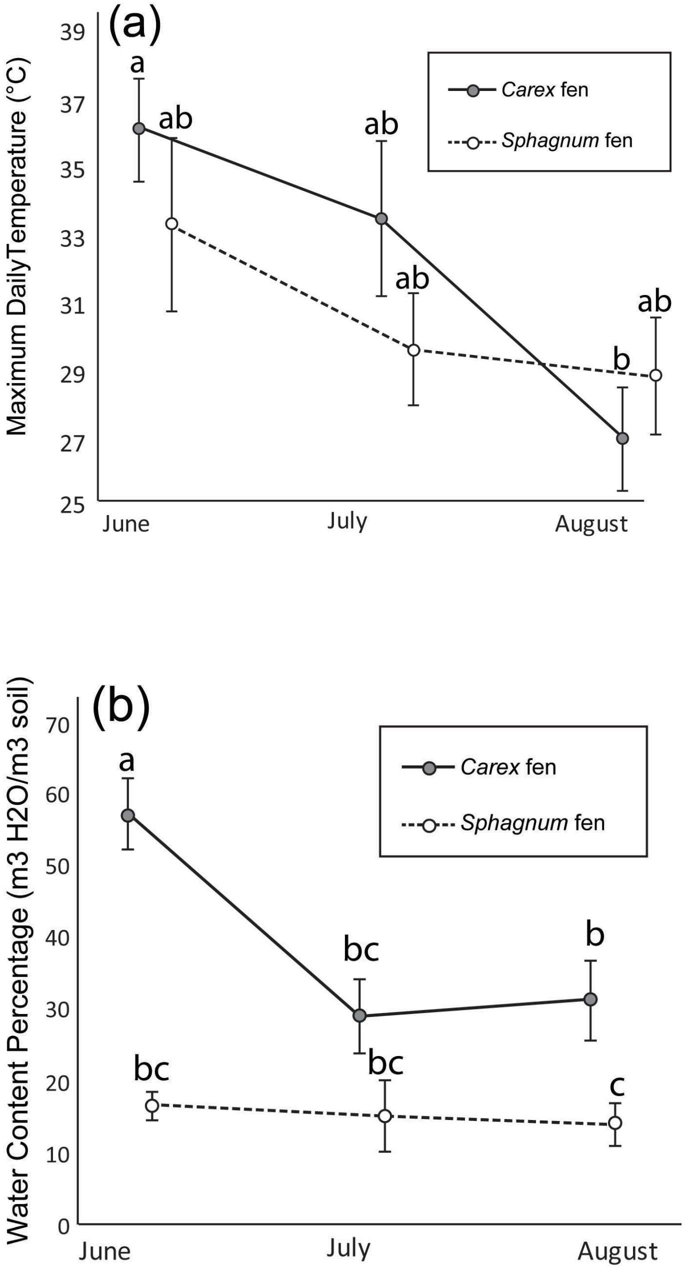

Figure 3.10 (a) Daily maximum temperature measured in the field at the *Carex* and *Sphagnum* fens by HOBO dataloggers placed 1 m north of emergence traps, and (b) volumetric peat moisture in the field within the emergence trap quadrats. Different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test.

Table 3.3 Daily minimum and average temperatures measured in the field at a Carex and Sphagnum fen in central Ontario over the 2018 growing season, by HOBO dataloggers placed 1 m north of emergence traps. Gravimetric moisture and pH were measured in the lab using two peat samples that were collected from inside the emergence trap quadrats and were used to quantify peat dwelling arthropods. Values are means (± standard error). Different letters denote statistically different groups based on a RM-ANOVA and Tukey's post hoc test.

Month	Site	Minimum Daily Temperature (°C)	Average Daily Temperature (°C)	Gravimetric moisture content (%)	pH
June	*Carex* fen	2.44 ± 1.1^{bc}	17.06 ± 0.7^{ab}	872. 18 ± 19.4	5.63 ± 0.1^{a}
	Sphagnum fen	1.20 ± 0.6^{c}	14.98 ± 1.3^{b}	811.12 ± 84.6	4.11 ± 0.1^{b}
July	*Carex* fen	8.39 ± 2.5^{abc}	18.83 ± 0.8^{ab}	640.39 ± 27.0	5.62 ± 0.1^{a}
	Sphagnum fen	8.75 ± 2.6^{ab}	17.90 ± 1.6^{a}	695.47 ± 70.7	4.11 ± 0.0^{b}
August	*Carex* fen	11.95 ± 1.7^{ab}	17.41 ± 0.7^{ab}	653.08 ± 25.4	5.55 ± 0.1^{a}
	Sphagnum fen	11.31 ± 1.9^{ab}	17.66 ± 0.9^{a}	655.26 ± 143.4	4.21 ± 0.1^{b}

Plant species richness and diversity was always significantly greater at the *Sphagnum* fen compared to the *Carex* fen across the growing season (see Appendix E), but LAI did not differ between sites or over the growing season. For the Mantel tests from the *Carex* fen environmental variables correlated with plant community (*Carex*: r_m=0.391, p=0.006, *Sphagnum*: r_m=0.391, p=0.005), and arthropod species composition was not statistically significantly correlated with environmental variables, but perhaps was biologically (r_m=0.190, p=0.063) which was also perhaps reflected in the partial mantel which correlated arthropod species and environmental variables while controlling for plant species (r_m= 0.174, p=0.080). Mantel and partial Mantel tests from the *Carex* fen also likely reflect significant correlations with temperature variables (maximum temperature and total abundance: r^2=0.299, p=0.035; maximum temperature and chironomid abundance: r^2=0.275, p=0.044; minimum temperature and arthropod abundance: r^2=0.359, p=0.018) and field moisture (moisture and ceratopogonid abundance: r^2= 0.606, $p<0.001$). Minimum temperature was also correlated with the abundance of chironomids, ceratopogonids, and total emergent arthropods.

Chapter 4

4 Discussion

4.1 Diversity of boreal peatland arthropods

Previous studies of individual boreal peatlands have shown that arthropods are highly diverse with Finnamore (1994) finding >2000 species at a single location. My study of two peatland sites found an order of magnitude lower species richness at either single site, but this is likely due to other studies using non-discriminant trapping methods such as aerial malaise traps which capture aerial arthropods or pan traps that attract arthropods from surrounding areas, and these arthropods may complete the majority of their development in other habitats and not within the peatland itself. The trapping methods I used (emergence traps, pitfall traps, and peat sampling) ensure that nearly all individuals and species I found inhabited the peatland sites.

That said, at both sites and for both the emergence and pitfall traps the true diversity (i.e., richness) was likely higher than my observed richness as indicated by both the richness estimators and the species accumulation-rarefaction curves, which did not display an asymptotic pattern. Richness estimators calculate or estimate ‘true’ species richness using a metric that takes into account the number of rare species encountered to estimate the number of unseen or undetected rare species in a sampling scheme (Smith and van Belle 1984). At both my peatland sites, a high number of singletons (i.e., morphospecies where only one individual was collected) were observed in both emergence and pitfall sampling methods. In my peat samples nearly all morphospecies were singletons to the extent that this data (containing zero abundance for most species) could not be quantitatively analyzed. Taken together, these results indicate that more species are left to be discovered at each of these peatland sites.

