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Article

Checklist of oribatid mites (Acari: Oribatida) from two contrasting boreal fens: an update on oribatid mites of Canadian peatlands

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Abstract

A checklist of the oribatid mite species from two boreal fens in Northern Ontario, Canada is presented. 174 peat soil samples, collected between 2015–2020, yielded a heterogeneous assemblage of 80 species, 57 genera and 33 families. Species richness and diversity were significantly higher in a *Sphagnum*-dominated fen (69 species) compared to a *Carex*-dominated fen (51 species), and although 40 species were found at both sites, overall composition was significantly different between the two sites. We also present an update to the seminal work of Behan-Pelletier and Bissett (1994) on Oribatida of Canadian peatlands with 45 new species records for peatlands. Records for the parthenogenetic families Brachychthoniidae Thor, 1934 and Suctobelbidae Jacot, 1938 were considerably expanded, but other families such as Punctoribatidae, Thor, 1937 remain poorly represented in Canadian peatlands. Taken together, species richness estimates range from 86–105 species based on our sampling and the number of undescribed species recorded suggests that the oribatid mite fauna still need further examination to encompass their actual biodiversity in peatlands. We report that the oribatid mite fauna of Canadian peatlands comprise 186 species that includes all published records as of February 2021 and species presented here.

Keywords: Canada, Acari, *Sphagnum*, *Carex*, NMDS, bog

Introduction

Oribatid mites (Acari: Oribatida) are commonly the dominant group of arthropods in terrestrial soils (Norton & Behan-Pelletier 2009) and are well represented in terms of diversity in wetlands such as peatlands (bogs and fens) (Belanger 1976; Behan-Pelletier & Bissett 1994; Lehmitz 2014; Lindo 2015; Barreto & Lindo 2018). Peatlands are defined as wetlands with organic soils over 40 cm deep, with high water table from precipitation (bogs) or precipitation and ground water connectivity (fens) (National Wetlands Working Group 1988). In Canada, peatlands cover ~13% (1,136,000 km²) of the landscape (Tarnocai *et al.* 2011) with the vast majority in the boreal and subarctic ecozones. Peatlands are important for carbon cycling (Harenda *et al.* 2018) since they store 1/3 of the world's terrestrial carbon (Bragazza *et al.* 2013), but only cover ~3% of the globe (Gorham 1991). In Canada it is estimated that they store 147 Gt carbon, or 59% of Canada's stored soil organic carbon (Tarnocai & Lacelle 1996). Oribatid mites are an important component of detrital food webs, being responsible for secondary decomposition of organic matter (McBrayer *et al.* 1997; Hubert 2001) and nutrient cycling (Crossley 1977) suggesting they play an important role in carbon transformation in high carbon-storage ecosystems like peatlands.

Despite their importance, peatlands and other wetland systems are understudied with respect to oribatid mite fauna in Canada compared to other habitat types, and it has been more than 25 years since Behan-Pelletier and Bissett (1994) published data on the taxonomy and ecology of oribatid

mites of Canadian peatlands. In that study, the authors listed 71 species (49 genera and 34 families) across four categories of peatland habitats (aquatic, mesic, xeric, epigeal). They also noted that parthenogenetic species are better represented in peatlands than in the general ‘soil-dwelling’ oribatid mite fauna, which was also recently noted in Maraun *et al.* (2019).

Since that work, only a handful of studies have directly examined oribatid mites in Canadian peatland habitats (bogs and fens) (Behan-Pelletier 1997; Lindo 2015; Barreto & Lindo 2018; and Markkula & Kuhry 2020 for subfossil), described species from peatlands (Behan-Pelletier & Eamer 2003; Norton & Behan-Pelletier 2007; Behan-Pelletier & Walter 2013; Walter & Latonas 2013), or provided records from non-specific *Sphagnum* moss habitats (McAdams *et al.* 2018; Meehan *et al.* 2020). In the United States recent studies of oribatid mites in peatland and/or *Sphagnum* moss habitats only include Donaldson (1996), Norton and Behan-Pelletier (2007), and Walter and Latonas (2013). The work of Belanger (1976) is still the most comprehensive study documenting 44 species in a *Sphagnum*-dominated fen in New York State, of which 25 species had been previously recorded from European peatlands. In Europe, however, oribatid mites in peatlands have been and continue to be much more intensively studied (Borcard & Matthey 1995; Borcard & Vaucher-von Ballmoos 1997; Ivan *et al.* 1997; Laiho *et al.* 2001; Ivan & Călugăr 2003; Starý 2006; Sidorchuk 2008; Mumladze *et al.* 2013; Markkula 2014; Lehmitz 2014; Melekhina *et al.* 2015; Minor *et al.* 2016, 2019; Seniczak *et al.* 2016, 2019, 2020; Lehmitz & Maraun 2016; George *et al.* 2017; Markkula *et al.* 2019; Juan-Ovejero *et al.* 2019; Lehmitz *et al.* 2020). In addition, subfossil oribatid fauna from European peatlands are also thoroughly investigated (Karppinen *et al.* 1979; Cañellas-Boltà *et al.* 2012; Markkula 1986; Markkula 2020; Markkula *et al.* 2018).

The objectives of this work are to: 1) characterize the oribatid mite fauna in two boreal peatlands: a nutrient-poor fen dominated by *Sphagnum* spp. mosses, and an intermediate nutrient level fen dominated by *Carex* spp. sedges using samples collected over five years, and 2) update the checklist of oribatid mites of Canadian peatlands using the species found in our sites, and published work since 1994. The checklist of Behan-Pelletier and Bissett (1994) was derived primarily from Marshall *et al.* (1987) and Behan-Pelletier (1989), and examination of specimens housed in the Canadian National Collection of Insects, Arachnids and Nematodes sampled from peatland sites in the Canadian provinces of Ontario, Quebec, Alberta, New Brunswick, and Newfoundland. Our updated data is mainly derived from Behan-Pelletier and Lindo (2019), which includes Alberta Biodiversity Monitoring Institute data and other published literature, and the specimens collected from objective 1.

Material & Methods

Study area

Sampling was conducted in two fen sites near White River, Ontario, Canada (48.21°N, 85.21°W) in the southern Boreal ecozone. These sites integrate a large boreal peatland complex that has been extensively studied by the Ontario Ministry of Natural Resources and Forestry for the past 17 years. The two sites are approximately 2 km apart and experience a continental climate strongly influenced by the proximity of Lake Superior, with mean annual temperature of 2.1°C and precipitation of 980 mm (~40% as snow). Temperatures can reach –40°C in the winter (ave. January temperature –14.2°C) and rarely exceed 30°C in the summer (ave. July temperature 14.7°C); the growing season is 70–100 days (see Webster & McLaughlin (2010) for a full site description).

