Ann. Zool. Fennici 56: 121–136 ISSN 0003-455X (print), ISSN 1797-2450 (online)
Helsinki 27 September 2019

Diverse mite communities (Acari : Oribatida, Mesostigmata) from a broadleaf forest in western Norway

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Received 6 May 2019, final version received 29 Aug. 2019, accepted 16 Aug. 2019

Seniczak, A., Bolger, T., Roth, S., Seniczak, S., Djursvoll, P. & Jordal, B. H. 2019: Diverse mite communities (Acari : Oribatida, Mesostigmata) from a broadleaf forest in western Norway. — *Ann. Zool. Fennici* 56: 121–136.

Broadleaf forests are rare in Norway and they are considered one of the most biodiverse terrestrial habitats in Fennoscandia. These forests are poorly studied in terms of their acarofauna. Mites of two groups, Oribatida and Mesostigmata, were studied in a broadleaf forest in western Norway. In total, 6350 oribatid mites, representing 67 species (i.e., 25% of the known Norwegian species) and 559 mesostigmatid mites representing 22 species (9% of the species recorded from Norway) were collected. The mean densities of Oribatida and Mesostigmata were 454 and 40 individuals per 0.5 dm^3, respectively. The most abundant member of Oribatida was *Oribatula exilis* (29% of Oribatida collected), while *Zercon lindrothi* made up 59% of Mesostigmata. Fifteen of the oribatid species were first records for Norway, including six new to Fennoscandia: *Phthiracarus compressus*, *Suctobelbella arcana*, *S. hammerae*, *S. prominens*, *Campachipteria patavina* and *Liebstadia longior*.

Introduction

Mites (Acari) are minute arthropods, barely visible to the naked eye, and are particularly abundant and diverse in temperate forests (Walter & Proctor 1999). They live in different forest microhabitats, from deep soils to tops of trees, but usually are most abundant and species-rich among mosses (e.g. Seniczak *et al.* 2018). Densities higher than 100 000 indiv./m^2 are commonly reported from the upper 10 cm of soil and litter and species richness may be over 100 (Walter & Proctor 1999, Norton & Behan Pelletier 2009, Bolger *et al.* 2014). One of the most abundant and diverse groups of mites are Oribatida, commonly called 'moss mites'. These are mainly saprophagous species which play a significant role in the decomposition of organic matter. Mesostigmata, on the other hand, are mainly predators, but some also feed on detritus

This paper was edited by Kai Ruohomäki

and fungi (Gulvik 2007). Worldwide, there are more than 11 000 described species of Oribatida (Subías 2019) and more than 11 000 species of Mesostigmata (Beaulieu *et al.* 2011).

Forests cover about 130 000 km^2 of Norway, i.e. one third of the mainland area (Norwegian Ministry of the Environment 2011), but broadleaf forests cover only 17% of the forest area. These forests are located mainly in the western and southern coastal areas where precipitation is high and winters are relatively warm, and they are considered "Norway's forest treasure", being one the most biodiverse terrestrial habitats in the entire Fennoscandia (Håpnes 2003).

Mites from broadleaf forests are poorly studied, both in Norway and elsewhere in Fennoscandia (Huhta *et al.* 2005). Most studies in Norway focused on coniferous forests (e.g. Hågvar & Abrahamsen 1980, 1984, Hågvar & Amundsen 1981, Hågvar 1991, 1998, Edsberg & Hågvar 1999, Thunes *et al.* 2003, 2004, Hågvar & Hågvar 2011) and only a few studies included birch forests (Cadwalladr 1969, Hågvar & Kjøndal 1981).

The broadleaf forest selected for the present study represents a unique type of habitat in the western-Norwegian fjord landscape considered a biodiversity hotspot area (Nordén *et al.* 2018). Due to its location on a very steep slope, the area has not been under pressure (apart from e.g., pollarding, extensive grazing), and has thus remained pristine. This study is part of a species inventory project of the rare and rich habitats for the Norwegian Biodiversity Information Centre. Broadleaf forests are presumably highly diverse (e.g., Skubała 1999, Huhta *et al.* 2010, Seniczak *et al.* 2018) and in Norway there have been very few, if any, inventories of mites in these forests, so the aim of this study was to increase the knowledge on the diversity of two mite groups, Oribatida and Mesostigmata.

In Norway, the checklist currently includes 244 species of Oribatida (Mehl 1979), and 240 species of Mesostigmata (Gwiazdowicz & Gulvik 2005, 2007, Gwiazdowicz *et al*. 2013, Bolger *et al.* 2018b). We, thus, expected that by studying broadleaf forests the number of recorded species could considerably increase. As the first step towards an assessment of the Norwegian acarofauna, here we present the data from one particularly rich broadleaf forest habitat.