Undetected species were particularly likely at the *Sphagnum* fen where, for the emergence traps, the total number of individuals collected was less than half of that collected at the *Carex* fen. Buddle *et al.* (2005) suggest that when estimating species richness using rarefaction curves, the true measure of ‘sampling effort’ is the number of individuals collected as opposed to the number of samples because richness and abundance are often strongly positively correlated. *Sphagnum*-dominated peatlands are predominantly studied in the literature versus *Carex*-dominated peatlands for arthropod surveys (but see data from the Crief fen near Hamilton, Ontario in Blades and Marshall 1994, and Dondale and Redner 1994). The high observed species richness of some previous surveys (Blades and Marshall 1994; Dondale and Redner 1994; Grégoire Taillefer and Wheeler 2012; 2013; 2018; 2019; Rosenberg *et al.* 1988) may be due to high sampling effort in these greater diversity *Sphagnum* sites, and/or adjacency to forested habitat and areas with a greater diversity of plant architecture, as was the case for the *Carex* dominated flats of the Wagner Bog just west of Edmonton, Alberta (Finnamore 1994). Similarly, in the two previous studies at the Crief fen (Blades and Marshall 1994; Dondale and Redner 1994) both observed similar arthropod species richness values in this sedge-dominated fen compared to an undisturbed *Sphagnum*-dominated site in the same region (the Oliver bog approx. 21 km distance from the Crief fen). However, for both sites it was postulated that some of the observed species came from the adjacent forests or intermixed trees (Finnamore 1994; Dondale and Redner 1994).

4.2 Dominant arthropod taxa in boreal peatlands

4.2.1 Diptera

Diptera dominated samples collected from emergent traps as well as from peat at both peatland sites. As with overall species richness estimates, true richness of the Diptera groups Chironomidae and Ceratopogonidae may be underestimated at both sites. In addition to the reasons outlined above for total richness, my estimates are likely low for these groups because species are more cryptic and harder to identify than some other groups (like the spiders). Rosenberg *et al.* (1988) collected arthropods using emergence traps from similar peatlands in Northern Ontario from 1984-1986 and found 84 species of chironomids compared to my morphospecies richness of 14. This was likely influenced by their higher sampling effort, a larger area was sampled (three different peatlands each with 15 traps) and the study was performed for a longer duration (from May to September), and for one of the peatlands sampling was conducted for a subsequent two summers. As well, Giberson *et al.* (2001) only found 24 species of Chironomidae and 12 species of Ceratopogonidae in coastal marsh pools on Prince Edward Island. Although marsh pools have different vegetation and typically higher water table, six of the seven families found in that study were also found in my study (Chironomidae, Ceratopogonidae, Tipulidae, Cecidomyiidae, and Sciaridae) suggesting wetland Dipteran composition is similar at least at the Family level.

Many Diptera are known wetland specialists (Marshall 1994), being aquatic (Teskey 1981) or semi-aquatic (Downes and Wirth 1981). High dipteran species richness is often associated with wetter habitats and open water. For instance, at three sites in the Boreal forest in Northern Quebec, Tremblay *et al.* (1998) found 60 species of insects, including 41 species of Chironomidae in lakes and flooded reservoir sites. Rosenberg *et al.* (1984) found 100 species of along the marsh-bordering shoreline of a Manitoba lake (Southern Indian Lake) at similar latitude to my study sites. That said, I found similar alpha-diversity of Ceratopogonidae and greater alpha-diversity of Chironomidae at my *Sphagnum*-dominated site which had a lower water table and less standing water compared to my *Carex* fen site. Diptera can also be abundant in more terrestrial systems, especially forests. In three different forest habitats in northern Alberta, Ryan and Hilchie (1981) found that most soil arthropods collected with emergence traps were dipterans. The dominant groups collected in these forest sites, however, were different from what I observed at my peatland sites, as the two most abundant groups were usually Cecidomyiidae, Mycetophilidae, or Bibionidae. Chironomidae and Ceratopogonidae were both observed in these forest collections but never exceeded 8% of individuals collected from any given trap (Ryan and Hilchie 1981). Tremblay *et al.* (1998) found that the total abundance of emergent arthropod individuals was not related to whether traps were in forest or peatland sites, but rather varied by site, suggesting that small-scale location may have a greater effect on abundance than habitat type. However, Ryan and Hilchie (1981) found total abundance of soil-dwelling arthropods was between three and ten times greater at a fen site compared to a forest site in northern Alberta largely due to an overwhelming abundance of Diptera larvae, suggesting that fens hold greater abundance of Diptera than forests. In support of this, Høye and Forechhamer (2008) found that fens in the high arctic of Greenland had the second highest abundances of Chironomidae compared to other more terrestrial sites, only being outperformed by a pond site.

4.2.2 Araneae and Carabidae

Spiders were the dominant ground-dwelling arthropod taxonomic group collected in the pitfall traps, and *Pardosa moesta* (Family Lycosidae), known to be a wide-spread boreal spider (Buddle *et al.* 2000, Pinzón *et al.* 2012), was the most abundant species from the *Carex* fen and the fourth most abundant from the *Sphagnum* fen. Many active hunting spiders like the lycosids are known to rely on speed (Bear and Hasson 1997) and visual cues to hunt (Persons and Uetz 1998), and the placement of my pitfall traps near or alongside the peatland boardwalks may have facilitated spider movement and increased the predominance of this group in my samples. For instance, *Arctosa raptor* (Kulczyński 1885) was often observed along boardwalks during my sampling (pers. obs.). Surprisingly, and contrary to several other Canadian peatland studies (Dondale and Redner 1994; Koponen 1994), I found no members of the spider family Linyphiidae in my pitfall traps. Potentially this could have been because trap lips were often 1-2 cm above the ground surface due to the high water table, which may have excluded small linyphiid spiders. Another explanation is that the diameter of my traps may have been too large to effectively capture this group. For instance, Work *et al.* (2002) showed that larger traps (15-20 cm dia.) generally caught more species than smaller traps (4.5-11 cm dia.), but more linyphiids were caught in the smaller traps (4.5 cm) and were least often captured in larger (11 cm) traps.

Similarly, I found lower than expected species richness and abundances of beetles in my ground-dwelling arthropod community. In the boreal zone, particularly in boreal forests, carabid beetles (Family Carabidae) alongside spiders are the dominant groups collected in pitfall traps. In a Boreal forest in Finland, Niemelä *et al.* (1996) found 51 carabid species, 212 spider species, and 23 ant species across a successional gradient of forests. Carabid beetles and spiders are so ubiquitous in boreal systems that they are often used as bioindicators of disturbance including in studies of forest harvest (Pinzón *et al.* 2012) and fire recovery (Buddle *et al.* 2000). However, carabids can also be absent from peatland studies, potentially because of their activity peaking in early spring or because of microhabitat homogeneity (Främbs 1994), such as that of the *Carex* fen, suggesting that carabids may not be good indicator species in peatlands systems.

