Article

Vertical Distribution of Mites (Acari) in a "Miniature Forest" of *Sphagnum* Mosses in a Forest Bog in Western Norway

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Abstract: The *Sphagnum* habitat is a "miniature forest" to the mites, of which the layers offer different microenvironmental conditions. We studied the vertical distribution of the Oribatida, Mesostigmata, and Prostigmata groups in four layers (0–5 cm, 5–10 cm, 10–15 cm, and 15–20 cm) of a forest bog on Neshalvøya, Norway, to improve the knowledge of the ecology of these mites. The sampled bog was grazed by farm animals; thus, another aim was to investigate the vertical distribution of the oribatid species, which are intermediate hosts of tapeworms. The selected study site is known for its valuable yet increasingly endangered nature, so our aim was also to contribute to the knowledge on its diversity. We collected *Sphagnum* samples in four replicates and extracted them in the laboratory in modified Berlese funnels. In total, 16.880 mites were studied, including 16.384 Oribatida, 466 Mesostigmata, and 30 Prostigmata. The total abundance of mites, the Oribatida and Mesostigmata groups, was the highest in the upper layer of *Sphagnum* and decreased with depth, while the abundance of the Prostigmata did not follow any pattern. Among the Oribatida, at deeper layers, significant declines in abundance were observed in adults, but not in juveniles. Most oribatid species, e.g., *Nothrus pratensis*, preferred the upper layer of *Sphagnum*, whereas some preferred deeper layers. For example, *Suctobelbella acutidens* and *Carabodes femoralis* preferred the 5–10 cm layer, *Quadroppia maritalis* the 10–15 cm layer, and *Ceratozetes gracilis* and *Eulohmannia ribagai* preferred the deepest layer of *Sphagnum*. Adults and juveniles of the same species showed a preference for the same layer. In total, 62 species of the Oribatida were recorded, including 11 species that are known to be intermediate hosts of tapeworms. Most of them occurred in the upper layer of *Sphagnum*. Over 20% of the species were found exclusively in deeper layers, so sampling these layers is important for a better evaluation of the mites' diversity. Studying the vertical distribution of the mites in bogs helps us to understand their ecology, including their role as intermediate hosts of tapeworms, as well as their diversity.

Keywords: Oribatida; Mesostigmata; Prostigmata; sample depth; tapeworm

1. Introduction

Mites (Acari), especially the suborder Oribatida, constitute the most abundant and diverse group of arthropods in peatlands, including bogs [1]. Their densities may reach up to 300,000 ind. m^{-2} [2], and a total of 410 oribatid species are known in the Holarctic peatlands [3]. On the regional scale, the highest diversity of the Oribatida, 126 species, has been reported from peatlands in the Swiss Jura [4], while the highest overall diversity of mites has been found in Western Norway (154 species, including 96 Oribatida, 33 Mesostigmata, and 24 Trombidiformes) [5,6]. These examples show that the mites constitute a crucial component of peatlands [2].

The vertical distribution of the mites in the soil is relatively well known in forests [7–11], grasslands [12–15], and agricultural fields [16,17], but little attention has been paid to peatlands in this respect. As shown in forests, changes in the abundance of soil fauna can strongly contribute to the altered vertical distribution of the soil organic carbon and its long-term storage [11]. *Sphagnum*-dominated peatlands are exceptional for many reasons, also because they consist of growing *Sphagnum* mosses and their dead decomposing parts, which form peat. The slow decay of *Sphagnum* is of key importance to peatlands, making waterlogging and carbon sequestration possible [18]. One of the factors affecting decomposition processes in peatlands is the biotic decomposer communities, including the abundant mites [2].

Borcard [1] described the peatland habitat as a "miniature forest", where the green *Sphagnum* tops form a "roof" corresponding to the forest canopy. *Sphagnum* stalks resemble tree trunks with branches, and the brown decomposing layer is similar to the forest floor. He sampled three layers of bogs in the Swiss Jura (0–3.5 cm, 3.5–7 cm, and 7–13 cm); however, because approximately 90% of the Oribatida inhabited the upper two layers and all species found in the deepest layer occurred in larger numbers closer to the surface, he focused on the two higher strata only. Of the 38 more abundant oribatid species, the majority preferred the upper layer, 7 preferred the deeper layer, and 5 occurred in both layers [1]. The vertical distribution of the adult Oribatida in peatlands was also investigated, based on single samples, in Poland [19] and Norway [20]. The vertical distribution of the Oribatida may vary depending on the season, time of day [21], *Sphagnum* thickness, and water content [22–24].