Although in the same area, the two fens differ in terms of nutrient status, water table depth and dominant vegetation. The *Sphagnum*-dominated fen (hereafter SF) is a 4.5 ha nutrient-poor fen (pH ~4.1) covered by mixed *Sphagnum* mosses (*Sphagnum angustifolium* (C.E.P. Jensen ex Russow),

Sphagnum fuscum (Schimp.) Klinggr., *Sphagnum girgensohnii* Russ., *Sphagnum magellanicum* Brid.) and other mosses (*Dicranum polysetum* Sw., *Pleurozium schreberi* (Michx.) Trevis), with sedges (*Carex disperma* Dewey, *Carex magellanica* Lam., *Carex oligosperma* Michx., *Carex pauciflora* Lightf.), and abundant shrubs such as leatherleaf (*Chamaedaphne calyculata* (L.) Moench), and Labrador tea (*Rhododendron groenlandicum* Oeder). The SF is sparsely treed with tamarack (*Larix laricina* (Du Roi) K. Koch) and black spruce (*Picea mariana* (Mill.) B.S.P.), bounded by a mixed-wood boreal forest and borders on a small lake. The water table at the SF is ~30 cm below the peat surface, depending on relative position considering the hummock-hollow topology that exists (see Asemaninejad *et al.* 2017); total peat depth is approx. 104–127 cm.

On the other hand, the *Carex*-dominated fen (hereafter CF) is a 10.2 ha mostly open fen surrounded by a mixed-wood forests, with two small streams that circle its edges, and has an intermediate nutrient status (pH ~5.4). The water table at this site is considerably higher than the SF, and it is not uncommon to have several centimeters of standing water at the surface for several months of the year. The vegetation at the CF is dominated by *Carex* sedges (*Carex lasiocarpa* Ehrh., *Carex oligosperma* Michx., *Carex stricta* Lamb.) and the shrub sweetgale (*Myrica gale* L.), alongside bog rosemary (*Andromeda polifolia* L.) and leatherleaf (*C. calyculata*). Patches of *S. angustifolium* are occasional and typically associated with sweetgale; the total peat depth is ~60 cm. For a complete description of plant communities at both sites, see Lyons *et al.* (2020).

Sampling design

To assess the oribatid fauna of these peatlands, peat soil samples ($8.52\text{g} \pm 0.26\text{g SE dwt}$) were collected in August 2015 (five samples/fen), June 2017 (16 samples/fen), June 2018 (18 samples/fen), June 2019 (16 samples/fen), August 2019 (16 samples/fen) and June 2020 (16 samples/fen), totaling 174 samples. Soil samples were placed in plastic bags and kept cool until return to the laboratory. Within 72 hours of collection, samples were extracted using Tullgren funnels over three days into 75% EtOH using a low wattage (25W) bulb. Following microarthropod extraction, all oribatid mites (Acari: Oribatida), as the dominant group in our samples (72% of all microarthropods) were morphotyped under a stereomicroscope (Nikon SMZ 745T). Representative individuals were slide mounted in Hoyer's and identified to the family and genus level under a compound microscope (Nikon Eclipse Ni) using keys in Norton & Behan-Pelletier (2009) and literature provided by The Ohio State University Summer Acarology course. Final species level identifications were made using primary literature and confirmed where possible against reference material. Additional sampling at the SF occurred in September 2012 (see Lindo 2015) and from litterbags at the SF in June 2016 (see Barreto & Lindo 2018).

Descriptive statistics

All descriptive statistics were performed with R statistical program (R Core Team 2020) using functions within the base package and “vegan” package (Oksanen *et al.* 2019). For each soil sample, we quantified the species richness and calculated the Shannon-Weiner diversity (H') and compared those between fen types using ANOVA. Species accumulation curves for both fens were generated in order of sampling and rarefied with 1000 permutations of samples added in random order. Species richness for each fen was estimated using Chao, Jackknife 1, Jackknife 2, and Bootstrap estimators, and we compared the overall community composition between sites using PERMANOVA with Bray-Curtis dissimilarity and visualized using NMDS ordination. All analyses use an alpha of 0.05, and final plots were created in R with “ggplot2” package (Wicham 2016).

Update on Oribatida of Canadian peatlands

Our updated checklist of the oribatid mite species of Canadian peatlands includes all the species records published in the previous checklist for Canadian peatlands (Behan-Pelletier & Bissett 1994), in the checklist of oribatid mites of Canada (Behan-Pelletier & Lindo 2019) and the species identified in this study. All species included are listed as found in one of the following habitats: peatland, bog, fen, *Sphagnum* moss (including non-specified peatland habitat), wetland, understory of Labrador tea (*Rhododendron (Ledum) groenlandicum*), temporary bog pool, *Sphagnum* area in swamp, and bog tundra.

Results

Oribatid mite fauna

In total, 80 species of oribatid mites distributed in 33 families were collected from the two fen sites (Table 1). Sample level species richness ($F_{1,172} = 404.91$, $P < 0.001$) and species diversity ($F_{1,172} = 223.00$, $P < 0.001$) were significantly higher in the SF (ave. richness = 23.48 (± 0.48 SE); ave. diversity $H' = 2.45$ (± 0.02 SE)) compared to the CF (ave. richness = 11.12 (± 0.37 SE); ave. diversity $H' = 1.66$ (± 0.04 SE)).