4.3 Other peatland arthropod taxa

Hymenoptera (ants, wasps, bees) and Lepidoptera (moths, butterflies) are less well studied in boreal peatlands than other taxonomic groups such as Diptera. Yet, in Finnamore's 1994 study, he found that the number of species of Hymenoptera in peatlands could be astronomically high (>2000). In my study, the emergence traps revealed 52 morphospecies that mostly existed as singletons, which could be related to my use of emergence traps but provides support for potentially high Hymenoptera diversity residing in peatlands. The singleton Hymenoptera from the *Sphagnum* fen and the *Carex* fen each composed approximately 10% of all species collected during the study, and the Hymenoptera as a group made up 68% of all species collected, but still relative to other peatland studies, my observed richness values for Hymenoptera are low. For instance, in a study of Quebec peatlands, Koponen (1994) found 169 species, but this was across multiple peatland sites. Similarly, Dondale and Redner (1994) found 198 Hymenoptera species from peatlands in Quebec and Ontario, but they also sampled many more peatland sites compared to the two peatlands surveyed here. Hymenoptera are also species-rich in neighbouring forest locations surrounding boreal peatlands. For example, in forests near Algonquin Park in central Ontario Smith *et al.* (2012) found 110 morphospecies of Hymenoptera within a single family (the family Braconidae). Likely most of my Hymenoptera are parasitoids, parasitizing other prominent groups like Diptera or Araneae, or being plants parasites, with many of these being host specialists (Finnamore 1994). Contrary to this however, Lozan *et al.* (2012) observed that many of the Hymenoptera which they reared from peatland lepidopteran larvae hosts were host generalists.

As in my study, Ryan and Hilchie (1981) showed a low proportion of their overall trap catch to be Lepidoptera in a survey of forest arthropods using emergence traps, despite the emphasis that this group often receives as peatland specialists in studies in Europe, particularly for conservation purposes as this group contains species that require the exact climate and food plants present in peatlands (Spitzer and Danks 2006). However, generalist species can occupy this habitat too; in a Czech bog 487 species of Lepidoptera were collected with light traps, 11 of which are found exclusively in bogs and 23 of which are characteristic of bogs (Spitzer *et al.* 1999). For leaf-rolling moth larvae, bog exclusive and bog characteristic species were found nearer to the center of the peatland habitat and away from trees and edges (Spitzer *et al.* 2003).

Although emergent traps and pitfall traps are specifically designed to capture and collect the arthropod communities that emerge as adults from soil-dwelling larvae and the ground surface-dwelling macro-arthropods, respectively, many other taxonomic groups were collected as ‘bycatch’ using these sampling methods. Notable in this group are Family Cicadellidae (leaf hoppers) in the emergent traps which reflect accidental trapping of hemimetabolous insects that often hopped into the trap while it was being erected (Ryan and Hilchie 1981), as well as smaller arthropods such as mites and Collembola in the pitfall traps.

4.4 Differences between *Sphagnum* and *Carex*-dominated peatland arthropods

Although only two peatland sites were surveyed for this study, I found generally low overlap of species composition between the two sites (i.e., high beta-diversity) which differed in above-ground vegetation as well as water table and soil nutrient status. The pitfall trap data showed very different communities between the two fens; however, the overall trap catch contained many singletons that may overestimate the beta-diversity between these two sites. More arthropod species were collected in pitfall traps at the *Sphagnum* fen overall, which makes sense considering the higher habitat heterogeneity available at the *Sphagnum* fen (Niemelä *et al.* 1996). However, on a monthly basis richness was the same at both the *Carex* and *Sphagnum* fens, possibly representing differences in the active periods of *Sphagnum* fen organisms (Hallander 1967), especially considering my small number of traps.

Whereas my overall pitfall trap catch was dominated by spiders, in the *Sphagnum* fen I found higher numbers of ants (family Formicidae) and Pselaphinae beetles (family Staphylinidae) causing overall arthropod abundances to be higher. A difference in the occurrence and abundance of these two taxonomic groups is likely related to differences in water table and soil moisture. Ant reproduction is reliant on thermoregulation (Hölldobler and Wilson 1990) and the availability of dry hummock habitat at the *Sphagnum* fen may be important for peatland ants. In a study similar to this one, higher ant abundances were found in a more sheltered peatland than an open one (Lesica and Kannowski 1998). *Sphagnum* bog inhabiting pselaphine beetles (Family Staphylinidae) have a significant preference for high humidity conditions (95%) (Reichle 1966) and are predators of other smaller arthropods such as Collembola (Schomann *et al.* 2008). The fact that they were found exclusively at the *Sphagnum* fen matches previous studies that found them in forested (Hammond *et al.* 2018b) and bog-like environments (Reichle 1966), suggesting that perhaps that they are less resistant to flooding events, or their preferred food source was less available at the *Carex* fen.

I found the *Carex* fen had higher abundances of holometabolous larvae in the peat sampling, and overall higher abundances of holometabolous insect adults in the emergence traps at the *Carex* fen, whereas only seven larvae were collected in total from the *Sphagnum* fen peat samples. Differences in larval numbers in peat soils between the two sites is likely related the *Sphagnum* fen's lower water table. Peat samples were taken from the top 5-10 cm of peat at both sites, which could be up to 10 cm above the water table at the *Sphagnum* site but at the same level as the water table at the *Carex* site. For moisture-dependent dipteran larvae (without the moisture retaining protection of a cocoon or sediment, chironomid larvae cannot survive longer than 2 hours in dry conditions (Suemoto *et al.* 2004)), the surface peat at the *Sphagnum* site was potentially too dry, and lower peat profiles may have been the optimal habitat in the peat strata

(Jackson and Mclachlan 1991). It is possible that many groups and individuals were present (but not sampled) in deeper peat soil layers, which would explain the abundances collected by the emergence traps in the *Sphagnum* fen. Finally, the beta-diversity (i.e., dissimilarity between *Carex* and *Sphagnum* sites) of the emergent arthropods increased over the growing season alongside the greater seasonal abundance shifts observed at the *Carex* fen compared to the *Sphagnum* fen site. Specifically, lower overall abundances in August at both sites led to *Sphagnum* and *Carex* fen community composition being highly dissimilar in overall community composition with non-overlapping occurrences in some of the less common species (e.g., *Pseudorthocladius* cf. *curtistylus*, Ceratopogonidae nr *Dasyhelea* sp. 1 and 2) thereby increasing the beta-diversity between the two sites.

4.5 Seasonal trends in peatland arthropods

Seasonal patterns in overall richness and abundance differed between the two peatland sites with the highest average sampling richness in the emergence traps occurring in June at the *Carex* fen, with little changes in average sampling richness in the *Sphagnum* fen over the growing season. Similarly, although both sites demonstrated decreasing average sampling abundances over the summer, the *Sphagnum* fen showed a non-significant decline over the season, whereas the *Carex* fen showed a much more dramatic change in abundances. This difference was driven by reductions in the abundances of some of the prominent nematoceran (family Chironomidae and Ceratopogonidae) morphospecies that had high average sampling abundance in the *Carex* site in June; abundances of these groups were much more similar in the later growing season months. Rosenberg *et al.* (1998) over three years of collection similarly found that mean weekly emerging Chironomidae populations had their highest abundances in late May to early June, then decreasing toward zero between mid-August and mid-September. Judd (1953) found 87% of >15,000 emergent arthropods in a marsh habitat near Hamilton, Ontario were dipterans, and that 92.5% of these belonged to the Chironomidae. In that study, Judd (1953) also found that Chironomidae were highly variable in terms of seasonal species richness (0-80 species) and abundances (0-409 individuals) and in contrast to the early season peaks in Rosenberg *et al.* (1998), Judd (1953) found certain species had their peak emergence later in the growing season, which may reflect the new presence of Chironomidae sp. 5 from the *Sphagnum* fen in August.