The aims of this study were (1) to contribute to the knowledge on the vertical distribution of the main mite groups (Oribatida, Mesostigmata, and Prostigmata) in bogs, also including the juvenile forms, which may be important for the results [6,25]; (2) to investigate the vertical distribution of the oribatid species, which are intermediate hosts of tapeworms [26,27] that may pose a risk to farm animals (cattle and sheep) grazing on the studied bog; (3) contribute to the knowledge of the biological diversity of Neshalvøya due to its valuable yet endangered nature [28,29].

2. Material and Methods

2.1. Study Area

The study site is located on Neshalvøya, Kvam municipality, Vestland province, Norway (Figure 1) (60.154° N 5.930° E, 35 m asl). The climate in the area is characterized by high annual precipitation (2300 mm) [30], low mean annual temperature (7.2 °C), mild winters (mean temperature of the coldest month is −2 °C), and cold summers (mean temperature of the warmest month is 12.5 °C) [31]. In the year of study (2008), according to the weather station closest to the study site (Omastranda, located ca. 7 km from Neshalvøya), the mean annual temperature was lower (5.2 °C) and the annual precipitation was higher (3198 mm) when compared to the data from longer periods. The temperature that year varied between −13.9 °C (25 March) and 28.5 °C (29 July). The mean temperature of the coldest month (March) was −1.4 °C, and that of the warmest month (July) was 15.3 °C. At the time of sampling, i.e., 28 May 2008, ca. 13 o'clock, the temperature was 18.7 °C (https://www.yr.no/, accessed 8 February 2024).

The bedrock of the peninsula consists mainly of phyllite, a type of foliated metamorphic rock with large elements of greenstone, as well as amphibolite, and some metasandstone which occurs in the upper region of Neshalvøya. Other types of rock include gneiss, found in the hills, and some olivine [28].

The peninsula has an area of 2.7 km² and is covered by forests, with some cultivation fields and cultural pastures. The peninsula is dominated by coniferous trees, mostly pine (*Pinus sylvetris* L.), and this tree dominated at the sampling site (Figure 2). Some spruce [*Picea abies* (L.) H.Karst] occurs close to the national highway. In addition, there is a great variety of broadleaf trees and bushes, mostly elm (*Ulmus glabra* Huds.), ash (*Fraxinus exelsior* L.), lime (*Tillia cordata* Mill.), oak (*Quercus* sp.), hazel (*Corylus avellana* L.), birch (*Betula pendula* Roth), black alder [*Alnus glutinosa* (L.) Gaertn.], gray alder [*A. incana* (L.) Moench],

