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Checklist of oribatid mites (Acari: Oribatida) from peatlands in the United States with notes on oribatid mites from a bog in Minnesota

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Abstract

Peatlands are important ecosystems for carbon storage worldwide and often contain unique species. Oribatid mites are the dominant soil arthropods in terrestrial systems like peatlands, where they show high diversity, yet are under-sampled. To create a checklist of oribatid mite species from peatlands in the U.S., we collected a total of 53 peat-soil samples between 2015 and 2020 from a peatland located at the Marcell Experimental Forest in Minnesota, U.S. that yielded an assemblage of 27 families, 43 genera and 49 species; species richness estimates range between 56–102 species. We compiled a final checklist with data from previous studies of American peatlands available online up until July 2024 that revealed an additional 107 species for a total of 156 species distributed in 83 genera and 27 families known from peatlands in the U.S. From our samples, *Punctoribates palustris* is present in the most states (N=6), and is known to be associated with *Sphagnum* mosses in North America. Other common peatland species such as *Eniochthonius mahunkai*, *Mainothrus badius* and *Limnozetes lustrum* were also abundant at our site. However, we also found species typical of drier environments (e.g., dry forests, dry montane regions, canopy habitats) such as *Eueremaeus* nr. *proximus*, *Scapheremaeus palustris*, and *Cepheus corae*. Thus, our results reinforce the idea that peatlands may have a specific subset of species that are common to these ecosystems, but that in general many different species can be occasionally found in peatlands.

Key words: *Sphagnum*; fen; soil; wetland; biodiversity; SPRUCE experiment

Introduction

Among arthropods, oribatid mites (Acari: Oribatida) often dominate terrestrial soils (Norton & Behan-Pelletier 2009), especially those with high organic accumulations such as boreal forests and peatland systems (Petersen & Luxton 1982). Oribatid mite diversity in boreal peatlands is well documented for Canada (Behan-Pelletier & Bisset 1994; Lindo 2015; Barreto & Lindo 2018, 2021; Barreto *et al.* 2024) and Europe (Markkula *et al.* 2019; Mumladze *et al.* 2013; Lehmitz *et al.* 2020). These studies indicate oribatid mite communities of peatland soils contain specialised species associated with acidic environmental conditions and a semi-aquatic habitat, but cosmopolitan species are also present. However, there are few studies of oribatid mite communities in peatlands of the U.S.

The National Wetlands Working Group (1997) define peatlands as wetlands with organic soils over 40 cm deep with a high water table from precipitation (bogs) or combined precipitation and ground water (fens). The U.S. Department of Agriculture (USDA) soil taxonomy classifies soils with organic accumulations greater than 40 cm as histosols (Soil Survey Staff 1999), and in the U.S., histosols, including peatlands, cover around 242,000 km^2 or 2.6% of the land area (Minasny *et al.* 2019), with peatlands covering ~2% (197,841 km^2) of the landscape (Xu *et al.* 2018). The vast majority of peatlands in the U.S. are in Alaska and Minnesota (Kolka *et al.* 2016; Minnesota Scientific and Natural Areas Patterned Peatlands 2022). Despite the small total area (~3% of the globe (Gorham 1991)), global peatlands store one third of the world's terrestrial carbon (Bragazza *et al.* 2013), with an estimated 455 PgC stored in peatlands of the U.S. (Mickler 2021). Slow decomposition by soil organisms facilitates this carbon storage, with oribatid mites playing key roles in secondary decomposition of organic matter (Gergócs & Hufnagel 2016; Sánchez-Chávez *et al.* 2023) and nutrient cycling (Wickings & Grandy 2011), thus important to carbon cycling.

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Considering the importance of peatlands and other wetland systems, their oribatid mite fauna is often neglected in the U.S. in comparison to other environments. Most work has been taxonomic or faunistic, starting with a brief descriptive study of mites from a “sphagnum swamp” in New York (Banks 1895). Other studies at least partly linked to peatlands in the U.S. include Behan-Pelletier (1989), Norton and Behan-Pelletier (2007), and Norton *et al*. (2022) who described species from various peatlands; Behan-Pelletier and Eamer (2003) who contributed to the knowledge of semiaquatic and aquatic species in the family Zetomimidae in North America, providing also identification keys and distribution records for the seven known species; Behan-Pelletier (1993, 1997) and Jacot (1930) who provided records from non-specific *Sphagnum* moss habitats; and Behan-Pelletier and Bissett (1994) who summarized the data on oribatid mites from peatlands collected by Palmer in their checklist for Canadian peatlands.

At the community ecology level, the peatland environment was mostly ignored until Belanger (1976) surveyed oribatid mites in a nutrient-poor fen located south of Oneida Lake, northeast of Syracuse (“Cicero Bog”). Over a seven-week period she investigated the vertical distribution pattern of 41 confirmed species within *Sphagnum* mats (mostly *S. fallax* (Klinggr.) Klinggr. and *S. magellanicum* Brid.). Three microhabitats were distinguished—*Sphagnum* tops, stalks, and peat—with stalks housing the highest abundance, richness, and diversity of oribatid mites.