Pitfall traps work by capturing arthropods that are running across the surface of the substrate, so the abundance of organisms in pitfall traps indicate periods when these organisms are active as well as abundance. For lycosid spiders, there are different peaks in activity during the season (Buddle 2000; Edgar 1971). Adult lycosids can be more active than juveniles and as they can live for multiple years their periods of high activity can vary by life stage and sex (Edgar 1971). For *P. moesta* in central Alberta the peak periods of activity are mid-May and early June (Buddle 2000), which fits well with my results of highest abundances of overall pitfall trap catch during my June sampling period.

Other surface-dwelling arthropod groups are also most active and found in highest abundance early in the season, including carabid beetles in forests in central Alberta (Niemelä *et al.* 1993) and staphylinid beetles in cereal fields in Czechia (Honěk 1988). Conditions affecting food resources can greatly impact predatory ground dwellers such as spiders, which is potentially reflected by the correlation of spider abundances with that of the emergent insects in this study. However, ants (22% of my pitfall catch) can be less reactive to season and abundance of food resources (Hölldobler and Wilson 1990) likely because of their colonial nature. Ant activity tends to correlate more with temperature, with peak activities around 20°C but foraging still able to occur at as low as 6°C as shown in a Finnish forest (Rosengren *et al.* 1979).

4.6 Environmental factors affecting peatland arthropod diversity

Differences in arthropod communities between the two peatland sites as well as changes in community composition over the growing season may be related to differences and shifts in environmental conditions. Specifically, moisture and temperature were variables that I related to my dominant emergent arthropod species; however, these variables cannot be disentangled from inherent seasonal patterns related to life history and autecological traits of the fauna. At both sites, the highest abundances of holometabolous larvae were found in peat samples which had moisture content between 600-800% gravimetric moisture. The distribution of larvae within peat and other soils is non-uniform. For example, Ryan and Hilchie (1981) extracted thousands of dipteran larvae individuals from peat via funnel extractions, but 30% of samples contained no individuals. This clumped distribution of larvae, that I also observed, may be related to optimal moisture conditions (Frouz 1999; Jackson and Mclaughlin 1991), or concentrated pockets of nutrients (Frouz 1999; Seastedt and Crossley Jr. 1980) that may dictate localized egg laying events (Reichle 1966). I observed higher larval abundances and the greatest number of emergent arthropods in the *Carex* fen in June when this site is often fully saturated, and the water table is at the soil surface (pers. comm. OMNRF), but the *Carex* fen experienced a dramatic decrease in soil moisture from June to July of 2018. For instance, I observed that during the first two days of sampling in June the water table was at or above ground level, but by the end of the sampling week (day 4-5) the water table was below ground level. The remaining summer was particularly dry with precipitation events only occurring for a total of 39 days and 232.9 mm at the *Carex* fen and 45 days and 193.7 mm at the *Sphagnum* fen, the lowest precipitation at either fen during June-August since 2016 (pers. comm. OMNRF). This particular site has historically shown extreme variations in water table; in 2005 the water table levels never exceeded ground level, whereas in 2004 they were at or above ground level throughout most of the growing season (McLaughlin and Webster 2010). This is in contrast to the *Sphagnum* fen, which showed no significant decrease in moisture levels and a lack of observable changes in water table during the study.

Temperature is also an important factor dictating arthropod diversity and distribution in the boreal zone (Hammond *et al.* 2018a; Loboda and Buddle 2018). Daily minimum temperatures were lowest earlier in the season (i.e., June) when nighttime temperatures sometimes dipped below freezing, compared August which had the warmest minimum temperatures. Additionally, daily maximum temperatures were higher in June and July than in August, leaving average daily temperature similar throughout the season. Temperature affects the physiological functioning and activity of emergent arthropods, since arthropods are ectotherms and there are high and low threshold temperatures that limit their ability to move (Sinclair *et al.* 2016). In arctic chironomids, higher minimum and mean temperatures allow these insects to be active and were thus found to be the main predictors of abundance (Hodkinson *et al.* 1996), as minimum temperature was in with emergent arthropods my study. However, it is possible that minimum temperature simply correlated with other seasonal factors such as changes in light (photoperiod).

Soil moisture and air temperature are not independent factors, and both are linked to general seasonal trends that are hard to disentangle from phenological trends in arthropod life histories. Insect development overall is altered by the temperature, with insects needing to spend a certain amount of time between their upper and lower temperature threshold, measured in degree-days (Wilson and Barnett 1983), with development time often taking longer at lower temperatures (Tobin *et al.* 2001). Similarly, Robinson *et al.* (2018) found that terrestrial invertebrate abundances significantly increase with warmer temperature, and Saska *et al.* (2013) found that pitfall trap-caught carabid abundances doubled with every 8°C increase in maximum temperature or 14°C increase in minimum temperature. Høye and Forchhammer (2008) performed a large-scale study of the phenology of high arctic species which dealt with many taxa collected in this study (e.g., Lycosidae, Chironomidae, Sciaridae) and other groups known from my peatland sites (i.e., Acari and Collembola). They showed that timing of snowmelt was important and may be more important than temperature for arthropod phenology (Høye and Forchhammer 2008), and that each taxon likely has an optimal period of activity during the year that, at least in high Arctic species, is strongly modified by timing of snowmelt (Høye and Forchhammer 2008).

Soil moisture was the variable that differed considerably between my two sites, and is known to significantly influence arthropod communities (Ziesche and Roth 2008). I found that moisture levels closely mirrored the abundance of some groups such as the ceratopogonids, and moisture was identified as a significant correlate in my backwards stepwise multiple regression, linking the emergent arthropod community with this environmental factor. The most abundant morphospecies in this group (Cecidomyiidae nr Cecidomyiinae sp. 1) was separated out in my PCA, and reached peak abundances in July rather than June, potentially being dependent on factors such as the phenology of a host plant, separating them from the other abundant Diptera. Some of the Hymenoptera that I collected also likely have a similar life history (gall wasps) as plant parasites (Finnamore 1994), however due to low abundances of most morphospecies and taxonomic impediments with this group it is challenging to draw further conclusions. The *Sphagnum* fen, unlike the *Carex* fen, also has many trees, such as tamarack (*Larix larcinia*) and black spruce (*Picea mariana*), which provide both direct shade over the understory vegetation, and a windbreak. Additionally, the presence of *Sphagnum* mosses could provide stability of environmental conditions by retaining soil moisture during dry conditions and provide a consistent humidity (Gerson 1969) and soil temperature (Longton 1979). Peatlands that are not sheltered and lack trees (such as is the case at the *Carex* fen) are more inclined to greater fluctuations in environmental conditions such as temperature (Spitzer and Danks 2006), although significant differences in my measures of temperature were more related to season than site.