and rowan (*Sorbus aucuparia* L.). Bogs cover a considerable area of the forest [28] and are grazed by farm animals (cattle and sheep). Neshalvøya drew special attention from scientists, including biologists, because of its valuable cultural landscape and nature, which have been endangered by the plans to build a shipyard [28,29].
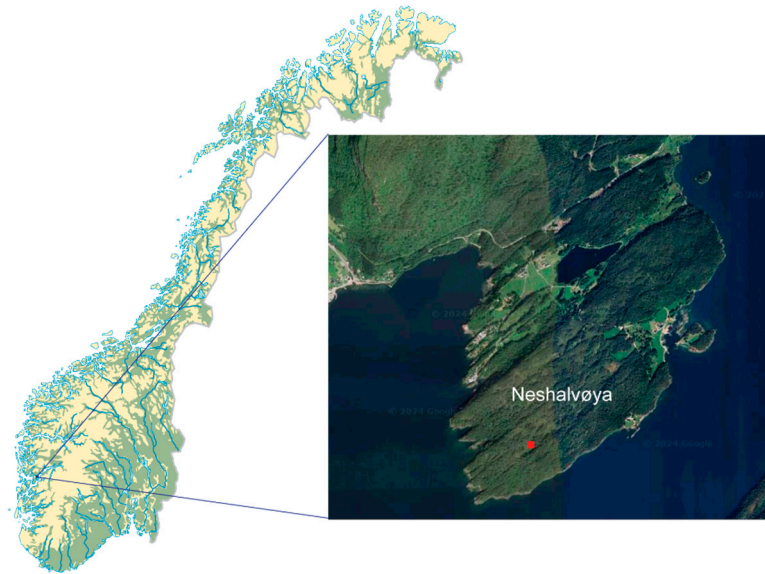
Figure 1. Location of the study site (red point) on Neshalvøya, modified from Google Maps.
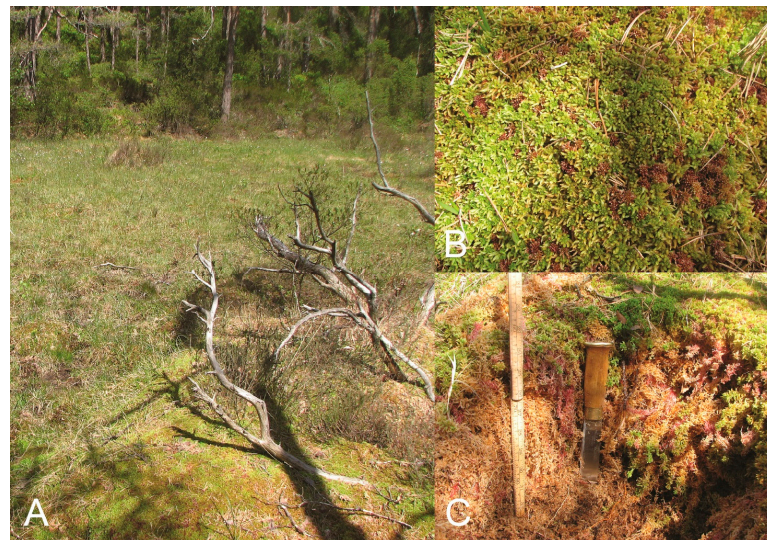
Figure 2. Study site on Neshalvøya; (**A**)—view at the forest bog, (**B**)—*Sphagnum* moss sampled, (**C**)—sampling of vertical *Sphagnum* layers.

2.2. Sampling and Identification

Samples of *Sphagnum* mosses were collected by Torstein Solhøy and Anna Seniczak on 28 May 2008 from the forest bog on Neshalvøya (Figure 1). Samples were taken at four randomly selected sites, at four depths (0–5 cm, 5–10 cm, 10–15 cm, and 15–20 cm), each measuring an area of 10 cm × 20 cm (Figure 2). The samples were transported in separate plastic bags within four hours to the laboratory of the University of Bergen for extraction.

Mites were extracted using self-made Berlese funnels where height-adjustable lamps were used to allow a gradual increase in the temperature above the samples, from ca. 24 °C to 37 °C. The extraction lasted 14 days. The mite groups (Oribatida, Mesostigmata, and Prostigmata) were counted under a stereomicroscope, including both adults and

juveniles. The Oribatida were further determined to species or genus level using the key for adults [32] and other publications to identify the juvenile instars [33–50]. Nomenclature follows Subías [51,52] and partly Weigmann [32]. The species list in Table 1 is presented in alphabetical order. Full names of species are given in Table 1, while in figures, abbreviations are used. Measurements of adults are based on Weigmann (2006) [32], or on the examined specimens. The samples are deposited at the University Museum of Bergen, Norway (ZMUB).

Table 1. Mean abundance in 1000 cm^3 ($\pm$ standard deviation); number of species (*S*) and Shannon (*Hs*) index of Oribatida in vertical layers of *Sphagnum*; species with significant differences in abundance are marked in bold; ^{ab}—different letters indicate significant differences between the means; RDA refers to best fitted species; length values are average values of the length of adults; *—indicates intermediate hosts of tapeworms after Denegri (1993) [26].

