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A Forest Pool as a Habitat Island for Mites in a Limestone Forest in Southern Norway

Anna Seniczak [1,*], Stanisław Seniczak [2], Radomir Graczyk [3], Sławomir Kaczmarek [2], Bjarte H. Jordal [1], Jarosław Kowalski [4], Per Djursvoll [1], Steffen Roth [1] and Thomas Bolger [5,6]

1 Department of Natural History, University Museum of Bergen, University of Bergen, P.O. Box 7800, 5020 Bergen, Norway; Bjarte.Jordal@uib.no (B.H.J.); Per.Djursvoll@uib.no (P.D.); Steffen.Roth@uib.no (S.R.)
2 Department Evolutionary Biology, Faculty of Biological Sciences, Kazimierz Wielki University, J.K. Ossolińskich Av. 12, 85-435 Bydgoszcz, Poland; stseni@ukw.edu.pl (S.S.); slawkacz@ukw.edu.pl (S.K.)
3 Department of Biology and Animal Environment, Bydgoszcz University of Science and Technology, Hetmańska 33, 85-039 Bydgoszcz, Poland; graczyk@utp.edu.pl
4 Gorzewo 7, 09-200 Sierpc, Poland; jt.kowalski@o2.pl
5 School of Biology and Environmental Science, University College Dublin, Belfield, D04 V1W8 Dublin 4, Ireland; tom.bolger@ucd.ie
6 Earth Institute, University College Dublin, Belfield, D04 V1W8 Dublin 4, Ireland
* Correspondence: Anna.Seniczak@uib.no

Abstract: Forest water bodies, e.g., pools, constitute 'environmental islands' within forests, with specific flora and fauna thus contributing considerably to the landscape biodiversity. The mite communities of Oribatida and Mesostigmata in two distinctive microhabitats, water-soaked *Sphagnum* mosses at the edge of a pool and other mosses growing on the medium-wet forest floor nearby, were compared in a limestone forest in Southern Norway. In total, 16,189 specimens of Oribatida representing 98 species, and 499 specimens of Mesostigmata, from 23 species, were found. The abundance and species number of Oribatida were significantly lower at the pool, while the abundance and species richness of Mesostigmata did not differ. Both the communities of Oribatida and of Mesostigmata differed among the microhabitats studied and analysis showed significant differences between the community structures in the two microhabitats. The most abundant oribatid species in *Sphagnum* mosses was *Parachipteria fanzagoi* (Jacot, 1929), which made up over 30% of all Oribatida, followed by *Atropacarus striculus* (C.L. Koch, 1835) and *Tyrphonothrus maior* (Berlese, 1910) (14% and 12% of Oribatida, respectively). Among Mesostigmata *Paragamasus parrunciger* (Bhattacharyya, 1963) dominated (44% of Mesostigmata), followed by *P. lapponicus* (Trägårdh, 1910) (14% of Mesostigmata). Most of these species, except *P. lapponicus*, were either absent or very uncommon in the other microhabitat studied. The specific acarofauna of the forest pool shows the importance of such microhabitats in increasing forest diversity. In addition, a quarter of the mite species found had not been reported from Norwegian broadleaf forests before, including five new species records for Norway and four new to Fennoscandia, all found in the medium-wet microhabitat. Most of these species are rarely collected and have their northernmost occurrence in the studied forest.

Keywords: Oribatida; Mesostigmata; new species records; Norway; Fennoscandia

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1. Introduction

Forest water bodies, e.g., lakes, ponds, pools or streams, constitute 'environmental islands' within forests, with specific flora and fauna, and are important elements contributing considerably to landscape biodiversity [1,2]. Forest ponds and pools often disappear naturally during the natural succession but in recent years many have disappeared more rapidly due to climatic changes and drainage of large areas for agricultural use [1]. The loss of these water bodies has inestimable effects on entire ecosystems, decreasing water retention [3] and leading to the disappearance of wet habitats that host their unique flora and fauna, including mites and other small invertebrates [4] and included references.

Forests are very rich in mites. For example, in some Norwegian coniferous forests the density of mites in soil exceeded 1 million individuals per m^2 [5], with 48 species of Oribatida and 12 species of Mesostigmata [6]. In broadleaf forests the density is often lower than in coniferous forests (around 50,000 individuals per m^2), but species richness is greater (approximately 100 spp.) [7,8]. Oribatida are usually the dominant mite taxon, and include mainly saprophagous species, which are important in the decomposition processes [9]. The Mesostigmata are a complementary mite group that contains mainly predatory species which control other microarthropod populations in the soil and on the vegetation [9].

Sphagnum spp. can be found in some forests, and they host an abundant and quite diverse mite fauna, especially Oribatida. For example, in one such habitat in Poland, the density of mites varied, depending on the season, from about 50,000 individuals per m^2 in winter up to about 90,000 individuals per m^2 in autumn, and Oribatida comprised over 90% of the specimens collected and were represented by 66 species from 30 families [10]. On average, Mesostigmata represented 1.5% of the individuals but their species composition was not reported.

During a species inventory study of mites in broadleaf forests in Norway we found a forest pool overgrown by *Sphagnum* mosses in one forest. We hypothesized that this distinct, water-soaked, microhabitat would host different Oribatida and Mesostigmata communities from those in the medium-wet forest floor nearby, thus contributing considerably to the forest biodiversity. In addition, since the limestone forest studied seems very different from other broadleaf forest types with respect to ptyctimous mites [11], we aim to present a more complete picture of the mite fauna based on Oribatida and Mesostigmata found in this forest.

2. Material and Methods

2.1. Study Site

The limestone forest studied was located in Verpåsen (58.451° N 8.705° E, 62 m a.s.l.), Arendal municipality, Agder province, Southern Norway (Figure 1). The area is characterized by an oceanic climate, with a mean annual temperature of 7.2 °C and an annual precipitation of 1010 mm [12]. The summers are relatively warm with an average temperature of 19.0 °C in July and August. In the coldest months (January and February) the average temperature is −1 °C. The vegetation zone is boreonemoral and markedly oceanic [13].