Similarly, differences in the microtopography of the two sites may also play a role in patterns of peatland arthropod diversity with greater environmental heterogeneity created by the *Sphagnum* fen's more varied microtopography creating a series of stable but unique niches in the dryer hummock tops and the more moist hollows, despite fluctuations in the water table (Spitzer and Danks 2006). The meso and microclimates at this level are found to be constant in bog systems, and the high diversity of plant habitats as well for plant parasitoids provides additional niches (Spitzer and Danks 2006).

4.7 Caveats, challenges and limitations

This study is not an exhaustive survey of boreal peatland arthropods; rather it forms a basis for further study by demonstrating that Diptera and Araneae are the dominant taxonomic groups in emergence and pitfall traps respectively, and potentially reflect the true peatland arthropod inhabitants. Although I used parametric statistics to compare similar sampling schemes at my two peatland sites, I cannot draw inference of differences between other *Sphagnum* and *Carex* dominated peatlands. Differences in dominant vegetation alongside known differences in water table and nutrient status between these two sites did not hold much explanatory power in explaining why these two sites had generally different arthropod composition, suggesting that additional environmental factors need to be considered in future work.

Several taxonomic groups were not fully explored due to taxonomic challenges, particularly the dominant nematocerous flies, which include the families Chironomidae and Ceratopogonidae. Both groups are highly diverse with 263 species of Ceratopogonidae, and 798 species of Chironomidae described from Canada (Savage *et al.* 2019). Taxonomic challenges beyond the high diversity include the necessity of observing (and therefore slide mounting) genitalia (McAlpine 1981; Brown *et al.* 2009), while for emergent adult Ceratopogonidae, as well as the Sciaridae (129 species described from Canada) (Savage *et al*. 2019), there is high sexual high dimorphism, as well as a lack of distinguishing features for males as opposed to females for ceratopogonids. Due to the inability to correlate male and female morphs, I chose to list the two sexes separately, but acknowledge that the members of two sexual morphospecies could belong to the same species.

Female chironomids are an extremely challenging group to identify since they often do not key out in family level keys, often cannot be identified to species (Rosenberg *et al.* 1988), and often only the adult males of a species are described (Ren *et al.* 2014) or included in species level keys (Langton and Pinder 2007). Even when females are described, they still may not be identifiable based on morphology, and even molecular studies face challenges in identifying females to a specific species with barcoding techniques because their sequences do not match known species of chironomids based on male morphotypes (Ekrem *et al.* 2010). I collected over 700 female chironomid individuals, with just under one third of the most prominent morph being males, a sex ratio imbalance which has been seen in other chironomid studies (Ekrem *et al.* 2010, Lindeberg 1971). It is known however that some species of chironomids can be parthenogenetic, but as Ekrem *et al.* (2010) acknowledge, these groups may only be facultative parthenogenetic. The most studied parthenogenic species of Chironomidae discussed in the literature are members of tribe Tanytarsini within the subfamily Chironominae (Lindeberg, 1971; Langton 1998), but Rosenberg *et al.* (1988) posit that several species which they collected are also likely parthenogenic.

Larvae in particular are difficult to identify to species, or even genus or higher level taxonomic categories. There are few good keys for Diptera larvae (see McAlpine *et al.* 1981), but many of the described larval forms are not the ones I found. The high number of singletons in much of my sampling, especially in the peat sampling, suggests that a greater sampling effort is required to reveal the true diversity at each peatland site, in particular for the dominant Diptera groups. Specifically, in order to better sample nematoceran larvae I would recommend sampling a larger volume of peat and/or performing a wet extraction, such as with a water bath (McElligott and Lewis 1994), or using an O'Connor funnel (Ryan and Hilchie 1981; O'Connor 1962), in order to more effectively characterize the diversity of this community. This would be especially important in the *Sphagnum* site where low abundances and high singletons of chironomid and ceratopogonid larvae are likely found deeper in the peat profile.

By comparison, in sampling of ground-dwelling spiders, although I obtained low abundance and biomass, I was able to identify many taxa to the genus or even species level. However, to obtain more quantifiable biomass estimates would require more extensive and continuous sampling over the growing season. As previously mentioned, spiders are often used as bioindicators of disturbance in boreal forest systems, whether peatland spiders can be used in a similar manner, for instance as indicators of food resources, climate changes, or other disturbances is unknown. Several spider groups have been estimated to be specialists of Canadian peatlands (Spitzer and Danks 2006; Dondale and Redner 1994).

4.8 Conclusions and significance

Boreal systems, and particularly boreal peatlands, are vulnerable to shifting climate under climate warming scenarios (IPCC 2014). Changes in vegetation and soil moisture alongside warming and shifts in precipitation are predicted that could have cascading effects on peatland arthropod diversity. For instance, changes in tree species distribution in the Boreal have occurred and are forecasted to continue occurring due to climate warming (NRCan 2019), specifically increasing deciduous cover. In peatlands, warming scenarios have shown that *Sphagnum* moss cover will likely decrease whereas vascular plant cover (including sedges and ericaceous shrubs) will likely increase (Buttler *et al.* 2015; Dieleman *et al.* 2015; Fenner *et al.* 2007; Jassey *et al.* 2013). Higher latitudes (such as the location of my study sites) are forecast to get increased precipitation and heat waves are expected to be more frequent, as average global temperatures are expected to increase by up to 4°C (IPCC 2014). Soil moisture levels are key to larval development of the groups which dominate peatlands (Frouz 1999) as well as being linked to temperature (Frouz 1999) and vegetation communities (De Bruyn *et al.* 2001).

In this study, I demonstrate that the ‘true’ peatland arthropods are predominantly members of the order Diptera, many of which live in the peat, and the order Araneae, which hunt on its surface. Both these groups therefore play an important role in above-ground (terrestrial) food webs and energy, nutrient, and other elemental transfer (e.g., Hg) to other organisms. This study provides some information about soil-dwelling larvae in peatlands, which are generally poorly known (McAlpine *et al.* 1981; Wrubleski 1987), and the emergent arthropods that are important food resources for above-ground animals. For example, shorebirds (Holmes and Pitelka 1968, Skagen 1997, Pedro and Ramos 2009) and songbirds (Orians 1966, Busby and Sealy 1978) feed on chironomids, with chironomids making up more than half of prey consumed by yellow warblers along a Manitoban ridge (Busby and Sealy 1978). Both wider scale climate factors (i.e., general increases in temperature) and increases in the number of degree days have been shown to determine the timing and abundance of emergence of chironomids in the high Arctic (Hodkinson *et al.* 1996). Specifically, the average and minimum daily temperatures were found to be the most influential factors in determining emergence timing and abundance in a high Arctic tundra heath with warmer years altering the seasonal patterns of emergence (Hodkinson *et al.* 1996), suggesting that under climate change the emergence patterns of dominant peatland arthropods will be affected. This could lead to ecological mismatches, where organism activity and availability of key resources are misaligned under changes to climate (Høye and Forchhammer 2008; Senner *et al.* 2017). As for the ground-dwelling spider communities, there may be compounding factors affecting their abundance and diversity under climate change. They are prone to changes in environmental conditions themselves, while also potentially relying on the insects, including emergent insects, as a food source. For instance, Høye *et al.* (2009) found that snowmelt timing significantly affected spider size, where earlier snowmelt may have allowed spiders more time to develop and grow. This effect was seen differentially between the two sexes (Høye and Hammel 2010), and they suggested that changes in climate could especially affect spiders at high altitudes. In wetlands in China, wolf spiders in the genus *Pardosa* have been shown to feed on insects in the family Chironomidae (Zhong *et al.* 2019). This suggests that any potential shifts in emergent arthropods might cascade.