TABLE 1. Updated checklist of Oribatida of Canadian peatlands.

| | Previously recorded ¹ | SF | CF |
|--|----------------------------------|----|----|
| Family Palaeacaridae Grandjean, 1932 | | | |
| <i>Palaeacarus hystricinus</i> Trägårdh, 1932 | + | + | + |
| Family Brachychthoniidae Thor, 1934 | | | |
| <i>Brachychthonius bimaculatus</i> Willmann, 1936 | | + | |
| <i>Brachychthonius</i> sp. | | | + |
| <i>Eobrachychthonius latior</i> (Berlese, 1910) | | + | |
| <i>Liochthonius brevis</i> (Michael, 1888) | | + | + |
| <i>Liochthonius forsslundi</i> (Hammer, 1952) | † | | |
| <i>Liochthonius lapponicus</i> (Trägårdh, 1910) | | + | + |
| <i>Liochthonius sellnicki</i> (Thor, 1930) | | + | + |
| <i>Liochthonius</i> sp. | + | | + |
| <i>Poecilochthonius spiciger</i> (Berlese, 1910) | | + | + |
| <i>Sellnickochthonius lydiae</i> (Jacot, 1938) | + | | |
| <i>Sellnickochthonius suecicus</i> (Forsslund, 1942) | | + | + |
| <i>Sellnickochthonius zelawaiensis</i> (Berlese, 1910) | | + | + |
| <i>Synchthonius crenulatus</i> (Jacot, 1938) | + | + | |
| Family Eniochthoniidae Grandjean, 1947 | | | |
| <i>Eniochthonius mahunkai</i> Norton and Behan-Pelletier, 2007 | † | + | + |
| <i>Eniochthonius minutissimus</i> (Berlese, 1903) | + | + | + |
| Family Hypochthoniidae Berlese, 1910 | | | |
| <i>Hypochthonius rufulus</i> C.L. Koch, 1835 | + | + | + |
| Family Trichthoniidae Lee, 1982 | | | |
| <i>Gozmanyina majestus</i> (Marshall and Reeves, 1971) | | + | |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|---|----------------------------------|----|----|
| Family Gehypochthoniidae Strenzke, 1963 | | | |
| <i>Gehypochthonius rhadamanthus</i> Jacot, 1936 | † | | |
| Family Parhypochthoniidae Grandjean, 1932 | | | |
| <i>Parhypochthonius aphidinus</i> Berlese, 1904 | + | | |
| Family Eulohmanniidae Grandjean, 1931 | | | |
| <i>Eulohmannia ribagai</i> (Berlese, 1910) | † | | |
| Family Euphthiracaridae Jacot, 1930 | | | |
| <i>Acrotritia ardua</i> (C.L. Koch, 1841) | + | + | + |
| <i>Microtritia minima</i> (Berlese, 1904) | | + | |
| <i>Microtritia simplex</i> (Jacot, 1930) | † | | |
| Family Phthiracaridae Perty, 1841 | | | |
| <i>Atropacarus striculus</i> (C.L. Koch, 1835) | † | | |
| <i>Hoplophorella thoreau</i> (Jacot, 1930) | | + | + |
| <i>Hoplophthiracarus illinoisensis</i> (Ewing, 1909) ² | + | | |
| <i>Phthiracarus boresetosus</i> Jacot, 1930 | | + | + |
| <i>Phthiracarus globosus</i> (C.L. Koch, 1841) | † | | |
| <i>Phthiracarus longulus</i> (C.L. Koch, 1841) | † | | |
| <i>Phthiracarus</i> sp. | | + | + |
| Family Perlohmanniidae Grandjean, 1954 | | | |
| <i>Perlohmannia</i> sp. nr. <i>coiffaiti</i> Grandjean, 1961 | † | | |
| Family Crotoniidae Thorell, 1876 (incl. Camisiidae auct.) | | | |
| <i>Camisia biurus</i> (C.L. Koch, 1839) | + | | |
| <i>Camisia foveolata</i> Hammer, 1955 | † | | |
| <i>Camisia lapponica</i> (Trägårdh, 1910) | † | | |
| <i>Camisia segnis</i> (Hermann, 1804) | + | | + |
| <i>Camisia spinifer</i> (C.L. Koch, 1835) | + | | |
| <i>Heminothrus longisetosus</i> Willmann, 1925 | | + | |
| <i>Platynothrus capillatus</i> (Berlese, 1914) | † | | |
| <i>Platynothrus peltifer</i> (CL Koch, 1839) | + | | |
| <i>Platynothrus punctatus</i> (L. Koch, 1879) | † | + | |
| <i>Platynothrus thori</i> (Berlese, 1904) ³ | + | | |
| Family Malaconothridae Berlese, 1916 | | | |
| <i>Malaconothrus mollisetosus</i> Hammer, 1952 | | + | + |
| <i>Tyrphonotheus foveolatus</i> (Willmann, 1931) | † | + | |
| <i>Tyrphonotheus maior</i> (Berlese, 1910) ⁴ | + | + | + |
| <i>Tyrphonotheus</i> sp. | + | | |
| Family Nanhermanniidae Sellnick, 1928 | | | |
| <i>Nanhermannia dorsalis</i> (Banks, 1896) ⁵ | + | + | |
| <i>Nanhermannia</i> n. sp. | + | | |
| <i>Nanhermannia</i> sp. | + | | |
| Family Nothridae Berlese, 1896 | | | |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|---|----------------------------------|----|----|
| <i>Nothrus anauniensis</i> Canestrini and Fanzago, 1876 | + | | |
| <i>Nothrus borussicus</i> Sellnick, 1928 | | | + |
| <i>Nothrus monodactylus</i> (Berlese, 1910) | | + | + |
| <i>Nothrus palustris</i> C.L. Koch, 1839 | + | | |
| <i>Nothrus pratensis</i> Sellnick, 1928 | † | | |
| <i>Nothrus silvestris</i> Nicolet, 1855 | † | | |
| <i>Nothrus truncatus</i> Banks, 1895 | † | | |
| <i>Nothrus</i> sp. | + | | |
| Family Trhypochthoniidae Willmann, 1931 | | | |