The forest studied has an area of 6.8 ha and is situated on the southeastern Norwegian bedrock area that consists mainly of gneiss with a district direction southwest–northeast, parallel to the coast, but also some granite. It is situated on an amphibolite ridge with heterogeneous terrain (hilly, rock walls, stone blocks, lime rich patches) and a small valley along the stream. The forest is medium wet and dominated by spruce (*Picea abies*) with occasional oak trees (mostly *Quercus robur*) and a strong mosaic pattern related to nutritional and lime-richness. Rich parts are otherwise characterized by large hazels (*Corylus avellana*). The herb layer is species-rich with a total of 16 red-list species recorded. Based on this the site is a High Conservation Value Forest (category A—very important) according to the Norwegian Environment Agency [14]. The area was probably an old pasture forest and may have been more open in the past, probably with more oak and hazel and less spruce [14].

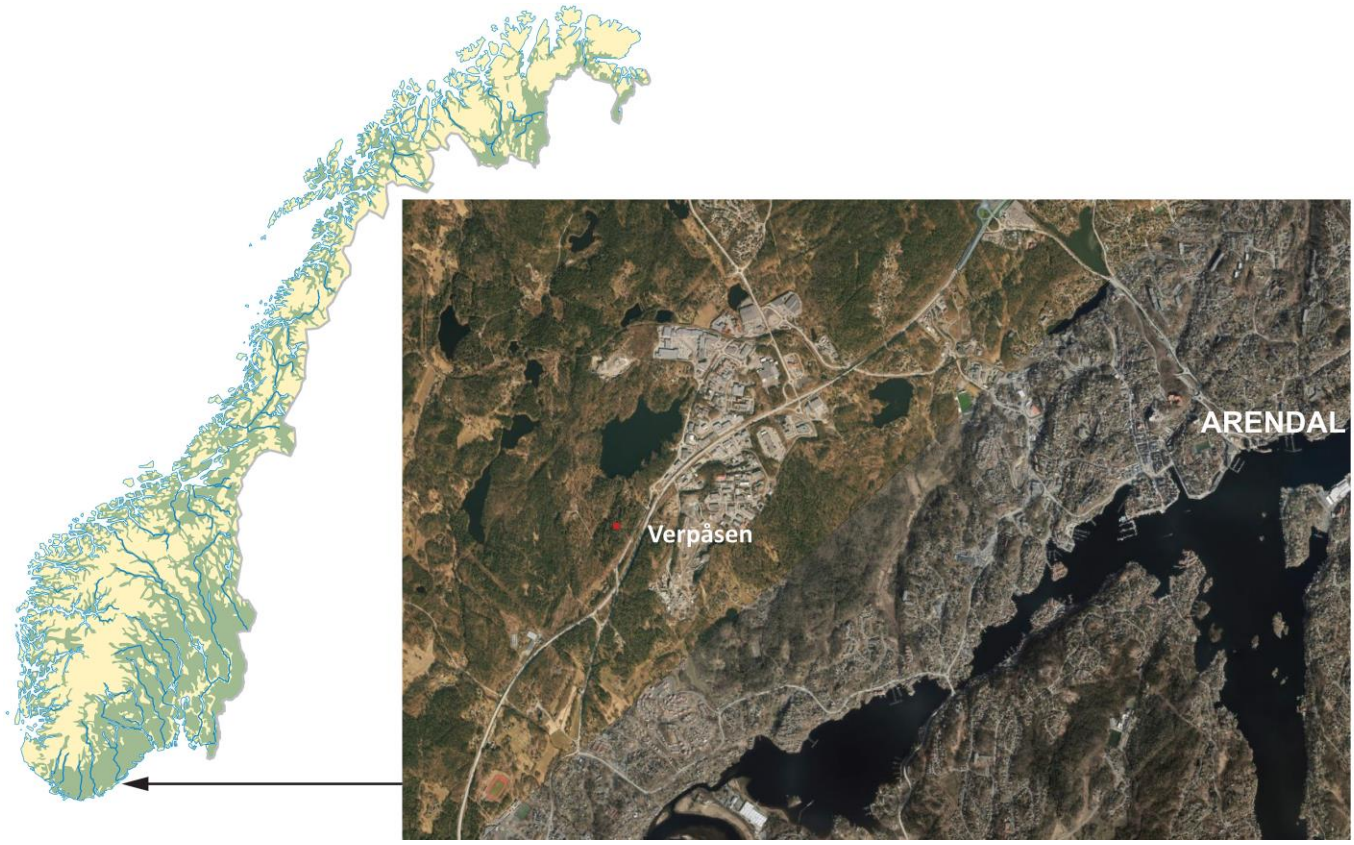

Figure 1. Location in Southern Norway of the limestone forest studied (modified from https://www.norgeskart.no (accessed on 8 June 2021)).

2.2. Sampling and Identification

In total, 11 samples, each with a volume of 500 cm^3 (ca 100 cm^2 in area and 5 cm deep), were collected by hand on 12 June 2017 from two types of forest microhabitat (Figure 2), (A) water-soaked *Sphagnum* mosses at the edge of a pool (five samples) and, (B) other mosses growing on the medium-wet forest floor nearby (six samples). Mites were extracted using modified Tullgren funnels for 14 days into 90% ethanol and sorted out from the samples under stereomicroscope. Oribatida were mounted on cavity slides in 90% lactic acid (AnalaR NORMAPUR, VWR Chemicals, Belgium) and adult specimens were identified using the keys [15–18], while juveniles were identified based on other publications [19–38]. The nomenclature of oribatid species follows [39–41] and partly [18,33,34]. Mesostigmata were mounted on permanent slides in PVA mounting medium (lactic acid, poly vinyl acetate and phenol solution, BioQuip Products, Inc., Compton, CA, USA) and identified following [42–51]. Information on other mite groups that were sorted out from the samples will be published later. Full names of species are given in Table 1. The arrangement of genera within families and the arrangement of species within genera is alphabetical, except in Table 2, where the species are ordered according to their preferences to the microhabitat. All species are deposited in 90% ethanol at the University Museum of Bergen, Norway (ZMBN).