Donaldson (1996) investigated the oribatid fauna associated with three species of *Sphagnum* moss (*S. cuspidatum* Ehrh. ex Hoffm., *S. recurvum* P.-Beauv., and *S. magellanicum*), at the Spruce Hole Bog, southwest of Durham, New Hampshire. She collected representatives of 31 confirmed species and detected an increase in diversity from the former *Sphagnum* species to the latter, which she linked to increasing height above the water surface and decreasing shade. Palmer (1990) did extensive sampling across numerous habitats including *Sphagnum* hummocks and hollows at Belanger’s site (“Cicero Bog”) and a *Sphagnum* carpet at Fiddler’s Green bog (Town of Eaton in Madison County, New York). From this work, Palmer and Norton (1990, 1992) examined thelytoky (female parthenogenesis) and genetic diversity of oribatid mites in the superfamily Crotonioidea, known to contain the largest concentration of thelytokous species in the animal kingdom. They considered four of the seven families in Crotonioidea to be thelytokous, although thelytoky was not correlated with geography.

Lastly, Barreto *et al.* (2023) used a field-based experiment located at the S1 Bog in Minnesota to test how oribatid mite abundance, richness and community composition respond to different warming temperatures (between 0°C and +9°C) crossed with elevated CO_2 conditions. The authors collected 10 samples (top 10 cm *Sphagnum* moss layer) once a year for four years (total 40 samples) in the Spruce and Peatland Responses Under Changing Environments (SPRUCE) experiment and found 48 species of oribatid mites, but faunistic aspects were not described or discussed.

No checklist of oribatid mites from American peatlands is currently available, and most of the faunistic and community-level data come from the eastern U.S. As a step forward, our objectives are to (1) expand the oribatid mite list from a bog in Minnesota using additional peat-soil samples that were collected over five years, and (2) create a checklist of oribatid mites of peatlands in the U.S. using the species from this site, specimens housed in the Canadian National Collection of Insects, Arachnids and Nematodes sampled from peatland sites in the U.S., and published work.

Material & Methods

Study area

Fieldwork was conducted in the S1 Bog that is located within the U.S. Department of Agriculture’s Marcell Experimental Forest (N 47°30.476’; W 93°27.162’) in northern Minnesota. This area is a well-studied system as it was established as an experimental forest in 1959 to investigate the role of peatlands in the Northern Lake States region (Verry *et al.* 2011). The S1 Bog is ombrotrophic, 8.1 ha, covered by *Sphagnum* cf. *divinum* Flatberg & Hassel, *Sphagnum angustifolium* (C.E.O. Jensen ex Russow) C.E.O. Jensen, and *Sphagnum fallax* Klinggr. (Walker *et al.* 2017; Norby *et al.* 2019). Two tree species, *Picea mariana* (Mill.) Britton, Sterns & Poggenburg (black spruce) and *Larix laricina* (Du Roi) K. Koch (tamarack), dominate the overstory vegetation, but low-lying shrub species are also present (e.g., *Chamaedaphne calyculata* (L.) Moench (leatherleaf), *Rhododendron groenlandicum* (Oeder) Kron & Judd (Labrador tea)). The S1 Bog was harvested in 1969 and 1974 to promote natural black spruce regeneration

(Perala & Verry 2011). The climate in the region is strongly continental with moist warm summers and dry, cold, sunny winters. Average annual precipitation is 780mm and average annual air temperature is 3.4°C (Sebestyen *et al.* 2011); average pH of the peat is 4.0 (Nichols 1998) and the water table fluctuates from several centimeters above the peat surface in hollows (low lying areas) to a maximum of 1.4m below the *Sphagnum* surface (Sebestyen *et al.* 2011). Full information about the Marcell Experimental Forest can be found in Kolka *et al.* (2011).

Sampling design

Sampling for this study was part of the Spruce and Peatland Responses Under Climatic and Environmental Change—SPRUCE—experiment (http://mnspruce.ornl.gov; Hanson *et al.* 2017), a large-scale warming and elevated atmospheric CO_2 experiment. The experiment has been described in detail in various published works (see Krassovski *et al.* 2015; Griffiths *et al.* 2017; Hanson *et al.* 2017) with the response of oribatid mite abundance and species richness to experimental treatments being minimal (Barreto *et al.* 2023).

As part of annual sampling of the SPRUCE experiment peat-soil samples (average 23.87g (± 3.25g SE) dwt) were collected annually in October between 2015 and 2019 (2015: 10; 2016: 10; 2017: 10; 2018: 13; 2019: 10 samples)—which includes samples from Barreto *et al*. (2023). In total, 53 samples were manually taken from the top 10cm of peat in the living *Sphagnum* moss layer, weighed, and placed into portable Berlese funnel traps (Bioquip® 2832) within one hour; soil fauna were extracted over 72 hours into 75% EtOH under a low wattage incandescent light bulb. After extraction, peat samples were re-weighed to establish moisture content and dry weight of the extracted sample.

All oribatid mites (Acari: Oribatida), the dominant group in our samples (58.39% of all microarthropods), were morphotyped and multiple individuals of each morphotype were slide mounted under a stereomicroscope (Nikon SMZ745T). Where possible, all morphotypes were identified to species-level using keys in Norton and Behan-Pelletier (2009) and Behan-Pelletier and Lindo (2023) under compound light microscope (Nikon Eclipse Ni-U). Naming conventions follow Subías (2022). For each soil sample, we quantified and estimated the species richness (Chao, Jackknife 1, Jackknife 2, and Bootstrap estimators). A species accumulation curve was generated in order of sampling and rarefied with 1,000 permutations of samples added in random order. All descriptive statistics were performed with R statistical program (R Core Team 2020) using functions within the "base" and "vegan" package (Oksanen *et al.* 2019).