| <i>Mainothrus badius</i> (Berlese, 1905) | + | + | + |
| <i>Trhypochthoniellus longisetus</i> (Berlese, 1904) | † | | |
| <i>Trhypochthoniellus setosus canadensis</i> Hammer, 1952 | + | | + |
| <i>Trhypochthonius cladonicola</i> (Willmann, 1919) | † | | |
| <i>Trhypochthonius tectorum</i> (Berlese, 1896) <i>s.l.</i> | + | | |
| <i>Trhypochthonius</i> sp. | + | | |
| Family Hermanniellidae Grandjean, 1934 | | | |
| <i>Hermanniella robusta</i> Ewing, 1918 | + | | |
| Family Neoliodidae Sellnick, 1928 | | | |
| <i>Platylodes scaliger</i> (C.L. Koch, 1839) | + | | |
| Family Gymnodamaeidae Grandjean, 1954 | | | |
| <i>Pleodamaeus</i> n. sp. | | + | + |
| Family Damaeidae Berlese, 1896 | | | |
| <i>Epidamaeus arcticolus</i> (Hammer, 1952) | † | | |
| <i>Epidamaeus bakeri</i> (Hammer, 1952) | † | | |
| <i>Epidamaeus gibbofemoratus</i> (Hammer, 1955) | † | | |
| <i>Epidamaeus kodiakensis</i> Hammer, 1967 | † | | |
| Family Liacaridae Sellnick, 1928 | | | |
| <i>Dorycranosus parallelus</i> (Hammer, 1967) | † | | |
| Family Cepheidae Berlese, 1896 | | | |
| <i>Cepheus</i> n. sp. | | + | |
| <i>Eupterotegaeus ornatissimus</i> (Berlese, 1908) | | + | |
| Family Astegistidae Balogh, 1961 | | | |
| <i>Cultroribula divergens</i> Jacot, 1939 | † | | + |
| <i>Cultroribula</i> sp. | + | | |
| Family Peloppiidae Balogh, 1943 | | | |
| <i>Ceratoppia bipilis</i> (Hermann, 1804) | + | + | + |
| <i>Ceratoppia quadridentata</i> (Haller, 1882) | † | | |
| <i>Ceratoppia quadridentata arctica</i> Hammer, 1955 | + | + | |
| <i>Ceratoppia sexpilosa</i> Willmann, 1938 | † | | |
| Family Carabodidae C.L. Koch, 1837 | | | |
| <i>Carabodes granulatus</i> Banks, 1895 | † | + | + |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|--|----------------------------------|----|----|
| <i>Carabodes labyrinthicus</i> (Michael, 1879) | † | | |
| <i>Carabodes polyporetetes</i> Reeves, 1991 | † | + | |
| <i>Carabodes radiatus</i> Berlese, 1916 | † | | |
| Family Oppiidae Grandjean, 1951 | | | |
| <i>Discoppia</i> sp. | | + | |
| <i>Lasiobelba</i> (<i>Antennoppia</i>) <i>rigida</i> (Ewing, 1909) | † | | |
| <i>Lauroppia maritima</i> (Willmann, 1929) ⁶ | † | | |
| nr. <i>Lauroppia</i> sp. | | + | |
| <i>Moritzoppia</i> nr. <i>clavigera</i> (Hammer, 1952) | | + | |
| <i>Oppiella nova</i> (Oudemans, 1902) | + | + | + |
| <i>Oppiella</i> (<i>Moritzoppia</i>) <i>translamellata</i> (Willmann, 1923) ⁷ | † | | |
| <i>Subiasella</i> (<i>Lalmoppia</i>) <i>maculata</i> (Hammer, 1952) | † | | |
| Family Quadroppiidae Balogh, 1983 | | | |
| <i>Quadroppia quadricarinata</i> (Michael, 1885) | + | + | + |
| <i>Quadroppia skookumchucki</i> Jacot, 1939 | † | | |
| Family Thyrisomidae Grandjean, 1954 | | | |
| <i>Pantelozetes</i> sp. ⁸ | † | | |
| <i>Pantelozetes alpestris</i> (Willmann, 1929) | † | | |
| Family Suctobelbidae Jacot, 1938 | | | |
| <i>Allosuctobelba</i> sp. 1 | | + | |
| <i>Allosuctobelba</i> sp. 2 | | + | |
| <i>Suctobelbella</i> (<i>S.</i>) <i>arcana</i> Moritz, 1970 | † | + | + |
| <i>Suctobelbella hammerae</i> (Krivolutsky, 1965) | † | | |
| <i>Suctobelbella hurshi</i> Jacot, 1937 | | + | + |
| <i>Suctobelbella laxtoni</i> Jacot, 1937 | | + | + |
| <i>Suctobelbella</i> nr. <i>longirostris</i> (Forsslund, 1941) | † | + | |
| <i>Suctobelbella palustris</i> (Forsslund, 1953) | | + | + |
| <i>Suctobelbella</i> nr. <i>palustris</i> (Forsslund, 1953) | † | | |
| <i>Suctobelbella</i> nr. <i>sarekensis</i> (Forsslund, 1941) | | | + |
| <i>Suctobelbella</i> sp. 1 | | + | + |
| <i>Suctobelbella</i> sp. 2 | | + | + |
| <i>Suctobelbella</i> sp. 3 | | + | + |
| <i>Suctobelbella</i> sp. 4 | | + | + |
| <i>Suctobelbella</i> sp. 5 | | + | |
| <i>Suctobelbella</i> spp. | + | | |
| Family Tectocephidae Grandjean, 1954 | | | |
| <i>Tectocephus sarekensis</i> Trägårdh, 1910 | † | | |
| <i>Tectocephus velatus</i> Trägårdh, 1905 | + | + | + |
| Family Caleremaeidae Grandjean, 1965 | | | |
| <i>Veloppia pulchra</i> Hammer, 1955 | † | | |
| Family Hydrozetidae Grandjean, 1954 | | | |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|---|----------------------------------|----|----|
| <i>Hydrozetes lacustris</i> (Michael, 1882) | † | | |
| <i>Hydrozetes octosetosus</i> Willmann, 1931 | † | | |
| <i>Hydrozetes</i> sp. | + | | |
| Family Limnozetestidae Grandjean, 1954 | | | |