There are over 113 million ha of peatlands in Canada (Tarnocai *et al.* 2011). It is essential to gain baseline knowledge of peatland species diversity, and particularly the organisms that are specific to the peat environment. Species diversity is known to underpin the maintenance of ecological functioning (the biodiversity-ecosystem function relationship), which is especially important in the face of environmental fluctuations (Loreau 2000). Biodiversity is declining globally (Baronosky *et al.* 2011; Hallmann *et al.* 2017), and mostly at small scales due to anthropogenic causes such as climate warming (Thomas *et al.* 2004), but also habitat loss and fragmentation (Sala *et al.* 2000). Therefore, for peatlands, ecosystems that are prone to both climate change and habitat loss, knowledge of arthropod diversity is of critical importance.

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Appendices

Appendix A: List of morphotypes identified to family level where possible, and the number of individuals collected using emergence traps from a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario in 2018. Species followed by an asterisk (*) were used in the Principal Component Analysis (PCA).

		***Carex* Fen**			***Sphagnum* Fen**		
Taxon	**Species**	**June**	**July**	**August**	**June**	**July**	**August**
Class Insecta							
Order Diptera							
Nematocerous Flies							
Family Cecidomyiidae							
	Cecidomyiidae sp. 1	0	0	0	0	1	0
	Cecidomyiidae sp. 2	0	0	0	0	1	0
	Cecidomyiidae sp. 3	0	1	0	0	1	2
	Cecidomyiidae nr Cecidomyiinae sp. 4*	1	8	2	2	14	1
	Cecidomyiidae sp. 5	0	2	0	0	1	6
	Cecidomyiidae sp. 6	0	0	1	0	0	0
	Cecidomyiidae sp. 7	0	0	0	0	1	0
	Cecidomyiidae sp. 8	0	0	0	0	1	1
	Cecidomyiidae sp. 9	0	0	0	0	1	0
	Cecidomyiidae sp. 10	0	4	0	0	0	0
	Cecidomyiidae sp. 11	0	1	1	0	0	0
	Cecidomyiidae sp. 12	0	0	0	0	0	1
	Cecidomyiidae sp. 13	0	1	0	0	0	0
	Cecidomyiidae sp. 14	0	0	0	0	1	0
	Cecidomyiidae sp. 15	0	1	0	0	0	0
Family Ceratopogonidae							
	Forcipomyia sp. 1 (female)	3	2	0	1	3	2
	Palpomyia sp. 1 (female)	13	0	0	4	0	0
	Ceratopogonidae nr. *Dasyhelea* sp. 1 * (female)	51	5	1	3	2	0
	Ceratopogonidae nr. *Dasyhelea* sp. 2* (male)	52	0	0	12	1	0

Ceratopogonidae nr. *Dasyhelea* sp. 3 (female)	0	0	0	20	0	0
Ceratopogonidae sp. 1 (male)	0	1	0	0	0	0
Ceratopogonidae sp. 2 male	1	0	0	0	0	0
Family Chironomidae						
Micropsectra sp. 1 (male)	1	0	0	5	0	0
Procladius sp. 1 (male)	0	0	0	0	1	0
Pseudorthocladius cf *curtistylus* *	350	321	20	104	82	16
Rheotanytarsus sp. 1 (male)	0	0	0	0	0	4
Tanypodinae nr *Zavrelimyia* sp. 1*	37	0	0	1	0	0
Chironomidae sp. 1	1	0	0	0	0	1
Chironomidae sp. 2 (male)	0	0	0	2	0	0
Chironomidae sp. 3 (male)	1	0	0	1	0	0
Chironomidae sp. 4 (female)	0	0	0	8	0	0
Chironomidae sp. 5 (female)	0	0	0	0	0	18
Chironomidae sp. 6 (female)	0	3	0	0	0	1
Chironomidae sp. 7 (female)	0	0	0	0	1	0
Chironomidae sp. 8 (female)	0	0	0	0	0	2
Chironomidae sp. 9 (female)	0	1	0	0	0	0
Family Mycetophilidae						
Mycetophilidae sp. 1	1	0	3	0	0	1
Family Sciaridae						
Chaetosciara sp. 1* (female)	3	1	13	6	0	19
Sciaridae sp. 1 (male)	0	4	0	0	0	0
Sciaridae sp. 2 (male)	0	0	1	0	0	0
Sciaridae sp. 1 (female)	0	1	0	0	0	3
Family Tipulidae						
Tipulidae sp. 1	0	1	0	0	0	0

Tipulidae sp. 2	0	0	0	0	0	1
Tipulidae sp. 3	0	0	0	0	1	0
Tipulidae sp. 4	0	0	1	0	0	0
Tipulidae sp. 5	0	4	7	0	0	0
Tipulidae sp. 6	0	1	0	0	0	0
Tipulidae sp. 7	0	1	0	0	0	0
Family Unknown						
Nematocera sp. 1	0	1	0	0	1	0
Nematocera sp. 2	0	0	0	0	1	0
Nematocera sp. 3	0	4	0	0	0	0
Nematocera sp. 4	0	0	0	0	0	1
Nematocera sp. 5	0	0	0	2	0	0
Suborder Brachycera						
Brachycera (remaining 35 morphs)	30	20	4	8	22	4
Family Phoridae						
Phoridae sp. 1*	4	3	8	7	1	12
Order Lepidoptera						
Family Unknown						
(11 morphs)	2	11	0	2	4	0
Order Trichoptera						
Family Unknown						
(2 morphs)	0	2	0	0	0	0
Order Hymenoptera						
Family Unknown						
(52 morphs)	19	22	14	14	27	16
Order Coleoptera						
Family Unknown						
(6 morphs)	3	0	1	2	0	0
			Bycatch**			
Order Diptera						
Family Culicidae	0	1	0	0	3	0
Family Simuliidae	7	0	0	59	3	1
Partial Nematocera	92	16	0	44	4	2
Partial Cecidomyiidae	0	0	0	1	3	2
Partial Chironomidae	13	3	3	0	1	0
Partial Brachycera	0	0	0	1	0	1
Partial Diptera	1	0	0	2	1	0
Order Psocoptera	0	0	0	0	2	1
Order Hemiptera	4	24	19	1	13	7
Order Ephemeroptera	0	0	0	1	0	0

Order Hymenoptera						
Family Vespidae	0	0	0	1	0	0
Family Formicidae	0	1	0	0	0	0
Order Lepidoptera	0	0	1	1	0	0
Partial Insect	5	1	1	0	2	0
Order Collembola	0	0	1	0	0	1
Class Arachnida						
Order Araneae	9	6	10	5	5	4
Order Opiliones	0	0	0	0	1	0
Subclass Acari	2	0	1	1	2	0
Class Gastropoda	0	0	1	0	0	0

**Bycatch are organisms considered aberrant or accidental to the trapping method. For emergence traps this included non-holometabolous adult insects, eusocial insects (Vespidae, Formicidae), aquatic insects (i.e., live in open water as larvae e.g., Culicidae, Simuliidae), and non-insect arthropods or other groups.