Checklist of Oribatida from American peatlands

The checklist of oribatid mites from American peatlands was created from: (1) species recorded from the Marcell Forest S1 Bog, (2) electronic records from the species represented in the Canadian National Collection of Insects, Arachnids and Nematodes collected from peatland sites in the U.S. and deposited by July 2024, and (3) published work. The latter include ecological studies (Belanger 1976; Behan 1978; Palmer 1990; Palmer & Norton 1990, 1992; Behan-Pelletier & Bisset 1994; Donaldson 1996; Behan-Pelletier & Eamer 2003; Barreto *et al.* 2023); species descriptions (Banks 1895; Behan-Pelletier 1989; Norton & Behan-Pelletier 2007, Norton *et al*. 2022); and records from non-specific *Sphagnum* moss habitats (Jacot 1930; Behan-Pelletier 1993, 1997). For published works we searched the Web of Science and Google Scholar in July 2024, and included all species present in the U.S. and recorded from any of the following habitats: 'peatland', 'bog', 'fen', '*Sphagnum* moss' (including non-specified peatland habitat), 'wetland', '*Sphagnum* area in swamp', 'bog tundra', 'temporary bog pool', or 'understory of Labrador tea (*Rhododendron* (*Ledum*) *groenlandicum*)'. All potential literature sources were validated by the site descriptions provided. Records resulting from 'wetland' where the site did not contain evidence of peat were not included.

Records that included only genus- or family-level determinations (e.g., from the S1 bog: *Liochthonius* sp., Damaeidae sp., *Quadroppia* sp., *Haplozetes* sp.) are not included. However, mites identified to the species level, but listed as nr., or new (undescribed) species were included in the checklist and counted. Authorship of species scientific names is provided in Table 1.

Results and Discussion

Oribatid mite fauna at S1 Bog

At the S1 Bog, we collected 31,934 adult oribatid mite individuals, of which six represented singletons—*Liochthonius* sp.; *Atopochthonius artiodactylus*; *Gozmanyina majestus*; *Trhypochthonius* nr. *americanus*; Damaeidae sp.; and *Phauloppia boletorum*. *Oppiella nova* was by far the most abundant species (~45% of all adult oribatids), followed by *Eniochthonius mahunkai* (~13%), and *Limnozetes lustrum* (~6%). In total, 49 species of oribatid mites distributed in 27 families were collected from the S1 Bog site (Table 1); on average, alpha diversity of each sample was ~20 species. The estimated total species richness for the S1 bog site is between 56–102 species, which suggests that not all species have been collected, although no new species records were added from the last sampling event (Figure 1).

TABLE 1. Checklist of Oribatida from American peatlands.

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Family Palaeacaridae Grandjean, 1932				
Palaeacarus hystricinus Trägårdh, 1932	NY			MN
Family Brachychthoniidae Thor, 1934				
Brachychthonius n. sp.				MN
Brachychthonius berlesei Willmann, 1928	NY			
Liochthonius brevis (Michael, 1888)[1]			AK[a]	MN
Liochthonius nr. *forsslundi* (Hammer, 1952)		NH		
Liochthonius sellnicki (Thor, 1930)				MN
Liochthonius nr. *sellnicki* (Thor, 1930)	NY			
Liochthonius simplex (Forsslund, 1942)				MN
Poecilochthonius cf. *spiciger* (Berlese, 1910)				MN
Sellnickochthonius lydiae (Jacot, 1938)[2]	NY			
Sellnickochthonius zelawaiensis (Sellnick, 1928)				MN
Synchthonius crenulatus (Jacot, 1938)	NY			
Family Eniochthoniidae Grandjean, 1947				
Eniochthonius mahunkai Norton and Behan-Pelletier, 2007			NY[b], WI[b]	MN
Eniochthonius minutissimus (Berlese, 1903)[3]	NY	NH		
Family Hypochthoniidae Berlese, 1910				
Hypochthonius rufulus C.L. Koch, 1835	NY	NH		MN
Family Trichthoniidae Lee, 1982				
Gozmanyina majestus (Marshall and Reeves, 1971)				MN
Family Gehypochthoniidae Strenzke, 1963				
Gehypochthonius rhadamanthus Jacot, 1936		NH		
Family Atopochthoniidae Grandjean, 1949				
Atopochthonius artiodactylus Grandjean, 1948				MN
Family Parhypochthoniidae Grandjean, 1932				
Parhypochthonius aphidinus Berlese, 1904	NY			
Family Mesoplophoridae Ewing, 1917				
Archoplophora rostralis (Willmann, 1930)		NH		

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TABLE 1. (Continued)