| <i>Limnozetes atmetos</i> Behan-Pelletier, 1989 | + | | |
| <i>Limnozetes borealis</i> Behan-Pelletier, 1989 | + | | |
| <i>Limnozetes canadensis</i> Hammer, 1952 | + | | |
| <i>Limnozetes ciliatus</i> (Schränk, 1803) | + | | |
| <i>Limnozetes guyi</i> Behan-Pelletier, 1989 | + | + | + |
| <i>Limnozetes latilamellatus</i> Behan-Pelletier, 1989 | + | | |
| <i>Limnozetes lustrum</i> Behan-Pelletier, 1989 | + | | |
| <i>Limnozetes onondaga</i> Behan-Pelletier, 1989 | | | + |
| <i>Limnozetes palmerae</i> Behan-Pelletier, 1989 | + | | |
| <i>Limnozetes</i> sp. | + | | |
| Family Ameronothridae Vitzthum, 1943 | | | |
| <i>Ameronothrus</i> sp. | + | | |
| Family Tegeocranellidae Balogh and Balogh, 1988 | | | |
| <i>Tegeocranellus muscorum</i> Behan-Pelletier, 1997 | † | | |
| Family Cymbaeremaeidae Sellnick, 1928 | | | |
| <i>Scapheremaeus palustris</i> (Sellnick, 1924) | + | | |
| Family Phenopelopidae Petrunkevich, 1955 | | | |
| <i>Eupelops septentrionalis</i> (Trägårdh, 1910) | + | + | |
| <i>Propelops</i> n. sp. | | + | + |
| Family Unduloribatidae Kunst, 1971 | | | |
| <i>Unduloribates diana</i> Behan-Pelletier and Walter, 2009 | | + | |
| Family Achipteridae Thor, 1929 | | | |
| <i>Achipteris coleoptrata</i> (Linnaeus, 1758) | + | + | |
| <i>Anachipteris</i> sp. | | + | + |
| <i>Parachipteris nivalis</i> (Hammer, 1952) | + | | |
| <i>Parachipteris travei</i> Nevin, 1976 | † | | |
| Family Tegoribatidae Grandjean, 1954 | | | |
| <i>Tectoribates borealis</i> Behan-Pelletier and Walter, 2013 | † | | |
| <i>Tegoribates americanus</i> Hammer, 1958 | + | | |
| Family Haplozetidae Grandjean, 1936 | | | |
| <i>Peloribates canadensis</i> Hammer, 1952 | † | | |
| <i>Peloribates pilosus</i> Hammer, 1952 | + | | |
| <i>Protoribates capucinus</i> Berlese, 1908 | † | | |
| <i>Protoribates haughlandae</i> Walter and Latonas, 2013 | † | | |
| <i>Protoribates lophotrichus</i> (Berlese, 1904) | | + | + |
| <i>Protoribates</i> sp. ⁹ | + | | |
| <i>Rostrozetes ovulum</i> (Berlese 1908) ¹⁰ | + | | |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|---|----------------------------------|----|----|
| Family Mochlozetidae Grandjean, 1960 | | | |
| <i>Podoribates longipes</i> (Berlese, 1887) | + | | + |
| Family Oribatulidae Thor, 1929 | | | |
| <i>Lucoppia</i> nr. <i>apletosa</i> (Higgins and Woolley, 1975) | | + | + |
| <i>Oribatula tibialis</i> (Nicolet, 1855) | + | + | |
| <i>Phauloppia boletorum</i> (Ewing, 1913) | + | + | |
| <i>Zygoribatula bulanovae</i> Kulijew, 1961 | + | | |
| Family Parakalummidae Grandjean, 1936 | | | |
| <i>Neoribates aurantiacus</i> (Oudemans, 1914) | + | | |
| Family Scheloribatidae Grandjean, 1933 | | | |
| <i>Dometorina plantivaga</i> (Berlese, 1895) | + | | |
| <i>Liebstadia</i> cf. <i>humerala</i> Sellnick, 1928 | | + | |
| <i>Liebstadia similis</i> Michael, (1888) | † | | |
| <i>Scheloribates laevigatus</i> (C.L. Koch, 1835) | + | | |
| <i>Scheloribates pallidulus</i> (C.L. Koch, 1841) | + | + | |
| <i>Scheloribates</i> sp. | † | | |
| Family Ceratozetidae Jacot, 1925 | | | |
| <i>Ceratozetes parvulus</i> Sellnick, 1922 | + | | + |
| <i>Dentizetes ledensis</i> Behan-Pelletier, 2000 | † | | |
| <i>Diapterobates humeralis</i> (Hermann, 1804) | + | | |
| <i>Diapterobates notatus</i> (Thörell, 1871) | + | | |
| <i>Fuscozetes bidentatus</i> Banks 1895 | + | | |
| <i>Fuscozetes fuscipes</i> (C.L. Koch, 1844) | + | | |
| <i>Ghilarovizetes longisetosus</i> (Hammer, 1952) | † | | |
| <i>Lepidozetes singularis</i> Berlese, 1910 | + | + | |
| <i>Melanozetes tanana</i> Behan-Pelletier, 1986 | † | | |
| <i>Neogymnobates luteus</i> (Hammer, 1955) | † | | |
| <i>Svalbardia paludicola</i> Thor, 1930 | † | | |
| <i>Trichoribates copperminensis</i> Hammer, 1952 | † | | |
| <i>Trichoribates polaris</i> Hammer, 1953 | † | | |
| <i>Trichoribates</i> n. sp. | | + | |
| <i>Trichoribates</i> sp. | + | | |
| Family Punctoribatidae Thor, 1937 | | | |
| <i>Mycobates incurvatus</i> Hammer, 1952 | † | | |
| <i>Mycobates yukonensis</i> Behan-Pelletier, 1994 | † | | |
| <i>Punctoribates palustris</i> (Banks, 1895) | † | + | + |
| <i>Punctoribates punctum</i> (C.L. Koch, 1839) | † | | |
| Family Zetomimidae Shaldybina, 1966 | | | |
| <i>Heterozetes aquaticus</i> (Banks, 1895) | † | | |
| <i>Heterozetes minnesotensis</i> (Ewing, 1913) | † | | |
| <i>Naiazetes</i> n. sp. | | | + |