Appendix B: List of morphotypes identified to family level where possible, and the number of individuals collected from peat samples taken from a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario in 2018.

		***Carex* Fen**			***Sphagnum* Fen**		
Taxon	**Species**	**June**	**July**	**August**	**June**	**July**	**August**
Order Diptera							
Nematocerous Flies							
Family Ceratopogonidae							
	Ceratopogonidae sp. 1	3	5	5	1	1	0
	Ceratopogonidae sp. 2	1	0	0	0	0	0
	Ceratopogonidae sp. 3	0	1	0	0	0	0
Family Chironomidae							
	Apsectrotanypus sp.	1	1	1	0	0	0
	Corynoneura sp.	1	0	2	0	0	0
	Pseudorthocladius sp.	2	4	6	0	0	0
	Chironomidae early instars	0	5	5	0	0	0
Family Tipulidae							
	Tipulidae sp. 1	2	0	0	0	0	0
	Tipulidae sp. 2	1	0	0	0	0	0
	Tipulidae sp. 3	1	0	0	0	0	0
	Tipulidae sp. 4	1	0	0	0	0	0
Family Unknown							
	Nematocera sp. 1	0	1	0	0	0	0
	Nematocera sp. 2	1	0	0	0	0	0
	Nematocera sp. 3	0	0	0	0	1	0
	Nematocera sp. 4	0	1	0	0	0	0
Suborder Brachycera							
	Brachycera sp. 1	0	1	0	0	0	0
	Brachycera sp. 2	0	1	0	0	0	0
	Brachycera sp. 3	0	0	0	0	1	0
	Brachycera sp. 4	0	0	1	0	0	0
Order Coleoptera							
	Coleoptera sp. 1	1	0	0	0	0	0
	Coleoptera sp. 2	0	0	0	1	0	0
	Coleoptera sp. 3	0	1	0	0	0	0
	Coleoptera sp. 4	0	0	0	0	1	0
Order Lepidoptera							
	Lepidoptera sp. 1	0	0	0	0	0	1

	Lepidoptera sp. 2	0	0	0	0	0	1
Order Unknown							
	Holometabolous larva sp. 1	1	0	0	0	0	0
	Holometabolous larva sp. 2	0	0	0	1	0	0

**Bycatch were mostly collected as singletons and included Enchytraeidae, Cladocera, Tardigrada, Collembola, Acari, Araneae, Formicidae, and Hemiptera.

Appendix C: List of morphotypes identified to family or genus level where possible, and the number of individuals collected using pitfall traps at a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario in 2018. Species followed by an asterisk (*) were used in Principal Components Analysis (PCA), and individuals which could not be morphotyped to species were excluded from analyses (**).

	***Carex* Fen**			***Sphagnum* Fen**		
Taxon Species	**June**	**July**	**August**	**June**	**July**	**August**
Order Opiliones	0	0	0	0	1	0
Order Araneae						
Family Lycosidae						
Alopecosa aculeata	0	0	0	4	0	0
*Arctosa raptor**	12	0	0	2	0	0
Pardosa fuscula	2	0	0	0	0	0
Pardosa hyperborea	0	0	0	7	1	0
*Pardosa moesta**	22	13	4	9	0	0
Pardosa uintana	1	0	0	0	0	0
Lycosidae sp. 1 (female)	0	0	0	0	1	0
Lycosidae sp. 2 (female)	0	0	0	2	0	0
Lycosidae juveniles**	1	0	0	6	4	3
Lycosidae subadults (female)**	1	1	1	0	0	0
Lycosidae subadults (male)**	0	0	0	0	0	1
Partial specimen**	0	3	0	1	0	0
Family Pisauridae						
Dolomedes striatus	3	0	0	0	0	0
Family Salticidae						
Salticidae sp. 1	0	0	0	1	0	0
Salticidae sp. 2	0	1	0	0	0	0
Family Thomisidae						
Xysticus sp. 1	0	0	0	1	0	0
Family Gnaphosidae						
Gnaphosidae sp. 1	0	0	0	2	0	0
Gnaphosa sp. 2	0	0	0	0	1	0
Family Philodromidae						
Philodromidae sp. 1	1	0	0	0	0	0
Family Unknown						
Araneae sp. 1*	1	2	3	1	3	2
Other Families (3 morphs)	0	1	0	1	3	0
Order Orthoptera						
Family Acrididae	0	0	1	0	2	1
Family Gryllidae	0	0	0	0	1	0

Family Tettigoniidae	0	0	0	0	1	0
Order Coleopera						
Family Staphylinidae						
Subfamily Paederinae	0	0	0	0	0	1
Subfamily Pselaphinae*	0	0	0	8	3	7
Suborder Curculionoidea	0	0	0	1	0	0
Family Chrysomelidae	0	0	0	1	0	0
Family Lycidae	0	0	0	2	0	0
Order Hymenoptera						
Family Formicidae						
Formicidae sp. 1*	4	3	0	6	4	8
Formicidae sp. 2*	1	3	0	8	4	0
Family Unknown						
Hymenoptera sp. 1	0	2	3	0	1	2
Bycatch						
Class Gastropoda	2	0	0	1	2	4
Subclass Acari	1	3	2	0	7	2
Order Collembola	0	17	7	5	4	18
Class Ectognatha (Partial specimens)	1	0	0	2	3	0
Order Hemiptera (3 morphs)	1	1	0	1	3	0
Order Hymenoptera (5 morphs)	3	1	2	2	5	2
Order Diptera						
Partial specimens	5	0	0	1	0	2
Nematocerous flies	0	4	0	3	4	3
Family Chironomidae	0	0	0	7	5	6
Family Mycetophilidae	0	0	0	1	0	0
Family Simuliidae	4	0	0	3	0	0
Family Sciaridae	0	2	0	0	0	0
Family Culicidae	0	2	0	0	0	0
Family Cecidomyiidae	0	0	0	0	0	2
Suborder Brachycera	3	2	5	4	1	0
Order Siphonaptera	0	0	0	0	0	1
Order Coleoptera (unknown larva)	0	1	0	0	0	0

Appendix D: Plant species and their relative abundance collected using point intercept measures at the locations of emergence trap plots from a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario in 2018.