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Family Euphthiracaridae Jacot, 1930				
Acrotritia ardua (C.L. Koch, 1841)[4,5]	NY		ME[c], CT[c]	MN
Acrotritia curticephala (Jacot, 1938)[6]		NH		
Microtritia minima (Berlese, 1904)	NY			
Microtritia simplex (Jacot, 1930)[7]		NH	ME[c]	MN
Family Phthiracaridae Perty, 1841				
Atropacarus striculus (C.L. Koch, 1835)[8]			CT[c], WI[d]	
Hoplophorella n. sp.				MN
Hoplophthiracarus illinoisensis (Ewing, 1909)[9]	NY	NH		MN
Phthiracarus boresetosus Jacot, 1930			WI[d]	
Phthiracarus compressus Jacot, 1930[10]	NY		CT[c]	
Phthiracarus erinaceus Jacot, 1930[11]			ME[c]	
Phthiracarus olivaceus Jacot, 1929[12]			NY[c]	
Phthiracarus setosus (Banks, 1895)			CT[c]	
Steganacarus thoreaui Jacot, 1930			ME[c]	
Family Crotoniidae Thorell, 1876 (incl. Camisiidae *auct.*)				
Camisia biurus (C.L. Koch, 1839)			NY[e], WV[d]	
Camisia horrida (Hermann, 1804)			AK[a]	
Camisia segnis (Hermann, 1804)	NY		AK[a]	MN
Platynothrus peltifer (C.L. Koch, 1839)	NY		AK[a]	MN
Platynothrus nr. *peltifer* (C.L. Koch, 1839)		NH		
Platynothrus punctatus (L. Koch, 1879)			AK[a]	
Family Malaconothridae Berlese, 1916				
Malaconothrus mollisetosus Hammer, 1952			AK[a]	MN
Malaconothrus nr. *processus* Hammen, 1952	NY			
Tyrphonothrus foveolatus (Willmann, 1931)				MN
Tyrphonothrus glaber (Michael, 1888)[13]			NY[f]	
Tyrphonothrus maior (Berlese, 1910)[14]	NY	NH	AK[a]	MN
Tyrphonothrus nr. *vietsi* (Wilmann, 1925)		NH		
Family Nanhermanniidae Sellnick, 1928				
Nanhermannia dorsalis (Banks, 1896)			ME[d], MS[d], NH[d]	MN
Nanhermannia elegantula Berlese, 1913			MS[d]	
Nanhermannia nana (Nicolet, 1855)[15]	NY			
Family Hermanniidae Sellnick, 1928				
Hermannia subglabra Berlese, 1910			AK[a]	
Family Nothridae Berlese, 1896				
Nothrus anauniensis Canestrini and Fanzago, 1876[16]	NY		NY[e]	MN
Nothrus biciliatus C.L. Koch, 1841	NY			
Nothrus pratensis Sellnick, 1928			NY[d]	
Nothrus silvestris Nicolet, 1855			NY[g], MS[d]	
Nothrus truncatus Banks, 1895		NH		
Nothrus n. sp. nr. *truncatus*[17]			NY[g]	

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TABLE 1. (Continued)

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Family Trhypochthoniidae Willmann, 1931				
Mainothrus badius (Berlese, 1905)[18]			NY[h,i]	MN
Mainothrus nr. *badius* (Berlese, 1905)[19]		NH		
Trhypochthoniellus excavatus (Willmann, 1919)			NY[i]	
Trhypochthoniellus nr. *excavatus* (Willmann, 1919)		NH		
Trhypochthoniellus longisetus (Berlese, 1904)[20]			NY[h]	
Trhypochthoniellus setosus canadensis Hammer, 1952			NY[e]	
Trhypochthonius nr. *americanus* (Ewing, 1908)				MN
Trhypochthonius tectorum (Berlese, 1896) *s.l.*	NY			
Family Hermanniellidae Grandjean, 1934				
Hermanniella robusta Ewing, 1918			NY[e]	
Family Caleremaeidae Grandjean, 1965				
Veloppia pulchra Hammer, 1955			AK[a]	
Family Damaeidae Berlese, 1896				
Damaeus grandjeani (Bulanova-Zachvatkina, 1957)			ME[d]	
Damaeus nasutus (Behan-Pelletier & Norton, 1985)			AK[d]	
Epidamaeus arcticolus (Hammer, 1952)			AK[d]	
Kunstidamaeus arthurjacoti Norton, Ermilov et Miko, 2022			NY[n]	
Parabelbella inaequipes (Banks, 1947)[21]	NY			
Family Astegistidae Balogh, 1961				
Cultroribula divergens Jacot, 1939		NH		
Cultroribula juncta (Michael, 1885)	NY			
Family Peloppiidae Balogh, 1943				
Ceratoppia bipilis (Hermann, 1804)	NY			
Ceratoppia quadridentata (Haller, 1882)				MN
Ceratoppia quadridentata arctica Hammer, 1955			NY[e], AK[a]	
Family Carabodidae C.L. Koch, 1837				
Carabodes cochleaformis Reeves, 1990			ME[d]	
Carabodes floridus Berlese, 1913			MS[d]	
Carabodes granulatus Banks, 1895[22]	NY	NH	NY[f], AL[d], MS[d]	
Carabodes labyrinthicus (Michael, 1879)			AK[a]	MN
Carabodes polyporetes Reeves, 1991			AL[d]	
Carabodes radiatus Berlese, 1916		NH		
Odontocepheus oblongus (Banks, 1895)			ME[d]	
Family Oppiidae Grandjean, 1951				
Oppiella nova (Oudemans, 1902)	NY	NH	AK[a], CO[d]	MN
Oppia (*Antennoppia*) *rigida* (Ewing, 1909)[23]		NH		
Oppia nr. *nitens* C.L. Koch, 1835	NY			MN
Family Quadroppiidae Balogh, 1983				
Quadroppia quadricarinata (Michael, 1885)	NY			
Quadroppia skookumchucki Jacot, 1939		NH		

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TABLE 1. (Continued)