Species	Abbreviation for RDA	Length (μm)	0–5 cm	5–10 cm	10–15 cm	15–20 cm
Adoristes ovatus (C.L. Koch, 1839) *	AdrOvt	590	1.75 ($\pm$1.71)	1.25 ($\pm$1.89)	0.00	0.00
Achipteria coleoptrata (Linnaeus, 1758) *		590	0.25 ($\pm$0.50)	0.00	0.00	0.00
Atropacarus striculus (C.L. Koch, 1835)		695	34.25 ($\pm$14.29)	43.50 ($\pm$3.79)	31.25 ($\pm$9.98)	35.50 ($\pm$6.24)
Banksinoma lanceolata (Michael, 1885)		330	0.75 ($\pm$0.96)	0.00	0.00	0.00
Camisia solhoyi Colloff, 1993		840	0.25 ($\pm$0.50)	8.75 ($\pm$11.81)	3.50 ($\pm$2.65)	0.50 ($\pm$1.00)
Carabodes femoralis (Nicolet, 1855) *	CarFem	658	0.75 ($\pm$0.96)	2.00 ($\pm$1.15)	0.50 ($\pm$1.00)	0.00
Carabodes labyrinthicus (Michael, 1879) *	CarLab	505	3.00 ($\pm$1.15)	0.75 ($\pm$0.96)	0.50 ($\pm$0.58)	1.00 ($\pm$2.00)
Carabodes reticulatus Berlese, 1913 *		755	0.25 ($\pm$0.50)	0.00	0.00	0.00
Carabodes rugosior Berlese, 1916 *		585	0.75 ($\pm$1.50)	0.25 ($\pm$0.50)	0.00	0.00
Ceratoppia sexpilosa (L. Koch, 1879)		700	0.50 ($\pm$0.58)	0.00	0.75 ($\pm$0.50)	0.25 ($\pm$0.50)
Ceratozetes sp.		340	0.00	0.00	0.25 ($\pm$0.50)	0.00
***Ceratozetes gracilis* (Michael, 1884) ***	CerGrc	545	0.75 ^{a} ($\pm$0.96)	3.75 ^{ab} ($\pm$2.75)	11.00 ^{ab} ($\pm$4.08)	11.75 ^{b} ($\pm$5.68)
Chamobates borealis (Trägårdh 1902)		370	0.00	0.00	0.00	0.25 ($\pm$0.50)
Chamobates pusillus (Berlese 1895)		420	1.00 ($\pm$1.41)	0.00	0.00	0.00
Cultroribula bicultrata (Berlese, 1905)		238	0.25 ($\pm$0.50)	0.75 ($\pm$0.96)	0.25 ($\pm$0.50)	0.00
Dameobelba minutissima (Sellnick, 1929)		260	0.00	0.00	0.50 ($\pm$1.00)	0.75 ($\pm$0.96)
Eniochthonius minutissimus (Berlese, 1904)		375	0.50 ($\pm$0.58)	0.00	0.50 ($\pm$0.58)	0.00
***Eulohmannia ribagai* (Berlese, 1910)**	EulRib	665	0.00 ^{a}	2.00 ^{ab} ($\pm$1.63)	5.00 ^{ab} ($\pm$1.41)	7.50 ^{b} ($\pm$5.07)
***Eupelops plicatus* (C.L. Koch, 1835)**	EupPlc	590	13.50 ^{a} ($\pm$5.45)	3.75 ^{ab} ($\pm$3.30)	1.00 ^{ab} ($\pm$1.41)	0.75 ^{b} ($\pm$1.50)
Eupelops torulosus (C.L. Koch, 1839)	EupTor	690	10.00 ($\pm$14.17)	0.00	0.00	0.75 ($\pm$1.50)