		***Carex* Fen**			***Sphagnum* Fen**		
Latin binomial	**Common name**	**June**	**July**	**August**	**June**	**July**	**August**
Trees							
Larix laricina	tamarack	0	0	0	0	4	0
Picea mariana	black spruce	0	0	0	2	2	1
Alnus incana	speckled alder	0	0	0	0	1	0
Shrubs							
Andromeda polifolia	bog-rosemary	17	19	8	8	17	21
Chamaedaphne calyculata	leatherleaf	15	64	40	108	75	103
Gaultheria hispidula	creeping snowberry	1	0	0	59	47	33
Kalmia polifolia	bog laurel	0	0	0	26	12	37
Myrica gale	bog-myrtle	22	42	41	0	0	2
Rhododendron groenlandicum	Labrador tea	0	0	0	44	67	46
Salix pedicellaris	bog willow	9	2	5	0	0	0
Vaccinium angustifolium	lowbush blueberry	0	0	0	56	58	58
Vaccinium myrtilloides	common blueberry	0	0	0	0	1	2
Vaccinium oxycoccos	bog cranberry	0	10	0	25	59	78
Herbs							
Drosera rotundifolia	round-leaved sundew	0	0	0	1	7	2
Geocaulon lividum	northern comandra	0	0	0	9	15	1
Maianthemum trifolium	three-leaf false lily of the valley	0	0	0	46	43	22
Comarum palustre	marsh cinquefoil	0	3	1	0	0	0
Triadenum fraseri	Fraser's marsh St. Johnswort	2	2	6	0	0	0
Viola palustris	marsh violet	12	12	9	0	0	0
Fragaria virginiana	wild strawberry	1	2	0	0	0	0

Lycopodium annotinum	stiff clubmoss	0	0	0	36	45	8
Sedges							
Calamagrostis canadensis	Canada bluejoint grass	7	4	4	0	0	0
Carex disperma	soft leaf	0	0	0	20	54	0
Carex lasiocarpa/Carex oligosperma	woolly fruit sedge/ few seed sedge	223	184	159	0	0	0
Carex pauciflora	few-flowered sedge	0	0	0	0	1	1
Carex stricta	tussock sedge	20	45	49	0	0	0
Mosses							
Pleurozium schreberi	red-stemmed feathermoss	0	0	0	102	22	30
Bryophyta sp. 1	terrestrial moss	0	0	0	3	0	0
Sphagnum angustifolium	fine bog moss	148	99	159	187	107	209
Sphagnum fuscum	rusty bog moss	0	0	0	70	235	40
Sphagnum girgensohnii	Girgensohn's bog moss	0	0	0	6	37	21
Sphagnum magellanicum	magellanic bog moss	0	0	0	52	22	176
Bare Soil/ Woody Debris/ Dead Vegetation	non-detects	23	12	19	136	89	44

Appendix E: Plant species richness, Shannon’s and Simpson’s diversity indices, and Leaf Area Index (LAI) for vegetation surveys performed using point intercept measures at the locations of emergence trap plots from a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario over the 2018 growing season.

Month	Site	Standardized Richness (sp/m^2)	Shannon's Diversity	Simpson's Diversity	LAI
June	*Carex* fen	8.00 ± 0.3^b	1.44 ± 0.1^b	3.00 ± 0.2^{cd}	0.57 ± 0.2
	Sphagnum fen	14.00 ± 0.4^a	2.32 ± 0.0^a	8.16 ± 0.4^{ab}	0.59 ± 0.1
July	*Carex* fen	7.40 ± 0.7^b	1.64 ± 0.1^b	4.33 ± 0.6^{bcd}	0.86 ± 0.1
	Sphagnum fen	13.20 ± 0.2^a	2.22 ± 0.0^a	6.86 ± 0.5^{abc}	0.66 ± 0.2
August	*Carex* fen	7.40 ± 0.7^b	1.59 ± 0.1^b	3.90 ± 0.5^{cd}	0.97 ± 0.1
	Sphagnum fen	12.80 ± 0.6^a	2.17 ± 0.1^a	6.50 ± 0.8^{abc}	0.56 ± 0.2

Diversity indices were calculated using the vegan package in R on standardized plant species abundances. Values are means, errors are standard error; different letters denote significantly groups based on a RM-ANOVA and Tukey’s post hoc test run in Statistica.

Appendix F: Characteristics used for identification purposes for the main target arthropod taxa and morphospecies collected from a *Carex*-dominated fen and a *Sphagnum*-dominated fen near White River, Ontario in 2018. The letters p.o. denote a personal observation.

Taxon	**Characteristics**	**Reference Literature**
Hymenoptera and Diptera	Winged adults: wing shape; wing venation; wing setae placement and density.	Marshall 2006; McAlpine *et al.* 1981
	Antennal length and morphology.	Marshall 2006; McAlpine *et al.* 1981
	Body length (used in combination with other traits) p.o.	
	Colour (used in combination with other traits) p.o.	
Nematocerous Flies	Antennae with four or more antennal flagellomeres and no stylus or arista; palps three to five segments long.	McAlpine *et al.* 1981
Family Cecidomyiidae	Wing venation; tarsomere morphology; ocelli; antennal morphology.	McAlpine *et al.* 1981
Family Ceratopogonidae	Adults: wing venation; anterior thoracic spiracle; postnotal groove; mouthparts (females); antennal morphology (males) p.o. Larvae: complete and sclerotized head capsule; smooth bodied with terminal abdominal setae; apneustic respiratory system.	McAlpine *et al.* 1981
Family Chironomidae	Adults: wing venation; anterior thoracic spiracle; mouthparts; genitalia. Larvae: complete and sclerotized head capsule; one or two unjointed parapods and some anal setae; apneustic respiratory system.	Langton and Pinder 2007; McAlpine *et al.* 1981; Oliver and Roussel 1983
Family Mycetophilidae	Wing venation; tibial spurs p.o.; costa p.o.	McAlpine *et al.* 1981
Family Sciaridae	Wing venation; strongly sclerotized wing veins p.o.; ocelli present; mesothoracic pleural sclerites.	McAlpine *et al.* 1981
Family Tipulidae	Adults: wing venation; dorsal thorax v suture. Larvae: head capsule reduced to rods; metapneustic respiratory system.	McAlpine *et al.* 1981
Suborder Brachycera	Antennal flagellum in a single segment often with arista or stylus; palp with two segments or less.	McAlpine *et al.* 1981
Family Phoridae	Wing venation; humpbacked appearance of thorax; large triangular palps p.o.	McAlpine *et al.* 1981
Order Araneae	All groups collected had eight eyes and lacked a cribellum.	Ubick *et al.* 2017
Family Lycosidae	Three rows of eyes; genitalia.	Ubick *et al.* 2017; Dondale and Redner 1990

Family Pisauridae	Eye arrangement; genitalia.	Ubick *et al.* 2017; Dondale and Redner 1990
Family Salticidae	Eye arrangement; legs prograde.	Ubick *et al.* 2017
Family Thomisidae	Eye arrangement; chelicerae lack teeth; anterior legs larger.	Ubick *et al.* 2017
Family Gnaphosidae	Eye arrangement; chelicerae and tarsal claws with teeth; fewer and longer anterior lateral spinnerets; genitalia.	Ubick *et al.* 2017
Family Philodromidae	Eye arrangement; legs prograde; long and narrow carapace.	Ubick *et al.* 2017

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