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Family Suctobelbidae Jacot, 1938				
Allosuctobelba obtusa (Jacot, 1938)[24]	NY			
Suctobelbella hurshi Jacot, 1937				MN
Suctobelbella nr. *laxtoni* Jacot, 1937				MN
Suctobelbella longirostris (Forsslund, 1941)				MN
Suctobelbella punctata (Hammer, 1955)			AK[a]	
Suctobelbella sarekensis (Forsslund, 1941)				MN
Family Tectocepheidae Grandjean, 1954				
Tectocepheus velatus (Michael, 1880)	NY	NH		MN
Family Limnozetidae Grandjean, 1954				
Limnozetes amnicus Behan-Pelletier, 1989			NY[j]	
Limnozetes borealis Behan-Pelletier, 1989			NY[e]	
Limnozetes ciliatus (Schrank, 1803)		NH		
Limnozetes lustrum Behan-Pelletier, 1989		NH	NY[j]	MN
Limnozetes onondaga Behan-Pelletier, 1989		NH	NY[j]	
Limnozetes palmerae Behan-Pelletier, 1989		NH	NY[j]	
Limnozetes sphagni (Michael, 1880)	NY			
Family Oripodidae Jacot, 1925				
Oripoda elongata Banks & Pergande, 1904		NH		
Family Parakalummidae Grandjean, 1936				
Neoribates aurantiacus (Oudemans, 1914)			NY[e]	
Family Tegeocranellidae Balogh and Balogh, 1988				
Tegeocranellus barbarae Behan-Pelletier, 1997			MS[k]	
Tegeocranellus muscorum Behan-Pelletier, 1997			NY[k]	
Family Cymbaeremaeidae Sellnick, 1928				
Scapheremaeus palustris (Sellnick, 1924)			NY[e]	
Family Cepheidae Berlese, 1896				
Cepheus corae Jacot, 1928			AK[a]	
Family Eremaeidae				
Eremaeus translamellatus Hammer, 1952			ME[d]	
Euremaeus columbianus Berlese, 1916			ME[l]	
Eueremaeus nr. *proximus* (Berlese, 1916)				MN
Family Phenopelopidae Petrunkevich, 1955				
Eupelops sulcatus (Oudemans, 1914)[25]	NY			
Eupelops septentrionalis (Trägårdh, 1910)			NY[e]	
Family Achipteriidae Thor, 1929				
Parachipteria nivalis (Hammer, 1952)			NY[e]	
Family Tegoribatidae Grandjean, 1954				
Tegoribates americanus Hammer, 1958			NY[e]	
Family Haplozetidae Grandjean, 1936				
Peloribates juniperi (Ewing, 1913)				MN
Protoribates capucinus Berlese, 1908[26]		NH		

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TABLE 1. (Continued)

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Protoribates haughlandae Walter & Latonas, 2013				MN
Rostrozetes ovulum (Berlese 1908)[27]	NY	NH		
Family Oribatulidae Thor, 1929				
Oribatula tibialis (Nicolet, 1855)			NY[e]	MN
Phauloppia boletorum (Ewing, 1913)			NY[e]	MN
Zygoribatula bulanovae Kulijew, 1961			NY[e]	
Family Scheloribatidae Grandjean, 1933				
Dometorina plantivaga (Berlese, 1895)	NY			
Liebstadia n. sp.				MN
Liebstadia similis Michael, (1888)			AK[a]	
Scheloribates pallidulus (C.L. Koch, 1841)	NY			
Family Ceratozetidae Jacot, 1925				
Ceratozetes parvulus Sellnick, 1922			AK[d]	
Ceratozetes nr. *parvulus* Sellnick, 1922	NY			
Dentizetes ledensis Behan-Pelletier, 2000				MN
Diapterobates humeralis (Hermann, 1804)	NY			
Diapterobates notatus (Thörell, 1871)			AK[d]	
Diapterobates variabilis Hammer, 1955			AK[a]	
Fuscozetes bidentatus Banks 1895	NY			MN
Fuscozetes fuscipes (C.L. Koch, 1844)		NH		
Lepidozetes singularis Berlese, 1910	NY	NH		MN
Melanozetes longisetosus Hammer, 1952			AK[d]	
Melanozetes meridianus Sellnick, 1928			AK[a]	
Melanozetes sellnicki (Hammer, 1952)			AK[d]	
Melanozetes tanana Behan-Pelletier, 1986			AK[d]	
Neogymnobates luteus (Hammer 1955)			AK[a]	MN
Svalbardia paludicola Thor, 1930			AK[d]	
Trichoribates n. sp.				MN
Trichoribates polaris Hammer, 1953			AK[a]	
Family Punctoribatidae Thor, 1937				
Mycobates hylaeus Behan-Pelletier, 1994				MN
Mycobates punctatus Hammer, 1955			AK[a]	
Pelopsis bifurcatus (Ewing, 1909)			GA[d]	
Punctoribates hexagonus Berlese 1908	NY			
Punctoribates palustris (Banks, 1895)[28]		NH	NY[f], AL[d], GA[d], WI[d]	MN
Family Zetomimidae Shaldybina, 1966				
Heterozetes aquaticus (Banks, 1895)			NH[m], NY[d]	
Heterozetes minnesotensis (Ewing 1913)			NY[m]	
Naiazetes reevesi Behan-Pelletier, 1996			MS[m]	
Zetomimus cooki Behan-Pelletier & Eamer 2003			MS[m], FL[m]	
Zetomimus francisi (Habeeb, 1974)			WI[m]	
Zetomimus setosus (Banks, 1895)[29,30]			NY[f,m], WI[d]	MN

......continued on the next page

TABLE 1. (Continued)

	Belanger (1976)†	Donaldson (1996)⁑	Previously recorded	S1 bog
Family Galumnidae Jacot, 1925				
Pergalumna curva (Ewing, 1907)[31]	NY			
Pergalumna cf. *dodsoni* Nevin, 1979				MN
Pergalumna emarginata (Banks, 1895)[32,33]	NY		NY[f]	
	40	**31**	**84**	**49**

† *Collohmannia* sp., *Suctobelbella* spp., *Xylobates* sp., *Ceratozetes* sp. A are listed in publication but not included here. The record of *Collohmannia* sp. is certainly incorrect (Roy Norton pers. comm.), and probably relates to *Epilohmannia*. In North America, *Collohmannia* is known only from a small area in the mountains of West Virginia (Norton & Sidorchuk 2014).