Material and methods

Site description

Samples were collected in a broadleaf forest located in western Norway (HOI, Kvam: Mundheim, Furhovda, 60.155°N, 5.896°E, 97 m a.s.l.). The study area covers 2.49 ha and belongs to the boreonemoral region and the highly oceanic vegetation section (Moen 1999). The climate is oceanic, with mean annual precipitation of between 2000 and 2600 mm (Førland 1993), and the mean annual temperature of 7.2 °C (Aune 1993). Summers are relatively cool, with the mean temperatures between 10 and 15 °C in July and August. Winters are relatively mild, and in February, the coldest month, the mean temperatures are between –3 and –1 °C. The sampling site is a steep and eastern exposed slope. The bedrock consists mainly of greenschist stone and slate. The loose substrate in the locality consist of weathered material.

The selected forest site belongs to an unusual type of habitat, which is a low-herb deciduous forest with little historical disturbance (Fig. 1). The forest is dominated by trees such as grey alder (*Alnus incana*), ash (*Fraxinus excelsior*), hazel (*Corylus avellana*), wych elm (*Ulmus glabra*) and silver birch (*Betula pendula*), while the ground is dominated mostly by mosses. Forests of this kind usually have a long history of moderate exploitation by humans such as harvesting of wood and sometimes grazing by domestic animals. Hazel coppices were harvested (preferentially with a diameter of 2–3 cm) to produce barrel hoops, whereas elm trees were pollarded for animal fodder. This types of activities ended during the first half of the 20th century. Only the steepest parts of the area around this forest were never used for spruce (*Picea abies*) plantations. As a result, sporadic spruce occurrence is common also at the sampling site.

Sampling and identification

A total of 14 samples, each 0.5 dm^3 in volume, were gathered by hand on 8 June 2017. They included moss collected from soil surface (5 samples), moss collected from tree bark at the ground

Fig. 1. Forest floor at the study site in Mundheim, Furhovda.

level (2 samples), moss collected from tree bark 1.5 m above ground (2 samples), moss collected from stump (2 samples), dead wood (1 sample) and moss collected from dead wood (2 samples). Mites were extracted using Tullgren funnels for 14 days, and preserved in 90% ethanol.

Specimens of Oribatida were mounted on slides in lactic acid. Adult specimens were identified using the keys of Gilyarov and Krivolutskii (1975), Pérez-Íñigo (1993, 1997) and Weigmann (2006), while juveniles were identified based on Seniczak (1972, 1989, 1990), Ermilov and Łochyńska (2009), Seniczak *et al.* (2009, 2013, 2016, 2017), and Seniczak and Seniczak (2010, 2011, 2018). The nomenclature of oribatid species follows Norton and Ermilov (2014), Subías (2004, 2019) and partly Weigmann (2006). Adult Mesostigmata were identified following Bhattacharyya (1963), Lundqvist and Johnston (1986), Hyatt and Emberson (1988), and Karg (1989, 1993). The specimens are deposited at the University Museum of Bergen, Norway, with the exception of some duplicates which were donated to those who performed identification (second and fourth authors of this paper).

Habitat preferences (Table 1) of oribatid mites were taken from Weigmann (2006), Beck *et al.* (2014), Schatz (2015), and Weigmann *et al.* (2015), and those of Mesostigmata from Hyatt and Emberson (1988), Karg (1989, 1993), Salmane and Brumelis (2010), Huhta (2016) and Bolger *et al.* (2018a). These habitats include the following types: alpine, subalpine, aquatic (reproduction and all stages of life cycle in water or at its margins; Schatz & Behan-Pelletier 2008), hygrophilous (living in wet places), mesohygrophilous (prefer high moisture but not wet places), xerophilous (living in dry places), arboricolous (living on trees), lichenicolous (living on lichens), muscicolous (living in mosses), praticolous (meadow species), silvicolous (forest species), tyrphophilous (bog species) and eurytopic (occurring in more than three habitat types).

New records of Oribatida for Norway are based on the checklist of Mehl (1979) and the following publications: Kulczyński 1902, Sellnick (1908), Thor (1930, 1934, 1937), Karppinen (1967, 1971), Cadwalladr (1969), Niedbała (1971b), Solhøy (1979), Hågvar and Abrahamsen (1980), Hippa *et al.* (1988), Colloff (1993), Solhøy and Solhøy (2000), Hodkinson and Bird (2004), Thunes *et al.* (2004), Skubała and Gulvik (2005), Seniczak *et al.* (2006, 2007a, 2007b, 2007c, 2010), Heggen (2010), Hågvar *et al.* (2009), Hein *et al.* (2013), Miko and Monson (2013), Seniczak and Graczyk (2013), Hågvar and Steen (2013), Seniczak *et al.* (2017). The species new to Fennoscandia are based on Lundqvist (1987) and Niemi *et al*. (1997) as well as on Koponen *et al.* (1997), Huhta *et al.* (1998, 2005, 2010, 2012a, 2012b), Huhta and Niemi

Table 1. Oribatida and Mesostigmata found in broadleaf forest in western Norway in various microhabitats. A: moss collected from ground, B: moss collected from tree at low level, C: moss collected from tree 1.5 m above ground, D: moss collected from stump, E: dead wood, F: moss collected from dead wood. Habitat types where species were found: al = alpine, aq = aquatic, ar = arboricolous, eu = eurytopic, hy = hygrophilous, li = lichenicolous, mh = mesohygrophilous, mu = muscicolous, pr = praticolous, si = silvicolous, su = subalpine, ty = tyrphophilous, xe = xerophilous. Species new to Norway are in boldface, and new to Fennoscandia are indicated with an asterisk (*).