The new records of Oribatida for Norway are based on the checklist [52] and later publications [7] and included references, [8,11,53–60]. Those new to Fennoscandia are based on [61–76]. The new records of Mesostigmata for Norway are based on [77–82] and those new to Fennoscandia are based on [83,84].

2.3. Statistical Analyses

Oribatid and mesostigmatid mite populations were characterized by the abundance (*A* in 500 cm^3), dominance (*D*, percentage of a particular species among Oribatida) and constancy (*C*, percentage of the samples where the species was present) indices, and their communities were characterized by the number of species (*S*) and the Shannon (*H'*) diversity index [85]. The basic statistical descriptors included the mean values and standard deviation. Equality of variance was tested with the Levene test, and normality of the distribution was tested with the Kolmogorov–Smirnov test. As the assumptions of variance analysis were not met, non-parametric tests were employed. ANOVA rank Kruskal–Wallis was utilized to test for significant differences between means [86]. Detrended correspondence analysis (DCA) was used to find the main gradients of Oribatida and Mesostigmata communities [87,88]. In scatter plot, the 'joint plot' function was used to visualize better the distribution of the data. These statistics were computed using STATISTICA 13.3 [89], MVSP 3.2 [90] and MS Excel 365 software [91].

A multivariate statistical test, PERMANOVA, was used to assess the significance of differences among locations for the Oribatida and Mesostigmata. This was carried out on Hellinger transformed data using Euclidean distance as the distance index. The tests were carried out using the 'adonis' function in the 'vegan' package in R with 999 permutations [92].

Indicator species analysis was used to identify species which showed a preference for one or other of the microhabitats. Two components are reported: 'specificy' which is the probability that a sample comes from the particular microhabitat if that species is present and 'fidelity' which is the probability of finding the species in a sample from a particular microhabitat [93,94]. The analysis was carried out using 'indicspecies' package in R [94]. The significance level for all analysis was accepted $\alpha = 0.05$.

Figure 2. Studied microhabitats: (**A**) water-soaked *Sphagnum* on pool and, (**B**) other mosses on medium-wet forest floor nearby in a limestone forest in Southern Norway.

3. Results

In total, 16,189 specimens of Oribatida representing 98 species and 34 families, and 499 specimens of Mesostigmata, from 23 species and nine families were found in the present study (Table 1). Oribatida were less abundant and less diverse in *Sphagnum* on pools than in other mosses growing on medium-wet forest floor nearby while Mesostigmata had similar abundance and species richness in both types of studied microhabitats (Figure 3).

Table 1. Oribatida and Mesostigmata in two microhabitats: A—*Sphagnum* on pool and, B—other mosses on medium-wet forest floor nearby in a limestone forest in Southern Norway; *A*—average abundance in 500 cm^3, *C*—constancy index, *D*—dominance index; abbreviations for detrended correspondence analysis (DCA) for species with $D \geq 1.0$; in bold—new record for Norway; underlined—new record for Fennoscandia; ns—not significant.

Order/Suborder and Family	Species	Abbreviations for DCA Analysis	Microhabitat A			Microhabitat B			ANOVA Rang Kruskal-Wallis	
Oribatida			***A***	***C***	***D***	***A***	***C***	***D***	**H**	***p***
Brachychthoniidae Thor, 1934	*Liochthonius brevis* (Michael, 1888)		0.0			1.3	17	0.07	0.83	ns
	L. neglectus Moritz, 1976	*L.neg*	0.0			39.5	33	1.97	1.83	ns
	L. tuxeni (Forsslund, 1957)		0.6	20	0.07	0.2	17	0.01	0.07	ns
	Neobrachychthonius magnus Moritz, 1976	*N.mag*	0.0			46.0	67	2.29	4.47	0.035
	***Sellnickochthonius jacoti* (Evans, 1952)**		0.0			0.7	17	0.03	0.83	ns
Eniochthoniidae Grandjean, 1947	*Eniochthonius minutissimus* (Berlese, 1904)		0.2	20	0.02	2.2	17	0.11	0.00	ns
Hypochthoniidae Berlese, 1910	*Hypochthonius rufulus* C.L. Koch, 1835		2.2	40	0.27	0.8	17	0.04	0.66	ns
Euphthiracaridae Jacot, 1930	*Acrotritia ardua* (C.L. Koch, 1841)	*A.ard*	8.6	100	1.04	0.0			8.97	0.003
	A. duplicata (Grandjean, 1953)		0.0			0.2	17	0.01	0.83	ns
	Euphthiracarus cribrarius (Berlese, 1904)		0.2	20	0.02	0.7	33	0.03	0.49	ns
Phthiracaridae Perty, 1841	*Phthiracarus anonymus* Grandjean, 1933		2.8	40	0.34	0.2	17	0.01	1.09	ns
	P. bryobius Jacot, 1930		2.0	80	0.24	1.3	67	0.07	0.31	ns
	P. clavatus Parry, 1979		0.0			1.5	17	0.07	0.83	ns
	P. crinitus (C.L. Koch, 1841)		0.2	20	0.02	0.0			1.20	ns
	P. laevigatus (C.L. Koch, 1841)		0.2	20	0.02	0.0			1.20	ns
	P. longulus (C.L. Koch, 1841)		0.4	40	0.05	3.5	83	0.17	3.31	ns
Steganacaridae Niedbała, 1986	*Atropacarus striculus* (C.L. Koch, 1835)	*A.str*	115.8	100	14.02	0.0			8.92	0.003
	Steganacarus magnus (Nicolet, 1855)		3.4	60	0.41	0.2	17	0.01	2.53	ns
	S. spinosus (Sellnick, 1920)		0.6	40	0.07	8.8	83	0.44	3.51	ns
Crotoniidae Thorell, 1876	*Camisia biurus* (C.L. Koch, 1839)		0.0			2.0	33	0.10	1.83	ns
	C. spinifer (C.L. Koch, 1836)		0.0			0.2	17	0.01	0.83	ns
	Platynothrus peltifer (C.L. Koch, 1839)	*P.pel*	19.0	80	2.30	0.2	17	0.01	5.24	0.022
Malaconothridae Berlese, 1916	*Malaconothrus monodactylus* (Michael, 1888)	*M.mon*	71.2	60	8.62	0.0			4.37	0.037
	Tyrphonothrus maior (Berlese, 1910)	*T.mai*	98.6	100	11.94	0.00			8.92	0.003
Nanhermanniidae Sellnick, 1928	*Nanhermannia coronata* Berlese, 1913		6.4	80	0.78	0.0			6.44	0.011
Nothridae Berlese, 1896	*Nothrus silvestris* Nicolet, 1855		0.0			2.7	67	0.13	4.47	0.035
Damaeidae Berlese, 1896	*Damaeus clavipes* (Hermann, 1804)		0.0			0.2	17	0.01	0.83	ns
	D. gracilipes (Kulczynski, 1902)		0.0			0.3	17	0.02	0.83	ns
	Porobelba spinosa (Sellnick, 1920)		0.0			8.7	83	0.43	6.19	0.013
Cepheusidae Berlese, 1896	*Cepheus cepheiformis* (Nicolet, 1855)		0.0			0.5	17	0.02	0.83	ns
Caleremaeidae Grandjean, 1965	*Caleremaeus monilipes* (Michael, 1882)	*C.mon*	0.0			59.8	33	2.98	1.83	ns
Eremaeidae Oudemans, 1900	*Eueremaeus silvestris* (Forsslund, 1956)		0.0			1.0	33	0.05	1.83	ns
	E. valkanovi (Kunst, 1957)		0.0			18.8	50	0.94	3.03	ns
Astegistidae Balogh, 1961	*Cultroribula bicultrata* (Berlese, 1905)		0.0			0.3	33	0.02	1.85	ns
	Furcoribula furcillata (Nordenskiöld, 1901)					1.3	33	0.07	1.83	ns
Liacaridae Sellnick, 1928	*Adoristes ovatus* (C.L. Koch, 1839)		0.8	60	0.10	4.2	67	0.21	0.89	ns
	Liacarus coracinus (C.L. Koch, 1841)		0.0			13.2	33	0.66	1.83	ns