⁑ *Eniochthonius* sp., *Hydronothrus* sp., *Trhypochthoniellus* sp., *Trhypochthonius* sp., *Trimalaconothrus* sp., *Nanhermannia* sp., *Ceratoppia* sp., *Tegeocranellus* sp., *Suctobelbella* sp., *Scheloribates* sp., *Eporibatula* sp., *Zygoribatula* sp., *Zetomimus* sp., *Eupelops* sp., *Achipteria* sp., *Acrogalumna* sp. are listed in the publication but not included here.

1 as *Brachychthonius perpusillus* Berlese 1910 in Behan (1978)
2 as *Brachychthonius lydiae* (Jacot, 1938) in Belanger (1976)
3 as *Hypochthoniella pallidula* (C.L. Koch, 1835) in Belanger (1976)
4 as *Rhysotritia ardua* (Koch, 1841) in Belanger (1976)
5 as *Pseudotritia ardua* (Koch) 1841 in Jacot (1930)
6 as *Rhysotritia curticephala* (Jacot, 1938) in Donaldson (1996)
7 as *Pseudotritia simplex* Jacot, 1930 in Jacot (1930)
8 as *Stegnacarus diaphanum* Jacot, 1930 in Jacot (1930)
9 as *Hoplophthiracarus paludis* Jacot, 1938 in Donaldson (1996) and Belanger (1976)
10 as *Phthiracarus compressum* Jacot, 1930 in Jacot (1930)
11 as *Phthiracarus erinaceum* Jacot, 1930 in Jacot (1930)
12 as *Phthiracarus olivaceum* Jacot, 1930 in Jacot (1930)
13 as *Nothrus simplex* Banks, 1895 in Banks (1895)
14 as *Trimalaconothrus novus* (Sellnick, 1921) in Belanger (1976), Donaldson (1996), and Behan (1978)
15 as *Nanhermannia nana* (Nicolet, 1855) in Belanger (1976)
16 as *Nothrus biciliatus* C.L. Koch, 1841 in Belanger (1976)
17 as *Nothrus truncatus* grp. N. sp. A in Palmer and Norton (1992)
18 as *Trhypochthoniellus badius* (Berlese) in Palmer (1990) and Palmer and Norton (1990)
19 as *Trhypochthoniellus* nr. *badius* (Berlese) in Donaldson (1996)
20 as *Trhypochthoniellus crassus* Warburton and Pearce 1905 in Palmer (1990)
21 as *Belba* sp. nr. *inaequipes* Banks, 1947 in Belanger (1976)
22 as *Carabodes omo* Jacot in Belanger (1976)
23 as *Lasiobelba rigida* (Ewing, 1909) in Donaldson (1996)
24 as *Suctobelba grandis obtusa* Jacot in Belanger (1976)
25 as *Eupelops bilobus* (Sellnick, 1928) in Belanger (1976)
26 as *Xylobates capucinus* (Berlese, 1908) in Donaldson (1996)
27 as *Rostrozetes foveolatus* Sellnick, 1925 in Belanger (1976) and Donaldson (1996)
28 as *Oribata palustris* Banks, 1895 in Banks (1895)
29 as *Oribatella setosa* Banks, 1895 in Banks (1895)
30 as *Zetomimus setosus* (Banks 1895) in Behan-Pelletier and Eamer (2003)
31 as *Galumna curva* (Ewing) in Belanger (1976)
32 as *Oribata emarginata* Banks, 1895 in Banks (1895)
33 as *Zetes emarginatus* (Banks) in Belanger (1976)

a (Behan 1978)
b (Norton & Behan-Pelletier 2007)

c (Jacot 1930)
d (Canadian National Collection of Insects, Arachnids and Nematodes 2024)
e (Behan-Pelletier & Bisset 1994)
f (Banks 1895)
g (Palmer & Norton 1992)
h (Palmer 1990)
i (Palmer & Norton 1990)
j (Behan-Pelletier 1989)
k (Behan-Pelletier 1997)
l (Behan-Pelletier 1993)
m (Behan-Pelletier & Eamer 2003)
n (Norton *et al.* 2022)

U.S. states: AK: Alaska; AL: Alabama; CO: Colorado; CT: Connecticut; FL: Florida; GA: Georgia; ME: Maine; MN: Minnesota; MS: Mississippi; NH: New Hampshire; NY: New York; WI: Wisconsin; WV: West Virginia.