Taxon	Habitat	A	B	C	D	E	F	Total
ORIBATIDA								
Brachychthoniidae								
Liochthonius lapponicus (Trägårdh, 1910)	hy si ty		5				16	21
L. neglectus Moritz, 1976	si	37			17			54
Neoliochthonius occultus (Niedbała, 1971)	si						11	11
Hypochthoniidae								
Hypochthonius rufulus C.L. Koch, 1835	ar mh	11			3	1	9	24
Eniochthoniidae								
Eniochthonius minutissimus (Berlese, 1904)	eu		1		28	1	6	36
Eulohmanniidae								
Eulohmannia ribagai (Berlese, 1910)	mh si al					1		1
Phthiracaridae								
Atropacarus striculus (C.L. Koch, 1835)	eu	11						11
Phthiracarus bryobius Jacot, 1930	mu si			1				1
P. clavatus Parry, 1979	hy	7			1	1	3	12
****P. compressus*** Jacot, 1930	si		1	2			4	7
P. crinitus (C.L. Koch, 1841)	si	1		2	2	21	38	64
P. laevigatus (C.L. Koch, 1841)	si mu xe	9					17	26
P. longulus (C.L. Koch, 1841)	si		6		2	3	5	16
Phthiracarus spp.		36	1	3	8		4	52
Euphthiracaridae								
Acrotritia duplicata (Grandjean, 1953)	si			3	5	12	8	28
Steganacarus magnus (Nicolet, 1855)	si	2					1	3
Malaconothridae								
Tyrphonothrus maior (Berlese, 1910)	aq mu ty hy	1						1
Nanhermanniidae								
Nanhermannia sellnicki Forsslund, 1958	hy si						1	1
Nanhermannia elegantula Berlese, 1913	si					5		5
Damaeidae								
Damaeus onustus C.L. Koch, 1841	eu	5						5
Porobelba spinosa (Sellnick, 1920)	si li mu pr xe mh	3	4		23			30
Cepheidae								
Tritegeus bisulcatus Grandjean, 1953	si	1						1
Eremaeidae								
Eueremaeus sp.		1	59	82			2	144
Caleremaeidae								
Caleremaeus monilipes (Michael, 1882)	si			1	1	5	12	19
Astegistidae								
Furcoribula furcillata (Nordenskiöld, 1901)	si	4	6	1	31			42
Liacaridae								
Adoristes ovatus (C.L. Koch, 1839)	si	8			2		2	12
Liacarus coracinus (C.L. Koch, 1841)	eu	1		2			1	4
Xenillus tegeocranus (Hermann, 1804)	si su	10	9	4	5		3	31
Peloppiidae								
Ceratoppia quadridentata (Haller, 1882)	eu	17					1	18
Carabodidae								
Carabodes areolatus Berlese, 1916	mu si mh ar			1				1
C. femoralis (Nicolet, 1855)	si ty	7					15	22
C. labyrinthicus (Michael, 1879)	ar mu si				1			1
C. marginatus (Michael, 1884)	mu si		1					1
C. reticulatus Berlese, 1913	si mu				1			1

continued

Table 1. Continued.