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TABLE 1. (Continued)

| | Previously recorded ¹ | SF | CF |
|--|----------------------------------|----|----|
| <i>Zetomimus cooki</i> Behan-Pelletier and Eamer, 2003 | † | | |
| <i>Zetomimus francisi</i> (Habeeb, 1974) | † | | |
| <i>Zetomimus setosus</i> (Banks, 1895) | † | | |
| Family Galumnidae Jacot, 1925 | | | |
| <i>Pergalumna emarginata</i> (Banks, 1895) | + | + | + |
| <i>Pilogalumna</i> sp. | | + | + |

¹ Original record by Behan-Pelletier and Bisset (1994) denoted by + with updates from Behan-Pelletier and Lindo (2019) denoted by †

² as *Hoplophthiracarus paludis* Jacot, 1938

³ as *Heminothrus thori* (Berlese, 1904)

⁴ as *Trimalaconothrus novus* (Sellnick, 1921)

⁵ probably *Nanhermannia coronata* Berlese, 1913

⁶ as *Oppiella maritima* (Willmann, 1929)

⁷ as *Oppiella translamellata* (Willmann, 1923)

⁸ as *Gemmazetes* sp.

⁹ as *Xylobates* sp.

¹⁰ as *Rostrozetes foveolatus* Sellnick, 1925

At the SF site we collected 69 species from 22,252 sampled adult individuals, of which 29 were unique to that site, and eight collected as singletons. The two most abundant species at the SF were the cosmopolitan *Tectocephus velatus* Trägårdh, 1910 and *Oppiella nova* (Oudemans 1902), followed by two known peatland species, *Malaconothrus mollisetosus* Hammer, 1952 and *Eniochthonius mahunkai* Norton and Behan-Pelletier, 2007. The estimated total species richness for the SF is between 74–85 species and new species records were still being added in our last year of sampling (Figure 1A) suggesting there are likely more species that were not collected.

At the CF we collected 51 species from 7,273 adult individuals of which 11 were unique to that site and not found in the SF, and four were singletons (*Cultroribula divergens* Jacot, 1939, *Liochthonius* sp., *Nothrus borussicus* Sellnick, 1928, *Trhypochthoniellus setosus canadensis* Hammer 1952). The two most abundant species at the CF were *Tyrphonotheus maior* (Berlese 1910) and *Mainothrus badius* (Berlese 1905), which contributed to >50% of all individuals collected at that site. The estimated richness for the CF is between 57–71 species, and several new species records were added in our last year of sampling at this site also (Figure 1B), suggesting there are more species that were not collected. Combined richness estimates for both these sites are 86–105 species.

In total, 40 species were shared between SF and CF sites (Supplementary Information Figure S1), but overall composition was significantly different between the two sites ($F_{1,172} = 104.60$, $P = 0.001$) (Figure 2). Notably, of the 40 shared species, 15 species were dominant (i.e., >10× more abundant) in the SF, of which five species had only one individual found in the CF (*Acrotritia ardua* (C.L. Koch 1841), *Carabodes granulatus* Banks, 1895, *Hoplophorella thoreau* (Jacot, 1930), *Nothrus monodactylus* (Berlese, 1910), *Sellnickochthonius zelawaiensis* (Berlese, 1910)). On the other hand, there were four species in the CF that, although found in the SF, were more dominant in CF (*Anachipteria* sp., *Limnozetes guyi* Behan-Pelletier, 1989, *T. maior*, *Liochthonius sellnicki* (Thor1930)).

Update on Oribatida of Canadian peatlands

Behan-Pelletier and Bissett (1994) originally listed 71 species of oribatid mites for peatlands in Canada; we found 141 species recorded from peatland habitats (including those 71) with some listed as subfossils in the updated list of oribatid mites of Canada by Behan-Pelletier and Lindo (2019). Our work expands the number of oribatid mites in Canadian peatlands to 186 species (Table 1). From

those, only 35 species are common to Behan-Pelletier and Lindo (2019) and this dataset (as indicated in Table 1).

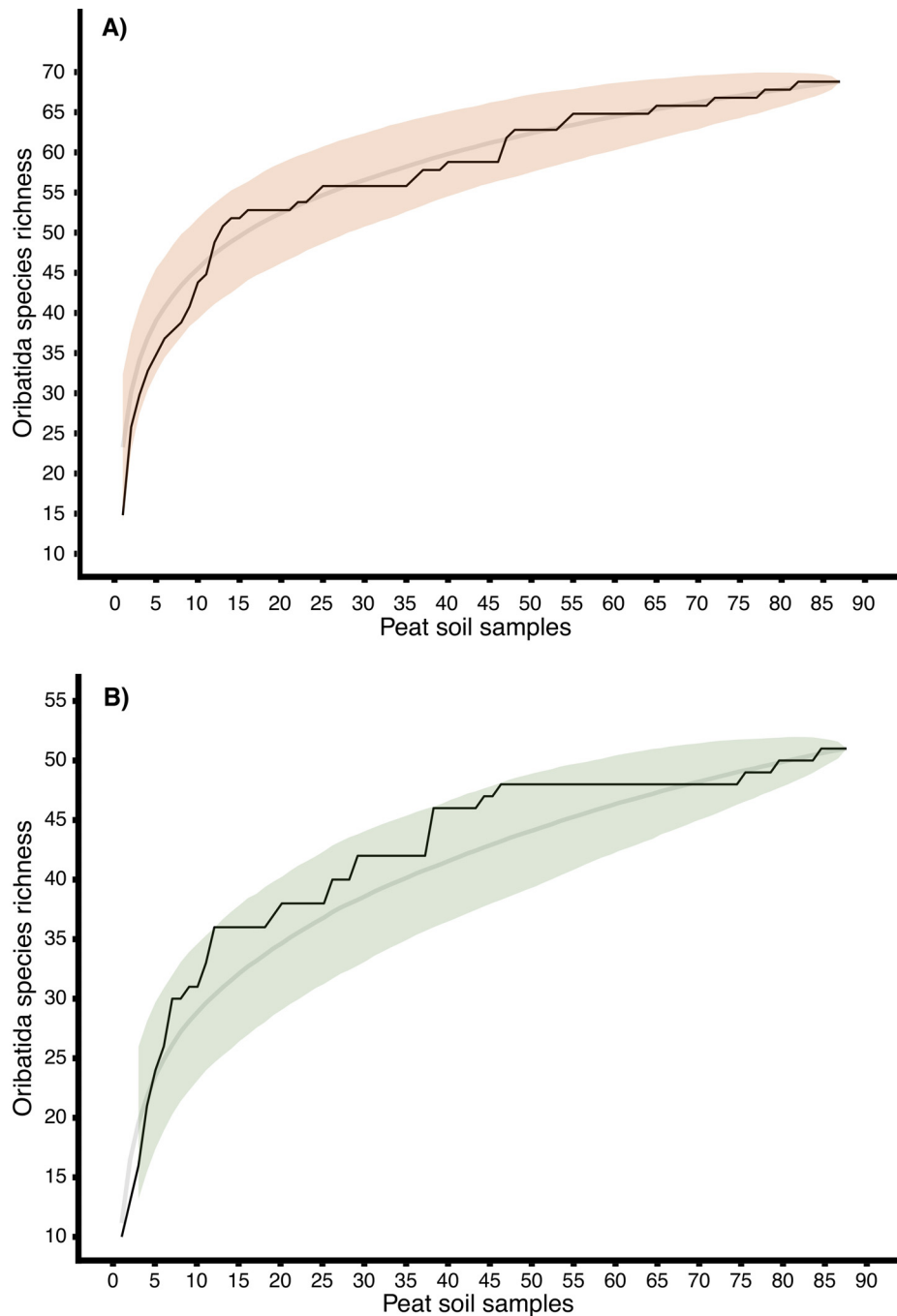


FIGURE 1. Species accumulation curves. (A) *Sphagnum*-dominated fen oribatid mite species (B) *Carex*-dominated fen oribatid mite species. Collector curves are in black for sampling effort over time on the X-axis (left to right 2015–2020). Rarefied accumulation curves (grey and brown/green) are plotted from means and standard deviation of 1000 permutations of samples in random order.