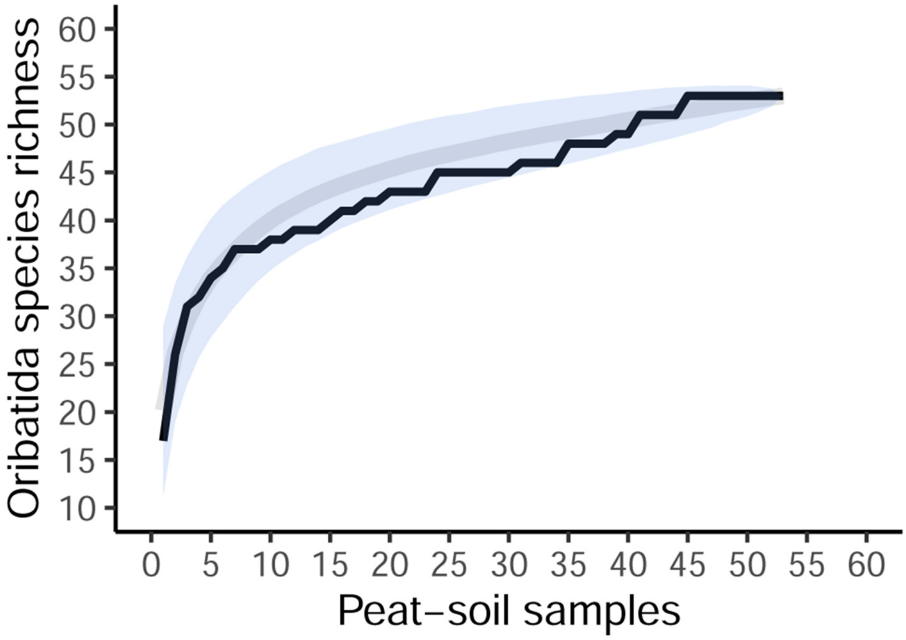

FIGURE 1. Species accumulation curve for the *Sphagnum*-dominated S1 Bog oribatid mite species showing cumulative richness. The collector curve is in black for sampling effort over time on the X-axis (left to right reads as time: 2015–2019), while the rarefied accumulation curve (blue) is plotted from means and standard deviation of 1,000 permutations of samples in random order.

Checklist of Oribatida from American peatlands

In total, we list 156 species recorded for American peatlands (Table 1) including the 49 species recorded from the S1 Bog site, of which only 26 species have been previously recorded for peatlands in the country. Previous work by Belanger (1976) (41 species) and Donaldson (1996) (31 species), the two other studies with the highest species richness, only share nine species occuring at both sites, and there are only six species recorded from all three sites. New York State has the greatest number of species recorded (73 species), largely due to the pioneering work of Belenger, followed by Minnesota (S1 Bog), and New Hampshire (Donaldson 1996). Similarly, the 49 species listed for Minnesota from this one peatland site, and the 31 species recorded from Donaldson for a single site in New Hampshire, suggest the importance of intensive sampling that is required to obtain comprehensive species lists for single peatland sites, and also highlight that these single sample locations are possibly a small proportional sample of peatland habitats within each State. Beyond these three sites, the state with the highest species richness is Alaska

(28 species) as sampled by Behan (1978) and electronic records from the Canadian National Collection of Insects, Arachnids and Nematodes, and Maine (10 species).

The most frequent species on the checklist is *Punctoribates palustris* recorded from five states (New York, New Hampshire, Minnesota, Wisconsin, Alabama and Georgia), *Nanhermannia dorsalis* from four states (Maine, New Hampshire, Minnesota, Mississippi), and *Carabodes granulatus* (New York, New Hampshire, Alabama, Mississippi). *Punctoribates palustris* is a widespread species, commonly associated with *Sphagnum* and other aquatic mosses as well as pond margins and muskeg; Behan-Pelletier and Lindo (2023) list records of *P. palustris* from thirteen U.S. states as well as in Canada. Similarly, *C. granulatus* is the *Carabodes* with the widest distribution in eastern North America and is recorded from at least 23 states (Behan-Pelletier & Lindo 2023), found in *Sphagnum* and other mosses, as well as leaf litter, rotten wood, lichens and fungi. The genus *Nanhermannia* is in need of revision, especially with respect to *N. dorsalis* which is a possible synonymy of *N. coronata* Berlese, 1913 that is known from peatlands in Europe (see Jacot 1937; Norton & Kethley 1990). That said, *N. dorsalis* and *N. nana* coexist in North American peatlands, although it is also unclear which records of *N. nana* from North America are valid (Roy Norton 2021, pers. comm.).

Of the S1 Bog species in Minnesota, 23 species are new records for peatlands in the U.S., including two new families (Trichthoniidae and Atopochthoniidae) and many new species in the Enarthronota Superfamily (i.e., within family Brachychthoniidae) for American peatlands, although these species have been previously recorded from peatlands in other countries. For instance, Barreto and Lindo (2021) found *Liochthonius brevis*, *L. sellnicki*, *Sellnickochthonius zelawaiensis*, *G. majestus*, *Tyrphonothrus foveolatus* and *N. dorsalis* in fen sites in Northern Ontario, Canada, which is only ~ 620 km away from the S1 Bog in Minnesota.

The oribatid mite fauna of the U.S. peatlands is highly similar to the peatland fauna of Canada, sharing 92 of the 156 species with the neighbour country, where 188 species have been recorded from peatlands (Barreto & Lindo 2021, Behan-Pelletier & Lindo 2023). This pattern is in line with the "classical" approach of zoogeographical regions proposed by Wallace (1876) that groups most of North America as part of the Nearctic region due to their biogeographical similarities in fauna taxa. The oribatid mite fauna of peatlands in the U.S. is also similar, albeit probably to a lesser extent, to the fauna in European peatlands. For instance, Seniczak *et al.* (2020) collected *Ceratoppia quadridentata* and *T. foveolatus* from *Sphagnum* mosses in Norway, Starý (2006) and Lehmitz *et al.* (2020) found *S. zelawaiensis* and *T. foveolatus* in peat bogs in the Czech Republic and Germany, respectively, and Minor *et al.* (2016) found *T. foveolatus* in peat bogs in Eastern Russia. A comparison between the oribatid mite diversity from the Nearctic region and the Palearctic region (roughly, Europe, northern Africa, and northern Asia) shows that only 359 out of the ~4,700 species are shared between the regions (Schatz 2004). It is important to note, though, that this similarity includes species from all habitats, not only peatlands as we were unable to validate all European habitat records.