Taxon	Habitat	A	B	C	D	E	F	Total
Tectocepheidae								
Tectocepheus velatus (Michael, 1880)	eu				1			1
Quadroppiidae								
Quadroppia quadricarinata (Michael, 1885)	eu	130	28	4	82	1	12	257
Oppiidae								
Berniniella sigma (Strenzke, 1951)	pr si	2						2
Dissorhina ornata (Oudemans, 1900)	eu	235	35	64	43	1	44	422
Moritzoppia keilbachi (Moritz, 1969)	si pr				125		26	151
Oppiella nova (Oudemans, 1902)	eu	2				18	44	64
O. splendens (C.L. Koch, 1841)	si mu	156	292	3	338		35	824
Suctobelbidae								
Suctobelbata truncicola (Forsslund, 1941)	si					5	5	10
Suctobelba regia Moritz, 1970	si	5	7	26	51		18	107
****Suctobelbella arcana*** Moritz, 1970	si	4						4
****S. hammerae*** (Krivolutsky, 1965)	si					1		1
****S. prominens*** (Moritz, 1966)	si pr xe	10						10
S. subcornigera (Forsslund, 1941)	eu	16	2	1	23	8	1	51
S. subtrigona (Oudemans, 1900)	eu	3						3
Autognetidae								
Autogneta traegardhi Forsslund, 1947	si	3			3		3	9
Thyrisomidae								
Banksinoma lanceolata (Michael, 1885)	pr ty si	1			1	4	3	9
Pantelozetes paolii (Oudemans, 1913)	eu pr xe	1						1
Phenopelopidae								
Eupelops acromios (Hermann, 1804)	ar si xe	1		1	2		1	5
Achipteriidae								
Achipteria punctata (Nicolet, 1855)	si pr	345	9	6			42	402
****Campachipteria patavina*** (Oudemans, 1914)	?			1				1
Oribatellidae								
Ophidiotrichus tectus (Michael, 1884)	ar si mu xe				6	11	17	34
Ceratozetidae								
Melanozetes mollicomus (C.L. Koch, 1839)	mu si ty al		71	82		15	52	220
Sphaerozetes piriformis (Nicolet, 1855)	ar mu si xe		18	34	13			65
Trichoribates trimaculatus (C.L. Koch, 1835)	ar mu pr si xe			1				1
Chamobatidae								
Chamobates birulai (Kulczynski, 1902)	si	4	17	5	1		1	28
Ch. borealis Trägårdh, 1902	si	522	130	22	209	4	268	1155
Haplozetidae								
Lagenobates lagenulus (Berlese, 1904)	ty si	1			1			2
Scheloribatidae								
****Liebstadia longior*** (Berlese, 1908)	si ty ar li mu				1			1
L. similis (Michael, 1888)	hy pr si		2	1		5		8
Scheloribates initialis (Berlese, 1908)	eu	3						3
S. latipes (C.L. Koch, 1844)	eu	1						1
S. laevigatus (C.L. Koch, 1835)	hy pr				1			1
S. pallidulus (C.L. Koch, 1841)	hy si				1			1
Oribatulidae								
Oribatula exilis (Nicolet, 1855)	ar mu	19	258	561	697		255	1790
MESOSTIGMATA								
Cillibidae								
Cilliba cassidea (Hermann, 1804)	mu mh pr si	20	1				4	25
Dinychidae								
Dinychus arcuatus (Trägårdh, 1943)	si	1						1
Trematuridae								
Trichuropoda ovalis (C.L. Koch, 1839)	si				1			1

continued

Table 1. Continued.

Taxon	Habitat	A	B	C	D	E	F	Total
Uropodidae								
Uropoda (*Uropoda*) *minima* Kramer, 1882	mh mu pr si	6			1	1	1	9
Zerconidae								
Zercon lindrothi Lundqvist & Johnston, 1986	si	229	27	4	22	7	57	346
Parasitidae								
Holoparasitus inornatus (Berlese, 1906)	mh mu pr si	2	4		1			7
Lysigamasus alstoni (Bhattacharyya, 1963)	pr			1				1
L. armatus Halbert, 1915	pr si						1	1
L. lapponicus (Trägårdh, 1910)	pr si	1	1		1	1	3	7
L. runcatellus (Berlese, 1903)	mu pr si		1		1		2	4
Paragamasus robustus (Oudemans, 1902)	mh mu pr si							4
P. integer (Bhattacharyya, 1963)	mu si			1				1
Pergamasus alpestris (Berlese, 1904)	mh si	7	4	1	2	1	3	18
P. longicornis (Berlese, 1906)	mh si				8		3	11
Veigaiidae								
Veigaia cerva (Kramer, 1876)	si	3				1	2	6
V. nemorensis (C.L. Koch, 1839)	si	1			1	2		4
V. transisalae (Oudemans, 1902)	mh si	35	3			1	4	43
Macrochelidae								
Geholaspis (*Geholaspis*) *longi-spinosus* (Kramer, 1876)	mh si	1	3			2	1	7
Macrocheles dentatus (Evans & Browning, 1956)	si	1					1	2
M. opacus (C.L. Koch, 1839)	pr si	1						1
M. submotus Falconer, 1924	mh pr si					1		1
Ascidae								
Asca aphidiodes (Linnaeus, 1758)	pr si	6				1		7
Unidentified		25	1	5	6	10	5	52

(2003), Penttinen *et al.* (2008), Siira-Pietikäinen *et al.* (2008), Penttinen and Huhta (2009), Elo *et al.* (2016, 2018).

Results

Mite fauna

In total, 6350 oribatid mites were extracted from the samples, including 1585 juveniles (25%). The total number of mesostigmatid mites was 559, including 52 juveniles and specimens that could not be identified. The mean ± SD density of Oribatida was 454 ± 250 indiv./0.5 dm^3 of collected substrate (moss or dead wood) and that of Mesostigmata 40 ± 19 indiv./0.5 dm^3. The highest density of Oribatida was in moss growing on stumps and the lowest in dead wood, while the density of Mesostigmata was similar in all sampled microhabitats (Fig. 2).