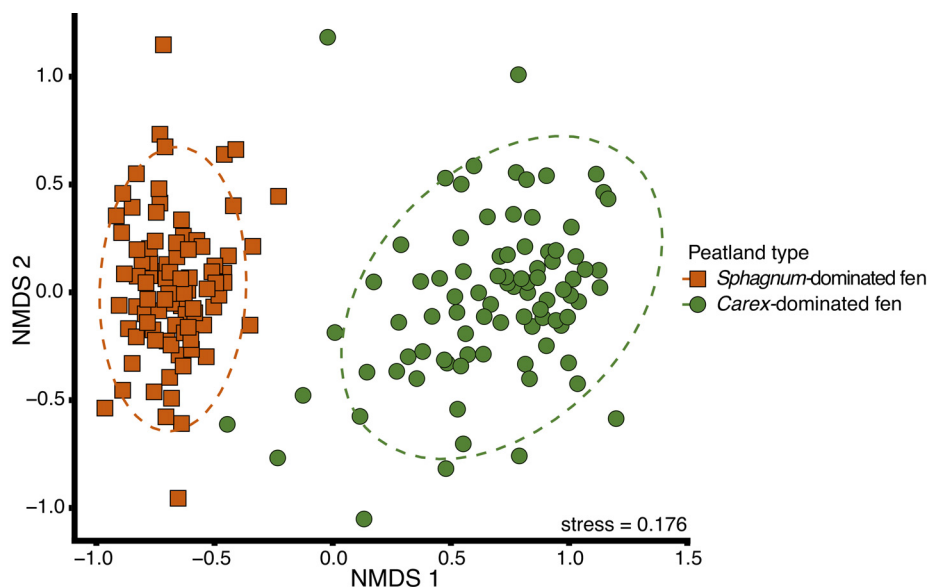


FIGURE 2. Non-metric multidimensional scaling (NMDS) plot depicting community assembly of oribatid mites in a *Sphagnum*-dominated (brown) and a *Carex*-dominated (green) fen. NMDS is based on Bray-Curtis percent similarity of species abundances for each species in 174 samples. Oribatida community composition was different between sites (PERMANOVA: $F_{1,172} = 104.60$, $P = 0.001$).

Discussion

Extensive sampling over five years at two peatland sites collected 80 species of oribatid mites, of which 69 occurred in the *Sphagnum*-dominated fen and 51 occurred in the *Carex*-dominated fen. This sampling, along with the updated checklist of oribatid mites in Canada (Behan-Pelletier & Lindo 2019) brings the total known peatland oribatid mite fauna to 186 species, of which 45 species are newly recorded in peatlands in Canada. Among species previously recorded and collected at both our sampling sites, several have also been found in abundance in Europe such as *Hypochthonius rufulus* C.L. Koch, 1836, *A. ardua*, *T. maior*, and *O. nova* (Seniczak *et al.* 2019). Several of these are cosmopolitan species found in a variety of habitats, thus not strict peatland species. For instance, *O. nova* is a species found around the world, and possibly the most common and widespread arthropod in terrestrial environments (Norton & Palmer 1991), which indicates that the oribatid mite fauna of peatlands also comprises non-peatland specialized species. Donaldson (1996) similarly suggests that there are only a few highly specialised species that occur in very high abundances in natural peatlands. Specifically, Donaldson (1996) found high abundance of the genus *Limnozetes* Hull, 1916, and particularly *L. palmerae* Behan-Pelletier, 1989, which they attributed to a semi-aquatic habitat association, preference for acidic environments, and its small size.

The SF in particular had a greater number of generalist (i.e., non-peatland specialist) species. For example, among the 29 species unique to the SF, *Gozmanyina majestus* (Marshall & Reeves 1971) was highly abundant, although previously recorded primarily in acidic forest soil (Cianciolo & Norton 2006), which might suggest that habitat associations are driven by pH (Kaneko & Kofuji 2000). Alternatively, the presence of non-peatland specialist species at the SF could be explained by wind dispersal of oribatid mites from the adjacent forest, a phenomenon seen for other oribatid mites (Behan-Pelletier & Winchester 1998). We also record several species previously not documented for

peatlands including members of Cepheidae Berlese, 1896 (*Cepheus* n. sp., *Eupterotegaeus ornatissimus* (Berlese 1908)) and Gymnodamaeidae Grandjean, 1954 (*Pleodamaeus* n. sp.) that are typically found in drier environments. As a result, the SF had higher species richness and diversity compared to the CF because of these unique species and species that appear to be peatland specialists, such as *E. mahunkai*, *M. badius*, and *L. guyi* that were also present. While we note that several mesophilous peatland species were found at the SF, some species were more commonly (e.g., *T. maior*, *L. guyi*) or solely (*T. setosus canadensis*, *L. onondaga* Behan-Pelletier, 1989) collected at the wetter CF that were typically semi-aquatic species. In addition to differences in water table that explain distributions of aquatic species, the SF site has greater vascular plant and moss species richness (Lyons *et al.* 2020), leading to heterogeneous microhabitats such as hummock/hollow topography (Barreto & Lindo 2018), and greater saprophytic fungal biomass (Lyons & Lindo 2020), and diverse fungal (Asemaninejad *et al.* 2017) and bacterial (Asemaninejad *et al.* 2019) communities that provide food resources for many oribatid mite species (Schneider & Maraun 2005; Lehmitz & Maraun 2016). We will also note that we observed a relatively high frequency of the zygomycete fungi *Basidiobolus* on slide mounted specimens, and two specimens parasitized with the non-photosynthetic algae *Helicosporidium*. *Basidiobolus* attaches to external surfaces of small arthropods for dispersal, while *Helicosporidium* was observed inside body cavities. Whether these observations reflect greater abundance of these microbial groups in peatlands or some enhanced synecological association warrants further investigation.