Several species listed are found in a variety of habitats and considered cosmopolitan, such as *Hypochthonius rufulus*, *Platynothrus peltifer*, *T. maior*, *Oppiella nova*, and *Tectocepheus velatus* (Behan-Pelletier & Lindo 2019; Subías 2022), which reinforces the idea that the peatland oribatid mite fauna also comprises non-specialist species (Donaldson 1996; Barreto 2021). In fact, some species collected during the S1 Bog sampling in Minnesota were unexpected as they are typically found in drier environments (e.g., dry forests, dry montane regions, canopy habitats); these include *Eueremaeus* nr. *proximus*, *Scapheremaeus palustris*, and *Cepheus corae*. Yet, to the best of our knowledge, we report the first record of *Mycobates hyaleus* and *Atopochthonius artiodactylus* for a peatland system, as they have been previously only collected in forests in North America (mosses, lichens, litter) (Behan-Pelletier & Lindo 2019). The presence of these species may be a result of the harvesting the site went through in 1969 and 1974 (Perala & Verry 2011) that led to a reduction in moisture. Drying has been documented as a major disturbance for peatland oribatid mite communities (Laiho *et al.* 2001; Lehmitz 2014) with soil fauna communities changing towards those of forests (Silvan *et al.* 2000). For instance, Lehmitz (2014) compared samples before and after a harvesting event in a German bog and concluded that harvesting favours terrestrial species.

Indeed, based on the oribatid mite community from the Spruce Hole Bog, New Hampshire, Donaldson (1996) posited that only a small portion of species found in peatlands are specialists occurring in very high abundances, likely due to a semi-aquatic habitat association and preference for acidic environments. In our case, peatland specialist species included the abundant *E. mahunkai*, *L. lustrum* and *Mainothrus badius*. Interestingly, Norton and Behan-Pelletier (2007) note that all known sites inhabited by *E. mahunkai* are peatlands (fens or bogs), while the specific name 'lustrum' from *L. lustrum* is Latin for bog and refers to the habitat of this species. These three species

(Barreto *et al.* 2021) and other oribatid mites (Minor *et al.* 2019; Lehmitz *et al.* 2020) have been shown to associate with high moisture levels.

Oribatid mites have been noted to be better represented by thelytokous species in peatlands compared to other ecosystems (Behan-Pelletier & Bissett 1994; Maraun *et al.* 2019), both in terms of number of thelytokous species and their collective proportional abundance. This was evident at the S1 Bog, based on reproductive modes indicated by Norton *et al.* (1993), Fischer *et al.* (2010) and Maraun *et al.* (2019). Thelytokous species represented ~90% of S1 Bog species, and this number is reduced to ~79% if we disregard the species without confirmation of reproduction mode in literature (i.e., the ones believed to be thelytokous but lacking data to support it). Similar trend is seen for the abundance of thelytokous species, that represented ~66% of all individuals, but ~52% if removing the aforementioned cases. This pattern might be related to a lower efficacy of free-standing spermatophores produced by males in wet habitat like peatlands (Norton & Palmer 1991), and/or because high accumulation of dead organic matter provides ample resources that are easy to access in these systems (Maraun *et al.* 2019).

Not surprisingly, peatland records for the thelytokous family Brachychthoniidae were extended, with five new species added to the checklist, similar to peatland sites in Canada (Barreto & Lindo 2021). A comparison between the species in the S1 Bog and the species previously recorded in American peatlands, highlights some species-poor families at our site. For instance, the predominantly sexual families Phthiracaridae (two records vs. eight from other peatlands) and Ceratozetidae (five records vs. 15 from other peatlands), and the predominantly thelytokous families Trhypochthoniidae (two records vs. seven records from other peatlands) and Nothridae (one record vs. six from other peatlands). We note that our site is surrounded by a predominantly deciduous forest, which could explain in part the low diversity in Phthiracaridae, as these mites are endophagous of decaying wood, including conifer needles, as immatures (Jacot 1939).

Our sampling from the S1 Bog in Minnesota contains at least four undescribed species (*Brachychthonius* n. sp., *Hoplophorella* n. sp., *Liebstadia* n. sp., and *Trichoribates* n. sp.), and we predict that many more undescribed species are likely contained within peatlands of the U.S. For instance, Alaska contains extensive peatland habitats that formed early in deglacial periods and that are estimated to be >15,000 years old (Jones & Yu 2010) and undescribed species have been recorded, for example, in Behan (1978) that showed that 13.4% of the species found in Alaska, including species from peatlands, were undescribed.

As not many peatland sites have been sampled in the U.S., this checklist has a geographical limitation. It is also important to note the relatively low area peatlands cover in the country, representing only ~2% of the landscape (Xu *et al.* 2018) with the vast majority concentrated in only two states in the country's North region, Minnesota and Alaska (Minnesota Scientific and Natural Areas Patterned Peatlands 2022). Nonetheless, the high diversity sampled from peatlands in other States, often from only one sample location, highlights the understudied oribatid mite fauna of many habitats in the U.S.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Conceptualization, C.B.; methodology, Z.L. and C.B.; formal analysis, C.B. and Z.L.; investigation, C.B. and Z.L.; resources, Z.L.; writing—original draft preparation, C.B.; writing—review and editing, Z.L.; funding acquisition, Z.L. All authors have read and agreed to the published version of the manuscript.

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