Table 1. *Cont.*

Order/Suborder and Family	Species	Abbreviations for DCA Analysis	Microhabitat A			Microhabitat B			ANOVA Rang Kruskal-Wallis	
Oribatida			***A***	***C***	***D***	***A***	***C***	***D***	**H**	***p***
Carabodidae C.L. Koch, 1843	*Carabodes areolatus* Berlese, 1916	*C.are*	0.2	20	0.02	40.5	83	2.01	4.53	0.033
	C. coriaceus C.L. Koch, 1835		0.0			0.7	17	0.03	0.83	ns
	C. femoralis (Nicolet, 1855)		0.0			9.5	33	0.47	1.83	ns
	C. labyrinthicus (Michael, 1879)	*C.lab*	1.0	60	0.12	24.8	100	1.24	7.57	0.006
	C. marginatus (Michael, 1884)	*C.mar*	0.0			24.7	17	1.23	0.83	ns
	C. ornatus Storkán, 1925		0.2	20	0.02	5.8	83	0.29	4.07	0.044
	C. rugosior Berlese, 1916		0.2	20	0.02				1.20	ns
	C. tenuis Forsslund, 1953		0.0			3.3	17	0.17	0.83	ns
	C. willmanni Bernini, 1975	*C.wil*	0.0			37.2	33	1.85	1.83	ns
Autognetidae Grandjean, 1960	*Odontocepheus elongatus* (Michael, 1879)		0.0			5.7	83	0.28	6.23	0.013
	Autogneta longilamellata (Michael, 1885)		0.0			0.2	17	0.01	0.83	ns
	Conchogneta dalecarlica (Forsslund, 1947)		0.0			2.2	67	0.11	4.50	0.034
Oppiidae Sellnick, 1937	*Dissorhina ornata* (Oudemans, 1900)		0.0			14.3	100	0.71	8.25	0.004
	***Graptoppia foveolata* (Paoli, 1908)**	*G.fov*	0.0			35.8	50	1.78	3.03	ns
	***Lauroppia beskidyensis* (Niemi et Skubala, 1993)**		0.0			0.2	17	0.01	0.83	ns
	Microppia minus (Paoli, 1908)		0.0			0.5	50	0.02	3.13	ns
	Moritzoppia keilbachi (Moritz, 1969)	*M.kei*	0.0			26.8	83	1.33	6.19	0.013
	M. translamellata (Willmann, 1923)	*M.tra*	15.6	20	1.89	0.0			1.20	ns
	Oppiella falcata (Paoli, 1908)	*O.fal*	0.0			465.5	100	23.16	8.25	0.004
	O. neerlandica (Oudemans, 1900)	*O.nee*	60.0	100	7.27	0.0			8.92	0.003
	O. nova (Oudemans, 1902)	*O.nov*	47.6	100	5.76	67.7	100	3.37	0.21	ns
	O. propinqua Mahunka et Mahunka-Papp, 2000	*O.pro*	38.8	100	4.70	0.0			8.92	0.003
	O. splendens (C.L. Koch, 1841)	*O.spl*	0.0			215.2	83	10.70	6.19	0.013
	O. uliginosa (Willmann, 1919)					0.7	33	0.03	1.83	ns
Quadroppiidae Balogh, 1983	*Rhinoppia subpectinata* (Oudemans, 1900)	*R.sub*	0.0			24.0	50	1.19	3.03	ns
	Quadroppia monstruosa (Hammer, 1979)		0.0			3.3	50	0.17	3.03	ns
Thyrisomidae Grandjean, 1953	*Q. quadricarinata* (Michael, 1885)	*Q.qua*	0.0			48.8	100	2.43	8.25	0.004
	Banksinoma lanceolata (Michael, 1885)		0.6	40	0.07	0.2	17	0.01	0.87	ns
Suctobelbidae Jacot, 1938	*Suctobelba regia* Moritz, 1970		0.0			13.2	83	0.66	6.19	0.013
	S. trigona (Michael, 1888)		0.0			2.0	17	0.10	0.83	ns
	Suctobelbella lobata (Strenzke, 1950)		0.0			1.0	17	0.05	0.83	ns
	***S. carcharodon* (Moritz, 1966)**		0.0			0.8	17	0.04	0.83	ns
	S. falcata (Forsslund, 1941)	*S.fal*	0.0			42.7	33	2.12	1.83	ns
	S. sarekensis (Forsslund, 1941)		0.0			18.7	50	0.93	3.03	ns
	S. similis (Forsslund, 1941)		0.0			0.3	17	0.02	0.83	ns
	Suctobelbella sp. 1		0.0			2.7	17	0.13	0.83	ns
	S. subcornigera (Forsslund, 1941)	*S.sbc*	2.6	60	0.31	87.8	100	4.37	6.13	0.013
	S. subtrigona (Oudemans, 1900)	*S.sbt*	0.0			75.8	67	3.77	4.47	0.035
Tectocepheidae Grandjean, 1954	*Tectocepheus velatus* (Michael, 1880)	*T.vel*	16.6	100	2.01	302.0	100	15.02	7.50	0.006
Licneremaeidae Grandjean, 1954	*Licneremaeus licnophorus* (Michael, 1882)		0.0			0.7	17	0.03	0.83	ns
Phenopelopidae Petrunkevich, 1955	*Eupelops plicatus* (C.L. Koch, 1835)		0.2	20	0.02	0.7	50	0.03	1.15	ns
	E. torulosus (C.L. Koch, 1839)		1.0	60	0.12	10.5	100	0.52	7.11	0.008
Achipteriidae Thor, 1929	*Achipteria magna* (Sellnick, 1928)	*A.mag*	0.0			63.2	67	3.14	4.47	0.035
	A. nitens (Nicolet, 1855)		0.0			5.3	33	0.27	1.83	ns
	Parachipteria fanzagoi (Jacot, 1929)	*P.fan*	278.8	100	33.76	1.5	33	0.07	7.86	0.005
Oribatellidae Jacot, 1925	*Oribatella quadricornuta* Michael, 1880		0.0			0.2	17	0.01	0.83	ns
	Ophidiotrichus tectus (Michael, 1884)		0.0			0.2	17	0.01	0.83	ns