Galumna obvia (Berlese, 1914) *		775	6.50 ($\pm$6.03)	4.75 ($\pm$5.62)	1.50 ($\pm$1.29)	0.75 ($\pm$1.50)
Hemileius initialis (Berlese, 1908)		500	0.25 ($\pm$0.50)	0.00	0.00	0.00
Hoplophthiracarus illinoisensis (Ewing 1909)		550	84.00 ($\pm$100.68)	28.25 ($\pm$33.23)	7.75 ($\pm$10.01)	1.50 ($\pm$2.38)
Hydrozetes lacustris (Michael, 1882)		480	0.00	0.00	0.00	0.25 ($\pm$0.50)
Hypochthonius rufulus C.L. Koch, 1835		675	12.75 ($\pm$10.37)	25.50 ($\pm$24.85)	13.50 ($\pm$16.66)	8.00 ($\pm$6.68)
Lagenobates lagenulus (Berlese, 1904)		300	0.00	0.00	0.00	0.25 ($\pm$0.50)
Liebstadia humerata Sellnick, 1928		345	0.25 ($\pm$0.50)	0.25 ($\pm$0.50)	0.00	0.00
Limnozetes ciliatus (Schrank, 1803)		300	0.00	0.00	0.00	0.50 ($\pm$1.00)
Limnozetes rugosus (Sellnick, 1923)		358	0.25 ($\pm$0.50)	0.00	0.00	0.25 ($\pm$0.50)
Liochthonius alpestris (Forsslund, 1958)		190	38.75 ($\pm$35.42)	26.50 ($\pm$22.49)	5.00 ($\pm$8.12)	0.75 ($\pm$0.96)
Liochthonius neglectus Moritz, 1976		194	0.50 ($\pm$1.00)	0.00	0.00	1.50 ($\pm$1.91)
Liochthonius sp.		182	0.50 ($\pm$1.00)	0.25 ($\pm$0.50)	0.00	0.00
Liochthonius strenzkei Forsslund, 1963		185	4.25 ($\pm$7.85)	12.50 ($\pm$25.00)	1.50 ($\pm$3.00)	0.25 ($\pm$0.50)
Malaconothrus monodactylus (Michael, 1888)	MalMon	415	17.50 ($\pm$11.47)	8.25 ($\pm$9.54)	2.00 ($\pm$2.71)	3.25 ($\pm$3.77)
Mortizoppia translamellata (Willmann, 1923)		295	50.00 ($\pm$37.73)	59.50 ($\pm$57.23)	24.25 ($\pm$29.83)	10.25 ($\pm$16.17)
Mucronothrus nasalis (Willmann, 1929)		690	3.50 ($\pm$6.35)	0.00	2.50 ($\pm$3.00)	1.75 ($\pm$1.71)
Nanhermannia coronata Berlese, 1913	NanCor	525	821.25 ($\pm$310.76)	491.75 ($\pm$275.73)	267.00 ($\pm$175.38)	270.75($\pm$73.71)
***Nothrus pratensis* Sellnick, 1928**	NotPrt	850	189.75 ^{a} ($\pm$60.67)	89.50 ^{ab} ($\pm$20.87)	47.25 ^{b} ($\pm$34.06)	39.00 ^{b} ($\pm$25.60)
Nothrus silvestris Nicolet, 1855		760	0.25 ($\pm$0.50)	0.25 ($\pm$0.50)	0.00	0.00
Odontocepheus elongatus (Michael, 1879)		655	0.00	0.50 ($\pm$0.58)	0.50 ($\pm$0.58)	0.00