Peatland records for the entirely parthenogenetic Brachychthoniidae Thor, 1934 were considerably expanded, with nine new species added to the checklist. As important was the update on Suctobelbidae Jacot, 1938, whose members are predominantly asexually reproducing species. Until Behan-Pelletier and Lindo (2019), only four named species of Suctobelbidae were listed for peatlands; here we add eleven more species in two genera (*Allosuctobelba* Moritz, 1970 and *Suctobelbella* Jacot, 1937), although with relatively lower taxonomic resolution as we were not able to confirm all species identities. While there are 12 described species of *Suctobelbella* in Canada (Behan-Pelletier & Lindo 2019), there are still many undescribed species. For instance, Beaulieu *et al.* (2019) estimate 48 undescribed or unrecorded *Suctobelbella* species but note that based on molecular barcode information this number may be an underestimate.

It has been noted that both the number of parthenogenetic species as well as their individual abundances are higher in peat bogs than other habitats (e.g., forest floor soils) (Maraun *et al.* 2019); while this was not overly evident for species richness in the SF (39 parthenogenetic vs. 30 sexual species), more than 2/3 of the species in the CF were parthenogenetic (36 parthenogenetic vs. 15 sexual species). Overall, the abundance of individuals of parthenogenetic species, however, was about 10-fold greater than that of sexual species at both fens. One possible explanation for higher richness of parthenogenetic species in the CF might be related to a lower efficacy of free-standing spermatophores produced by males in wet habitats (Norton & Palmer 1991), resulting in taxonomic groups like Brachychthonidae and Eniochthonidae Grandjean, 1947 within the Enarthronota being preadapted to these wet habitats (Behan-Pelletier & Bisset 1994).

Notably missing from the peatland fauna in Canada compared to other boreal systems (Behan-Pelletier 1999) are species in the predominantly sexually reproducing Punctoribatidae Thor, 1937, many of which are found in dry microhabitats. However, while the family is present in all ecozones of Canada (Beaulieu *et al.* 2019), different genera exhibit different habitat preferences. For example, two of the five described *Punctoribates* Berlese, 1908 in Canada (*P. palustris* (Banks, 1895) and *P. punctum* (C.L. Koch, 1839)) are reported from *Sphagnum* in peat bog and wet *Sphagnum* habitats, respectively, while only two of the 17 described *Mycobates* Hull, 1916 (*M. incurvatus* Hammer, 1952 and *M. yukonensis* Behan-Pelletier, 1994) are recorded from bog tundra or peat habitats (Behan-Pelletier & Lindo 2019). That said, while there are 35 described species in Punctoribatidae,

there are an estimate 30 additional unrecorded or undescribed species in Canada (Beaulieu *et al.* 2019).

Among the 45 species as new records for Canadian peatlands, at least five species from our sampling are confirmed as undescribed (*Pleodamaeus* n. sp., *Cepheus* n. sp., *Propelops* n. sp., *Trichoribates* n. sp., *Naiazetes* n. sp.), suggesting great potential for more species to yet be described, and clearly more taxonomic studies are needed on peatlands in North America. For example, despite *Protoribates haughlandae* Walter and Latonas, 2013 being widely distributed across the province of Alberta (Walter & Latonas 2013), this species has only recently been collected by the systematic sampling of peatland sites. Even though the oribatid mite fauna in Europe is considerably more studied than in Canada, many studies still list species as morphospecies, which could also potentially translate to new species or new records for peatlands worldwide (e.g., Sidorchuk 2008; Markkula 2014; Seniczak *et al.* 2020).

Embedded in the expanded checklist of Canadian peatland oribatid mites are geographical as well as habitat factors that dictate the presence and distribution of these mites. Prior to 1994, the vast majority of peatland records were for eastern Canada and within the boreal ecozone. The addition of records from western Canada and the subarctic will continue to increase the number of known peatland species, as does extensive and repeated sampling at single locations. Thus we suggest that future studies focus more on these sites with repeated sampling and/or more consideration of habitat specific associations. For instance, Donaldson (1996) found significantly different oribatid mite species assemblages across three different *Sphagnum* moss habitats within a single location, while at the same time, the abundance and dominance of particular species changed over one growing season. Taken together, this work highlights that, despite the importance of peatlands as soil reservoirs for carbon and biodiversity, peatlands and other wetland systems remain understudied with respect to oribatid mite fauna in Canada compared to other habitat types.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Both authors contributed to the sampling, identifications, and written work; CB performed sample processing and data analysis, while the project was conceived and funded by grants to ZL.

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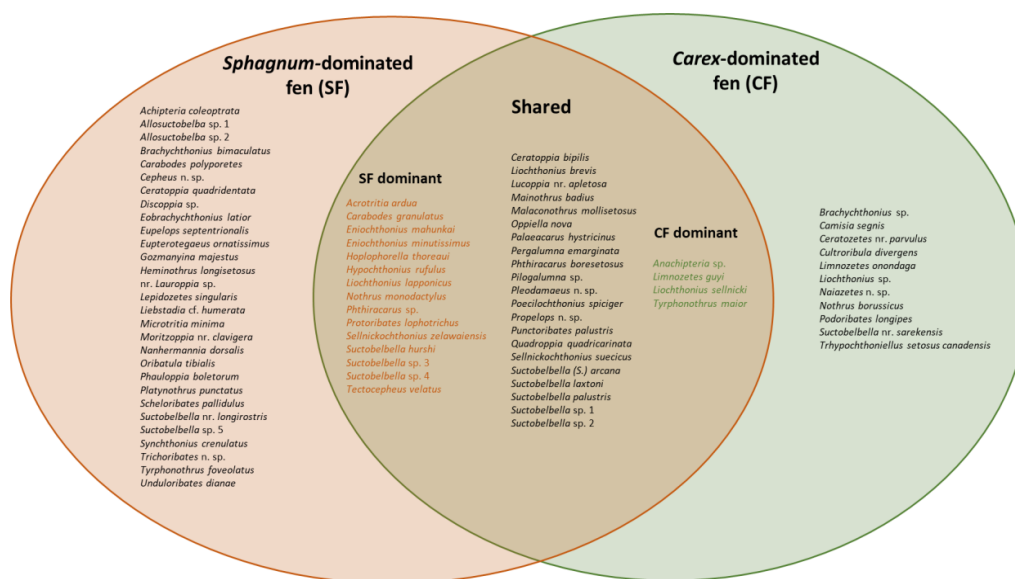


FIGURE S1. Venn diagram showing the overlap between species extracted from peat soil samples collected in a *Sphagnum*-dominated fen (SF) and a *Carex*-dominated fen (CF) between 2015–2020 near White River Ontario, Canada. Shared species that were dominant (i.e., $>10\times$ more abundant) in either fen have different colours.