Table 1. *Cont.*

Order/Suborder and Family	Species	Abbreviations for DCA Analysis	Microhabitat A			Microhabitat B			ANOVA Rang Kruskal-Wallis	
Oribatida			***A***	***C***	***D***	***A***	***C***	***D***	**H**	***p***
Haplozetidae Grandjean, 1936	*Lagenobates lagenulus* (Berlese, 1904)		0.0			0.2	17	0.01	0.83	ns
Oribatulidae Thor, 1929	*Oribatula exilis* (Nicolet, 1855)	*O.exi*	0.0			85.2	100	4.24	8.25	0.004
	O. tibialis (Nicolet, 1855)		0.0			2.2	50	0.11	3.03	ns
Parakalummidae Grandjean, 1936	*Neoribates aurantiacus* (Oudemans, 1914)		0.0			0.3	17	0.02	0.83	ns
	Scheloribates initialis (Berlese, 1908)		3.4	60	0.41	4.0	67	0.20	0.08	ns
Scheloribatidae Grandjean, 1933	*S. pallidulus* (C.L. Koch, 1841)		0.0			0.5	17	0.02	0.83	ns
	Liebstadia longior (Berlese, 1908)		0.0			0.2	17	0.01	0.83	ns
	L. similis (Michael, 1888)		0.0			1.0	33	0.05	1.83	ns
Ceratozetidae Jacot, 1925	*Fuscozetes fuscipes* (C.L. Koch, 1844)	*F.fus*	36.6	100	4.43	0.0			8.92	0.003
	Sphaerozetes orbicularis (C.L. Koch, 1835)		0.0			0.25	50	0.12	3.03	ns
Chamobatidae Thor, 1937	*Chamobates borealis* Trägårdh, 1902		0.22	80	0.27	0.22	50	0.11	0.08	ns
	C. pusillus (Berlese, 1895)		0.0			0.43	33	0.22	1.83	ns
	C. rastratus (Hull, 1914)		0.0			0.02	17	0.01	0.83	ns
Galumnidae Jacot, 1925	*Pergalumna nervosa* (Berlese, 1914)		0.0			0.03	17	0.02	0.83	ns
	Mesostigmata									
Epicriidae Berlese, 1885	*Epicrius mollis* (Kramer, 1876)	*E.mol*	1.8	40	4.79	0.3	17	0.64	1.09	ns
Zerconidae Berlese, 1892	*Prozercon kochi* Sellnick, 1943	*P.koc*	2.2	40	5.85	1.5	50	2.89	0.04	ns
	Zercon lindrothi Lundqvist et Johonston, 1986	*Z.lin*	0.0			1.5	50	2.89	3.06	ns
	Z. triangularis C.L. Koch, 1836	*Z.tri*	0.0			3.5	50	6.75	3.06	ns
	Z. zelawaiensis Sellnick, 1944	*Z.zel*	0.0			30.2	67	58.20	4.47	0.035
Macrochelidae Vitzthum, 1930	*Macrocheles opacus* (C.L. Koch, 1839)		0.2	20	0.53	0.0			1.20	ns
Parasitidae Oudemans, 1901	*Holoparasitus inornatus* (Berlese, 1906)	*H.ino*	0.0			1.2	50	2.25	3.03	ns
	Paragamasus celticus (Bhattacharyya, 1963)	*P.cel*	1.6	60	4.26	0.0			4.40	0.036
	P. robustus (Oudemans, 1902)	*P.rob*	0.4	20	1.06	0.5	50	0.96	0.41	ns
	P. runcatellus (Berlese, 1903)	*P.run*	0.0			1.7	50	3.22	3.06	ns
	P. parrunciger (Bhattacharyya, 1963)	*P.par*	16.6	40	44.15	0.0			2.64	ns
	P. lapponicus (Trägårdh, 1910)	*P.lap*	5.2	60	13.83	5.5	67	10.61	0.32	ns
	Pergamasus crassipes (Linne, 1758)	*P.cra*	2.4	60	6.38	0.5	33	0.96	1.68	ns
	P. septentrionalis (Oudemans, 1902)		0.2	20	0.53	0.2	17	0.32	0.02	ns
	Parasitus lunulatus (J. Muller, 1859)		0.2	20	0.53	0.0			1.20	ns
	Vulgarogamasus kraepelini (Berlese, 1905)	*V.kra*	0.2	20	0.53	1.0	17	1.93	0.00	ns
	Other Parasitidae, juveniles	*Paras*	2.4	80	6.38	1.0	50	1.93	0.57	ns
Veigaiidae Oudemnas, 1939	*Veigaia cerva* (Kramer, 1876)		0.0			0.2	17	0.32	0.83	ns
	V. kochi (Trägårdh, 190 1)		0.2	20	0.53	0.2	17	0.32	0.02	ns
	V. nemorensis (C.L. Koch, 1839)	*V.nem*	0.2	20	0.53	2.5	50	4.82	1.61	ns
Ascidae Voigts et Oudemans, 1905	*Asca aphidioides* (Linne, 1758)		0.0			0.3	17	0.64	0.83	ns
	Cheiroseius mutilus (Berlese, 1916)	*C.mut*	1.6	60	4.26	0.0			4.37	0.037
Laelapidae Berlese, 1892	***Pachylaelaps dubius* Hirschmann et Krauss, 1965**		0.0			0.2	17	0.32	0.83	ns
Trachytidae Trägårdh, 1938	*Trachytes aegrota* (C.L. Koch, 1841)	*T.aeg*	2.0	40	5.32	0.0			2.64	ns
Uropodidae Kramer, 1881	*Uropoda misella* (Berlese, 1916)		0.2	20	0.53	0.0			1.20	ns