Samples of moss collected from the soil had an area of 100 cm^2 and were 5 cm deep. The mean ± SD Oribatida and Mesostigmata densities in this substrate were 163 600 ± 9000 indiv./m^2 and 30 669 ± 5000 indiv./m^2, respectively.

In total, 67 species of Oribatida representing 30 families, and 22 species of Mesostigmata from nine families were collected (Table 1). The Shannon diversity index (H') was 2.54 and 1.52 for Oribatida and Mesostigmata, respectively. However, only four species of Oribatida (*Quadroppia quadricarinata*, *Dissorhina ornata*, *Suctobelbella subcornigera* and *Chamobates borealis*) and one species of Mesostigmata (*Zercon lindrothi*) were found in all studied microhabitats, whereas 40% of all oribatid species and 48% of all Mesostigmata were found exclusively in one type of microhabitat. Relative abundances of ten oribatid species and one mesostigmatid species were greater than 1% (Fig. 3). The most

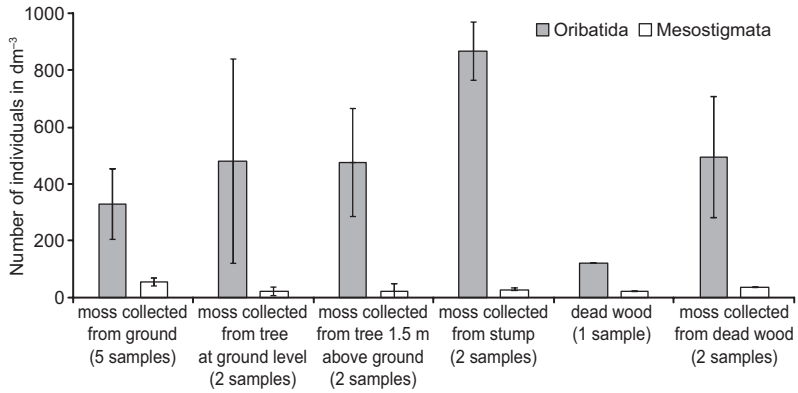

Fig. 2. Densities (mean ± SD) of Oribatida and Mesostigmata in sampled microhabitats.

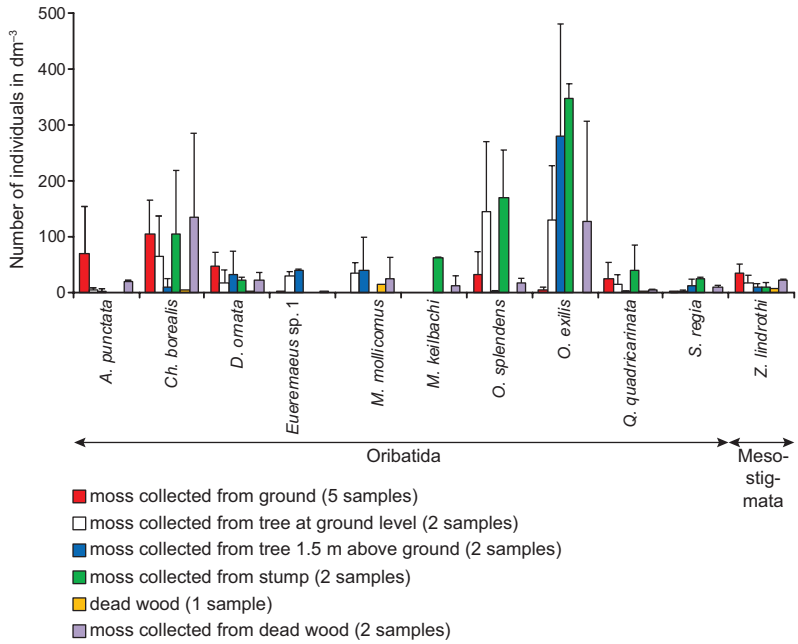

Fig. 3. Densities (mean + SD) of Oribatida and Mesostigmata with a relative abundance greater than 1%.

abundant oribatid species was *Oribatula exilis* (29%) followed by *Chamobates borealis* (17%), and the most abundant member of Mesostigmata was *Zercon lindrothi* (59%). *Oribatula exilis* was most abundant in moss on stumps but also quite abundant in other microhabitats (Fig. 2), however, only few specimens of this species were found among mosses on the soil surface, and it was entirely absent from dead wood. *Chamobates borealis* and *Z. lindrothi* were equally abundant in nearly all microhabitats, with fewer specimens found in moss collected from tree 1.5 m above ground and in dead wood. All mesostigmatids and most oribatids were silvicolous, and only 13 oribatid species (19%) were eurytopic, but those were usually not abundant (Table 1).

New species records in Norway

Fifteen species of Oribatida found in our study are new to the Norwegian fauna (Table 1). The majority of these species (60%) were represented by fewer than 10 individuals. All these species are regarded as silvicolous. The following six of the species new to Norway are also new to Fennoscandia: *Phthiracarus compressus*, *Suctobelbella arcana*, *S. hammerae*, *S. promi-*

nens, *Campachipteria patavina*, and *Liebstadia longior*.