Table 2. Preference of species for one or other of the microhabitats: A—*Sphagnum* on pool and, B—other mosses on medium-wet forest floor nearby in a limestone forest in Southern Norway.

Species	Specificity	Fidelity	*p*-Value
	A		
A. ardua	1.00	1.00	0.01
A. striculus	1.00	1.00	0.01
F. fuscipes	1.00	1.00	0.01
O. neerlandica	1.00	1.00	0.01
O. propinqua	1.00	1.00	0.01
P. fanzagoi	0.99	1.00	0.01
N. coronata	1.00	0.80	0.04
T. maior	1.00	0.80	0.05
P. peltifer	0.98	0.80	0.04
	B		
D. ornata	1.00	1.00	0.01
O. falcata	1.00	1.00	0.01
Q. quadricartinata	1.00	1.00	0.01
O. exilis	1.00	1.00	0.01
S. subcornigera	0.97	1.00	0.02
C. labyrinthicus	0.96	1.00	0.01
E. torulosus	0.93	1.00	0.04
M. keilbachi	1.00	0.83	0.05
O. elongatus	1.00	0.83	0.02
O. splendens	1.00	0.83	0.03
P. spinosa	1.00	0.83	0.05
S. regia	1.00	0.83	0.02
C. areolatus	0.99	0.83	0.05
C. ornatus	0.97	0.83	0.05

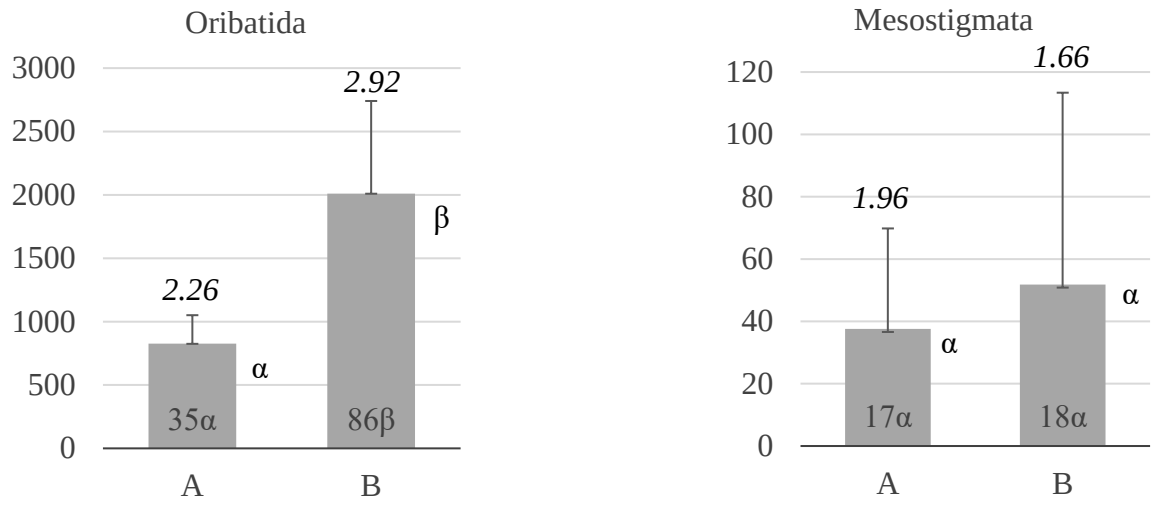

Figure 3. Average abundance (in 500 cm^3) of mites (bars) with standard deviation (whiskers), Shannon index (above bars) and number of species (within bars) in the two microhabitats: A *Sphagnum* on pool and, B other mosses on medium-wet forest floor nearby in a limestone forest in Southern Norway; different Greek letters indicate significant differences at $p \leq 0.05$.

Thirty-five species of Oribatida and 17 species of Mesostigmata were found in *Sphagnum* mosses (Table 1). Among Oribatida the most abundant was *Parachipteria fanzagoi* (Jacot, 1929), which comprised over 30% of all Oribatida collected and was followed by *Atropacarus striculus* (C.L. Koch, 1835) and *Tyrphonothrus maior* (Berlese, 1910) (which made 14% and 12% of Oribatida, respectively). These three species showed clear preferences to the *Sphagnum* microhabitat on the pool (Table 2). Among Mesostigmata, *Paragamasus parrunciger* (Bhattacharyya, 1963) dominated (it comprised 44% of Mesostigmata), fol-

lowed by *P. lapponicus* (Trägårdh, 1910) which comprised about 14% of mesotigmatid mites. None of the Mesostigmata species showed clear preferences to the microhabitat on the pool (Table 2).

In total, 86 species of Oribatida and 18 species of Mesostigmata were found in the second microhabitat. Most of the species abundant in *Sphagnum*, except *P. lapponicus*, were either absent or very uncommon here. The most abundant oribatid species was *Oppiella neerlandica* (Oudemans, 1900) which comprised approximately 20% of Oribatida and was followed by *Tectocepheus velatus* (Michael, 1880) and *Oppiella splendens* (C.L. Koch, 1841) (15% and 11% of Oribatida, respectively). Among Mesostigmata more than 55% of the individuals were *Zercon zelawaiensis* Sellnick, 1944 while *P. lapponicus* comprised approximately 11% of this group.

There were significant differences between the communities in both microhabitats as assessed by PERMANOVA (Oribatida F = 9.4143, p = 0.004, Mesostigmata F = 3.0248, p = 0.009) and these communities were clearly grouped by detrended correspondence analysis (Figure 4). The abundance of most Oribatida species with dominance index above 1 differed significantly between the two microhabitats, while in Mesostigmata, significant differences were observed in only a few cases (Table 1).

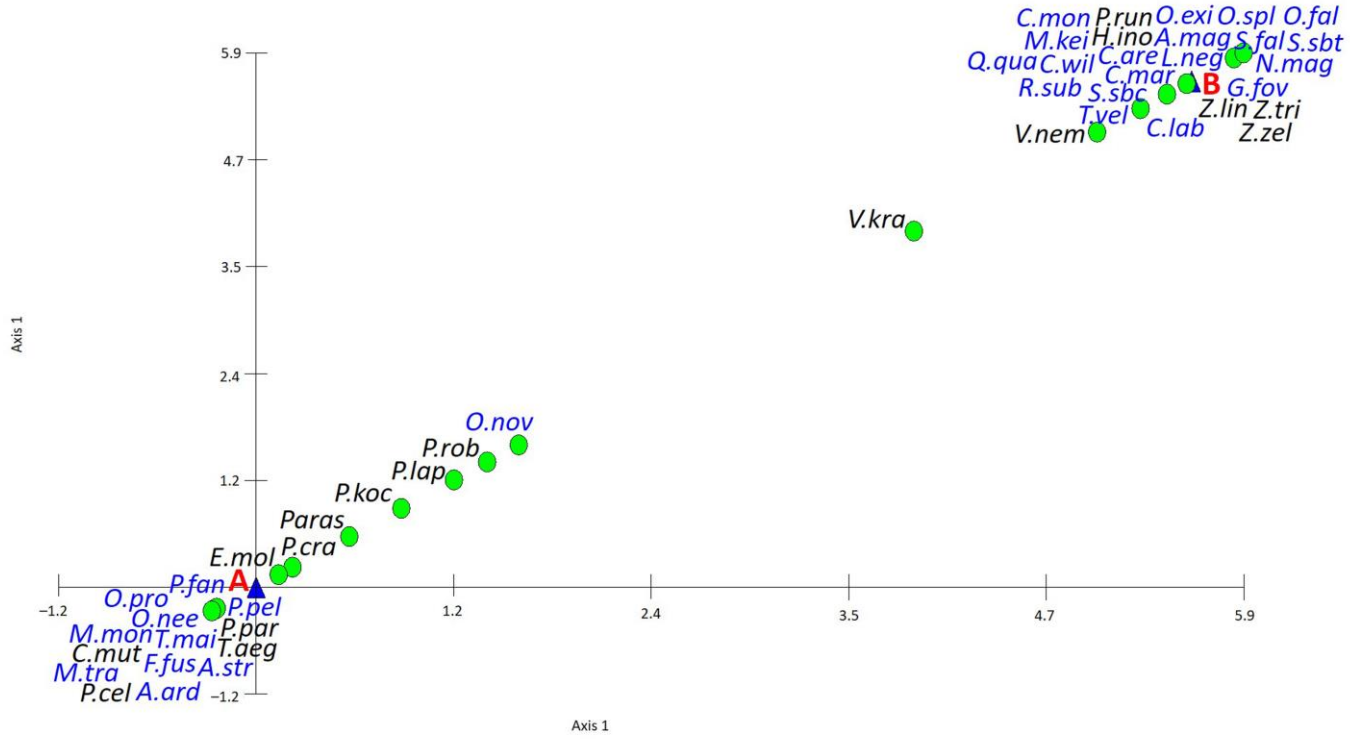

Figure 4. Detrended correspondence analysis (DCA) for species of Oribatida and Mesostigmata communities with $D \geq 1.0$ in two microhabitats: A—*Sphagnum* on pool and, B—other mosses on medium-wet forest floor nearby in a limestone forest in Southern Norway; eigenvalues for axis 1 λ= 0.906 (100, 0%), for axis 2 λ= < 0.001 (<0.001%); triangles indicate distribution of microhabitats and circles indicate distribution of species in DCA ordination space; Oribatida are marked in blue, Mesostigmata in black; see Table 1 for abbreviations of species names.

Five species newly recorded for Norway were determined: *Graptoppia foveolata* (Paoli, 1908), *Lauroppia beskidyensis* (Niemi et Skubala, 1993), *Sellnickochthonius jacoti* (Evans, 1952), *S. carcharodon* (Moritz, 1966) (Oribatida), and *Pachylaelaps dubius* Hirschmann et Krauss, 1965 (Mesostigmata)—all of them occurred only in medium-wet forest floor. The latter four species were also new records to Fennoscandia (Table 1).