Neoliochthonius occultus (Niedbała, 1971)

The holotype of this species was found in Poland in litter from the herb layer in spruce forest with some old beech trees and hornbeams (Niedbała 1971a). The species has a European and Atlantic distribution (Subías 2004, 2019), and is found on the forest floor, usually in coniferous forests, but its ecology still remains unclear (Weigmann 2006). In Canada it was found in soil of a moist coniferous forest at a high altitude (Berch *et al.* 2007). It is also known from Sweden (Moritz 1976). We found this species only in one of the microhabitats (moss on dead wood) and only in low numbers.

Phthiracarus bryobius Jacot, 1930

A Holarctic species and found in the USA, Poland, Germany, Ireland, Finland, Spain, Romania, Mongolia, Japan, Nepal, Crimea and Caucasus (Niedbała 1992, Huhta *et al.* 2010, 2012a, 2012b, Niedbała & Ermilov 2014, Weigmann *et al.* 2015, Arroyo *et al.* 2017). It has also been reported from Costa Rica but most probably it has been introduced there only in recent years (Niedbała 2008). In Finland it is quite abundant in different forest types, both coniferous and broadleaf (Huhta *et al.* 2010, 2012a, 2012b), while in Ireland it was found in grasslands and among mosses growing in canopies of Scots pine (Arroyo *et al.* 2017). Subías (2004, 2019) synonymised this species with *Phthiracarus clavatus* Parry, 1979 — found in Norway (Mehl 1979) — but many other authors distinguish the two species (Niedbała 1992, 2015, Niedbała & Olszanowski 2008, Weigmann *et al.* 2015, Arroyo *et al.* 2017).

Phthiracarus compressus Jacot, 1930

A Holartic and north-oriental (Subías 2004, 2019) forest species (Weigmann 2006), also found in swamps (Niedbała 1992). It has previously been reported from Denmark (Niedbała 1992), but not from Fennoscandia. We collected only few individuals, from tree bark and mosses growing on dead wood.

Phthiracarus crinitus (Koch, 1841)

This forest species is found in the western parts of the Palaeractic in decaying wood (Weigmann 2006) and among mosses on the forest floor (Niedbała 1992). According to Subías (2004, 2019), it is found less frequently in the north, but it has been reported from various habitats in Finland, including deciduous and marsh forest, swamps, dead wood and ant hills (Penttinen *et al.* 2008, Huhta *et al.* 2005, 2010). We found this species in nearly all microhabitats, but usually only single individuals were encountered. It was relatively abundant only in dead wood (17% of all Oribatida found there) and in mosses growing on dead wood (4% of all Oribatida found there).

Nanhermannia elegantula Berlese, 1913

A species with mainly Holartic distribution with a peculiar extension to the south Atlantic island of Santa Helena (Subías 2004, 2019). It is found mostly in broadleaf forests, e.g. from oak logs (Bluhm *et al.* 2015) and has been reported as rare in coniferous forests (Weigmann 2006). Based on measured enzyme activity in this species, it was classified as a herbo-fungivorous grazer, i.e. able to digest all main food components of both green plants and fungi (Siepel & De Ruiter-Dijkman 1993). It has been reported from Sweden (Lundqvist 1987) and Finland (Niemi *et al.* 1997) where it was found only in dead wood and only in low numbers.

Berniniella sigma (Strenzke, 1951)

A species present in the western Palaeractic and central-western Asia (Subías 2004, 2019). According to Weigmann (2006) it lives in meadows and pine forests, and was one of the dominant species in a young pine forest in Germany (Kreibich & Alberti 2006). We found only two individuals in one sample of moss from the soil surface. It has also been reported from other broadleaf forests: the holotype originated from raw humus of a beech-forest in Holstein (Germany) (Strenzke 1951), and in Finland it was found in a maritime deciduous forest (Niemi *et al.* 1997).

Moritzoppia keilbachi (Moritz, 1969)

A species distributed in Palaearctic, Ethiopian and Neotropical regions (Subías 2004, 2019), and is found in different forests but also in meadows (Weigmann 2006). In Ireland, it was found in moss from the canopy and soil surface in oak forests (Arroyo *et al.* 2017). It has also been reported from caves in Sweden (Hippa *et al.* 1988) and from different habitats in Finland, including pine forest and alpine areas (Huhta *et al.* 2010). According to Niemi (1995), it is quite common and sometimes very abundant. We found it only among mosses growing on a stump and dead wood. It constituted 7% and 2% of Oribatida specimens, respectively.