4. Discussion

The oribatid communities differed more between the two microhabitats than did the mesostigmatid communities. This shows that oribatid communities are more variable between microhabitats studied compared to Mesostigmata and their overall species richness is, therefore, more affected by the microhabitat diversity in the forest. Similar observations were made in studies of other microhabitats (beech litter, moss on beech litter, moss on beech stumps, rotting beech wood, damp litter, and moss on beech trunks) studied in a beech forest reserve in Poland [95]. Oribatid mites are mainly saprophagous, and therefore are more dependent on the type of vegetation, while Mesostigmata are mainly predators, feeding on nematodes, springtails, juvenile mites, and some insect larvae [96]. Therefore, they need to be more mobile, looking for their prey, whereas the slower moving Oribatida are surrounded by stationary food resources [95].

The number of oribatid species found at the pool was similar to the records from the edge of 16 water bodies in Northern Poland [4]. In Poland, with a two times higher sampling effort (10 replicates vs. 5 replicates in the present study) the average number of species was 26 and ranged from 17 to 41 [4], while in the present study 35 species of Oribatida were found. Water-saturated microhabitats are challenging for Oribatida, and most oribatid species prefer high or medium values of humidity [97,98]. Therefore, it is not surprising that Oribatida were significantly less abundant and less diverse at the pool. However, there are species, that are specifically either aquatic (i.e., with reproduction and all life stages inhabiting submerged habitats) or amphibious (i.e., living in water but seem to need saturated air to reproduce), adapted to live there [99], and therefore require wet microhabitats to live in woodlands.

Sphagnum mosses were dominated by the species characteristic of wet habitats, including *Parachipteria fanzagoi*, *Tyrphonothrus maior*, and *Atropacarus striculus*. These three species together made up almost 60% of all Oribatida there, while in the alternative microhabitat they were absent (*T. maior*, *A. striculus*) or very few (*P. fanzagoi*). The same species were also recorded abundantly in mires in Western Norway [53], while at the pond in Poland they occurred less abundantly but nevertheless were a stable component of the oribatid communities found in all seasons [10]. Among 46 Holarctic mires analyzed, *P. fanzagoi* was found in seven of them, *T. maior* in 24 and *A. striculus* in 29 [100].

Parachipteria fanzagoi was found in all studied microhabitats in mires in Western Norway but was particularly abundant in the *Sphagnum* section *Acutifolia*. Its age structure was similar in all compared microhabitats, and in July the juveniles made 70% of its populations [53]. In contrast, *A. striculus* did not show preferences to any *Sphagnum* [53]. It was represented in extracted samples only by the adults and, therefore, it is likely that juveniles are found elsewhere. Ptyctimous mites, to which *A. striculus* belongs to, have a remarkable ecology where immatures form galleries inside dead wood, cones or conifer needles and do not leave them before adult stage. They can only be obtained by dissecting these shelters and, therefore, are difficult to find [101,102].

Although *P. fanzagoi* and *A. striculus* occur frequently in mires, they are also found in damp forests and meadows [7,18,25,103]. For example, in a broadleaf forest in Eastern Norway *P. fanzagoi* was the second most abundant and frequent species [8]. In turn, *A. striculus* was the most abundant ptyctimous species in several broadleaf forests studied in Norway and comprised nearly 30% of all ptyctimous mites collected [11]. It was also the most common and abundant ptyctimous mite in studies in Finland [73] and in the Białowieża primeval forest in Poland [104].

In contrast to the species mentioned above, *Tyrphonothrus maior* is aquatic and, as the name implies, a tyrphobiont, i.e., restricted to mires. It lives in *Sphagnum* mosses and feeds on them [105]; in forests it can only be found in *Sphagnum* pools like the one studied here. Although few oribatid species are found solely in mires [106], their total diversity in undisturbed peatlands can be comparable to forests [53]. Wet *Sphagnum*-dominated habitats must therefore be underestimated in terms of their biodiversity value.

Another example on how water bodies make forest diversity more unique is the mesostigmatid species *Cheiroseius mutilus* (Berlese, 1916), that is found only in water-soaked microhabitats. It was previously recorded from mires in Norway [80] and Finland [66]. Although the communities of Mesostigmata did not include species that were clear indicators of either microhabitat, some of the collected species are more specialized. One of them is *Epicrius mollis* (Kramer, 1876), which can be found in forests, but more so in mires [107,108]. The most abundant Mesostigmata species in this study, *Paragamasus parrunciger*, is mainly found in forests, meadows and pastures [108,109], but also occurs abundantly in wetlands [66]. However, Mesostigmata communities are relatively depauperate in mire habitats [109].

In addition to showing an interesting contribution of the forest pool in increasing the mites' diversity, this study also revealed a very interesting acarofauna in a very limited patch of limestone forest. A quarter of the species found had not previously been reported from Norwegian broadleaf forests, and five species were recorded as new for Norway, including four new to Fennoscandia. These were all in the medium-wet microhabitat. These unique characters of a rare acarofauna, already noticed in ptyctimous Oribatida [11], are likely explained by the specific environmental conditions created by the limestone background and specific vegetation of limestone forests [110].

Quite surprisingly most oribatid species that are new records for Norway, have previously been recorded mainly in Southern and Central Europe, often in warm habitats, and are considered rare. One of these rare species is *Graptoppia foveolata* [111] that has been considered to be a southern palearctic species [41]. In Fennoscandia, only two specimens have been found in Southern Sweden [112], while in our study it was rather abundant. Also, *Suctobelbella carcharodon* has peculiar occurrences and has been found only in south-central Europe: at a gypsum slope [113], in a gypsum cave [114] and in various broadleaf forests in Germany [111], at higher altitudes in Slovakia [115] and Northern Spain [116] and in warm mountain grasslands in the Czech Republic [117]. Similarly, *Lauroppia beskidyensis* has been known only from mountainous habitats in Poland [118,119] and Albania [120]. It cannot be excluded that some of these rare species extended their ranges of distribution in relation to climatic changes, but the lack of earlier data on mites from the Norwegian broadleaf forests makes such comparisons impossible. However, since these species are rarely found in other countries, their presence can probably be related to the natural character of the forest studied that was also supported by the records of red-list species from other groups [14]. These examples contribute to results from other broadleaf forests in Norway [7,8,11] that indicate these forests represent a real treasure of Fennoscandian and European biodiversity [121].

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