Suctobelbata truncicola (Forsslund, 1941)

A species known from the Palaearctic region (Subías 2004, 2019) and the holotype was collected in Sweden from under the bark of an old spruce trunk. The species was also found under the bark of dead pine and birch trees (Forsslund 1941). It is therefore a silvicolous species living under tree bark of dead wood (Starý 2002). It is not common (Weigmann *et al.* 2015), although Starý (2002, 2006) found it in considerable numbers in dead wood in a mixed mountain forest. We found only few individuals in dead wood and among mosses growing on dead wood.

Suctobelba regia Moritz, 1970

A European species (Subías 2004, 2019), typical for acidic forest soils (Weigmann 2006), also known from Sweden (Lundqvist 1987) and Finland (Elo *et al.* 2016). We found it in nearly all habitats, except in dead wood. Its abundance was low among mosses growing on the soil surface while it was quite abundant among mosses growing on tree bark and dead wood constituting 3% of Oribatida in those microhabitats.

Suctobelbella arcana Moritz, 1970

A Holarctic species typical for forest soils (Weigmann 2006), which was also confirmed in our study. We found the species only among mosses collected from the ground but in low numbers. In Ireland, it was also found in agricultural grasslands (Arroyo *et al.* 2017). This species has not been previously reported from Fennoscandia.

Suctobelbella hammerae (Krivolutsky, 1965)

The only individual of this species was found from dead wood. Subías (2004, 2019) considered this taxon to be a synonym of *Suctobelbella duplex* (Strenzke, 1950) (also not known from Fennoscandia), while other authors recognized it as a valid species (e.g. Starý 2005, Weigmann 2006, Weigmann *et al.* 2015). This species is typical for broadleaf forests, and have been recorded in soils of numerous forests in Germany (Weigmann *et al.* 2015) and in mosses on beech trunks in a mountainous beech forest in the Czech Republic (Starý 2005). Our finding is the first record from Fennoscandia.

Suctobelbella prominens (Moritz, 1966)

A European species (Subías 2004, 2019), which is rarely collected and then usually found in deciduous forest soils (Weigmann *et al.* 2015). It was also found in rotting spruce wood in a moist highland (Starý 2005, 2008). It has not been previously reported from Fennoscandia.

Campachipteria patavina (Oudemans, 1914)

A European species, found on dry leaves (Oudemans 1927), dry mosses on oak trees (Kunst 1959), in nests of moles and rodents (Oudemans 1913, Dubinina *et al.* 1966), and in ant mounds (Olszanowski *et al.* 1996). It is found very rarely, e.g. in Poland it has been found in only one locality, and has not been previously found in Fennoscandia. We found only one individual on tree bark.

Lagenobates lagenulus (Berlese, 1904)

A species widely spread throughout the Holarctic (Starý 2008) and considered a tyrphophil (typical for bogs) (Weigmann 2006, Schatz 2015). It, however, also occurs in low abundances in other wet habitats, including humid coniferous and broadleaf forests (Maraun 1997, Starý 2008, Huhta *et al.* 2010, Schatz 2015). We found only

two individuals: one among moss on the ground and one on a tree stump. Single individuals of this species were also reported from Finland, but they were present in very different habitats such as seashore, dry meadows and dead wood (Huhta *et al.* 2010).

Liebstadia longior (Berlese, 1908)

A Holarctic species (Subías 2004, 2019) found in forests, swamps and bogs, mainly among mosses and lichens on tree bark (Weigmann 2006). We found it among mosses growing on tree bark. This is the first record of this species from Fennoscandia.

Discussion

Broadleaf forests in western Norway are rich habitats with high mite diversity. As we documented here, mites were very abundant and rich in species in the forest studied despite rather limited sampling. We found 89 species in total (67 of Oribatida and 22 of Mesostigmata), representing 39 families. Moreover, 15 oribatid species were first records in Norway and seven species of Mesostigmata from the same forest were earlier noted as new to Norway (Bolger *et al.* 2018b). These findings support our hypothesis that sampling in broadleaf forest can considerably increase the knowledge on the mite diversity in Norway.

Broadleaf forests are characterized in general by quite abundant and species-rich communities of Oribatida and Mesostigmata. Although abundances of these groups are usually lower in broadleaf than in coniferous forests, species diversity is usually higher in the former (e.g. Skubała 1999, Huhta *et al.* 2005, 2010). Although we are unaware of studies from Fennoscandia reporting mite abundancies along with diversity indices in similar microhabitats as in the present study, our results are comparable to those from a natural lowland beech forest in Poland, where similar microhabitats as in present study were sampled (Seniczak *et al.* 2018). Although the average density of Oribatida was higher in that forest (2154 indiv. per 500 cm^3), the average density of Mesostigmata was similar to that in our study (64 indiv. per 500 cm^3), and species diversities of both groups were similar to those in our study (mean Shannon's diversity index $H' = 2.20$ for Oribatida and $H' = 1.76$ for Mesostigmata) (Seniczak *et al.* 2018).

The importance of elm-dominated forests and similar forest ecosystems for biodiversity of western Norway has been shown for vascular plants (Moe & Botnen 1997, Nordén *et al.* 2013), lichens (Ihlen *et al.* 2001, Nordén *et al.* 2013) and fungi (Gaarder *et al.* 2012). Studies on invertebrate fauna in old broadleaf forests in Norway, however, are rare (Nordén *et al.* 2013) and they mainly focused on specific insect fauna of old and dead oak wood in southern and eastern Norway (e.g. Hauge *et al.* 1975, Skarpaas *et al.* 2011, Sverdrup-Thygeson *et al.* 2011). In line with Nordén *et al.*'s (2013) prediction for old broadleaf forests of the entire Norway, we confirmed the specific relevance of this kind of habitats for mites in western Norway.

In western Norway, many areas of semi-natural forests remain protected against plantation forestry and intensive grazing by their steep topography amidst fjords and mountains. These forests contain several-hundred-year-old large trees which is the most important factor in maintaining high biodiversity (Nilsson *et al.* 2001, 2002). Left after previous land-use as woodlands with pollarding and grazing, many of these oldest and largest trees are now beginning to die which has raised conservation and management issues (*see* e.g. Nordén *et al.* 2018 and references therein).

Most of the species found in our study are typical forest species, and only about 19% of Oribatida also occur frequently in non-forested habitats. This seems quite comparable to studies in a German beech forest and in three types of forests in Poland (Wunderle 1992, Skubała 1999). Eurytopic species were usually not abundant in our study, and mite communities were clearly dominated by silvicolous, arboreal and muscicolous species. The most abundant was *Oribatula exilis*, an arboreal and muscicolous species found in large numbers on tree trunks (Huhta *et al*. 2012b). It was also abundant on oak branches in Finland (Koponen *et al.* 1997). In turn, *Chamobates borealis* is a typical soil species, found in forests with different humidity

conditions (Weigmann 2006). The most abundant and widespread mesostigmatid mite found in this study was *Zercon lindrothi*. However, little is known about its biology. It has been recorded from a lichen heath in Norway (Lundqvist & Johnston 1986) and in association with ants from several locations in Finland (Huhta 2016).

As shown in our study, sampling of different forest microhabitats is important for discovering the species diversity. Only a small portion of species (6%) were found in all sampled microhabitats, and many species were found in only one habitat. This agrees with other studies carried out in forests where different microhabitats supported peculiar oribatid faunas (e.g. Hansen 2000, Eissfeller *et al*. 2013, Skubała 2016).

Studies in forests have contributed markedly to the knowledge of the acarofauna in different countries. In Finland, the number of oribatid species collected from 9 sites, each with four forest types (dry coniferous forest, mesic coniferous forest, mesic broadleaf forest, marsh forest) ranged from 74 (in dry coniferous forests) to 82 (in mesic broadleaf forests), that accounts for some 25% of total number of oribatid species known from Finland (Penttinen *et al*. 2008). Similarly in Poland, in three types of forests some 20% of the country's oribatid diversity was found, including 15 species new to Poland and 3 new to science (Skubała 1999). In Germany, in just one type of broadleaf forest, about 15% of the total species diversity of the country was found (Wunderle 1992).

In Norway (including Svalbard) the number of oribatid species exceeds 300, based on the checklist of Mehl (1979), several other publications (Kulczyński 1902, Sellnick 1908, Thor 1930, 1934, 1937, Karppinen 1967, 1971, Cadwalladr 1969, Niedbała 1971b, Solhøy 1979, Hågvar & Abrahamsen 1980, Hippa *et al*. 1988, Colloff 1993, Solhøy & Solhøy 2000, Hodkinson & Bird 2004, Thunes *et al*. 2004, Skubała & Gulvik 2005, Seniczak *et al*. 2006, 2007a, 2007b, 2007c, 2010, Hågvar *et al*. 2009, Heggen 2010, Hein *et al*. 2013, Miko & Monson 2013, Seniczak & Graczyk 2013, Hågvar & Steen 2013, Seniczak *et al*. 2017), and the data from the present study. In Mesostigmata, 240 species are currently known from Norway (Gwiazdowicz & Gulvik 2005, 2007, Gwiazdowicz *et al*. 2013, Bolger *et al*. 2018b).

In summary, rather a small sampling (a total volume of 7 dm^3) from a single broadleaf forest recovered nearly 7000 mites, which represented 67 species, i.e. almost one quarter of all oribatid species and 22 species, i.e. 9% of all mesostigmatid species known from Norway. The number of oribatid species in the Norwegian fauna increased by 5%, and earlier, the number of mesostigmatid species by 3% (Bolger *et al*. 2018b), six species new to Fennoscandia and one oribatid species that requires further investigations were found. This shows the potential of the future acarological studies in Norway, and the unique value of the country's broadleaf forests.

Acknowledgements

This study was supported by the grant no. 811030 from The Norwegian Taxonomy Initiative (KR 35-16 Norwegian Forest Oribatida (NFO), highly diverse, but poorly known).

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