Table 1. *Cont.*

| Species	Abbreviation for RDA	Length (µm)	0–5 cm	5–10 cm	10–15 cm	15–20 cm
Oppiella nova **(Oudemanns, 1902)** *	OppNov	270	200.00 [a] (±82.25)	99.00 [ab] (±14.31)	70.50 [ab] (±35.05)	46.00 [b] (±37.73)
Rhinoppia subpectinata (Oudemans, 1900)		333	0.75 (±0.96)	8.25 (±11.32)	4.75 (±8.22)	1.25 (±1.89)
Paleacarus hystricinus Trägårdh, 1932		300	0.00	0.75 (±1.50)	0.00	0.00
Phthiracarus boresetosus Jacot, 1930		703	0.25 (±0.50)	0.25 (±0.50)	0.00	0.00
Phthiracarus clavatus Parry, 1979		965	0.25 (±0.50)	0.25 (±0.50)	0.00	2.00 (±4.00)
Phthiracarus italicus (Oudemans, 1900)		895	0.00	0.00	0.25 (±0.50)	0.00
Platynothrus peltifer (C.L. Koch, 1839) *	PltPel	875	45.25 (±48.46)	8.50 (±11.93)	2.50 (±2.52)	1.75 (±2.36)
Quadroppia maritalis **Lions, 1982**	QuaMar	190	0.25 [a] (±0.50)	50.50 [ab] (±45.21)	115.25 [b] (±114.60)	18.75 [ab] (±8.26)
Rhysotritia ardua (C.L. Koch, 1841)		818	3.25 (±4.57)	1.50 (±2.38)	3.00 (±3.56)	2.75 (±3.20)
Rhysotritia duplicata Grandjean, 1953		876	0.25 (±0.50)	0.50 (±1.00)	0.00	0.00
Scheloribates laevigatus (C.L. Koch, 1835) *		595	1.25 (±2.50)	3.50 (±4.36)	0.50 (±1.00)	0.00
Steganacarus magnus (Nicolet, 1855)		1380	1.25 (±1.89)	0.75 (±0.50)	1.25 (±2.50)	1.00 (±0.82)
Suctobelbella acutidens (Forsslund, 1941)	SucAct	208	0.00	8.50 (±7.94)	0.00	0.00
Suctobelbella arcana Moritz, 1970		203	47.50 (±33.36)	25.50 (±20.07)	7.50 (±6.45)	5.00 (±4.24)
Suctobelbella falcata (Forsslund, 1941)		240	0.50 (±1.00)	0.00	1.50 (±2.38)	0.00
Suctobelbella forsslundi (Strenzke, 1950)		208	0.00	3.50 (±4.12)	0.25 (±0.50)	2.00 (±2.31)
Suctobelbella latirostris (Strenzke, 1950)		245	0.25 (±0.50)	0.00	0.00	0.00
Suctobelbella longirostris (Forsslund, 1941)		300	1.50 (±1.73)	7.25 (±8.38)	13.25 (±12.71)	5.25 (±6.40)
Tectocepheus velatus **(Michael, 1880)**	TecVel	300	266.50 [a] (±211.42)	37.50 [ab] (±29.03)	13.50 [ab] (±9.26)	10.50 [b] (±11.03)
Tyrphonothrus foveolatus (Willmann, 1931)		410	0.00	0.00	1.00 (±2.00)	0.25 (±0.50)
Tyrphonothrus maior (Berlese, 1910)		568	0.00	0.00	0.00	0.25 (±0.50)
Malaconothrus vietsi (Willmann, 1925)		335	0.25 (±0.50)	0.00	0.00	0.00
S			48	38	37	35
*H*s			1.966	2.149	2.116	1.768

2.3. Statistical Analyses

Mite communities were characterized by the abundance (*A*), while the Oribatida community was additionally characterized by the number of species (*S*) and the Shannon (*H*s) index. We calculated the community body size (CBS) index [53] based on the abundance of the adult Oribatida per sample and body size (mean length in µm) of the species. Statistical differences between the abundance of species in four layers were calculated. First, the 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. Kruskal–Wallis ANOVA by Ranks was utilized to test for significant differences between the means [54]. The significance level for all analyses was accepted at $\alpha = 0.05$. These calculations were carried out with STATISTICA 12.5 software.

Multivariate analyses were performed using CANOCO 5.15 software (Microcomputer Power, Ithaca, NY, USA) [55,56]. Dependent variables (quantitative continuous) were abundances of oribatid species (juveniles and adults), the total abundance of Oribatida juveniles and adults, the total abundance of all Oribatida, the abundance of the adult Oribatida divided into two size groups (<500 µm and ≥500 µm), the abundance of the Mesostigmata, the abundance of the Prostigmata, and the total abundance of Acari. These data were log-transformed, log (x + 1) [57], considering the down-weighting of rare species. Independent variables (factors) were the depths of 0–5 cm, 5–10 cm, 10–15 cm, and 15–20 cm, labeled 5, 10, 15, and 20, respectively. First, we checked with univariate analyses if there was a relationship between the number of the juvenile Oribatida, adult Oribatida, all Oribatida, number of the Mesostigmata, number of the Prostigmata, number of the Acari, and depth of samples. Furthermore, multivariate analysis was used to test if the variation in the community of the juvenile Oribatida, adult Oribatida, and all Oribatida was significantly explained by the depth of samples.

3. Results

In total, 16.880 mites, including 16.384 Oribatida, 466 Mesostigmata, and 30 Prostigmata, were extracted from the samples. The total abundance of mites, the Oribatida and Mesostigmata, was the highest in the upper layer of *Sphagnum* (0–5 cm) and decreased with depth (Figure 3). In the deepest layer sampled (15–20 cm), the total abundance of the mites and of the Oribatida made up only ca. one-fourth of the abundances in the upper layer.
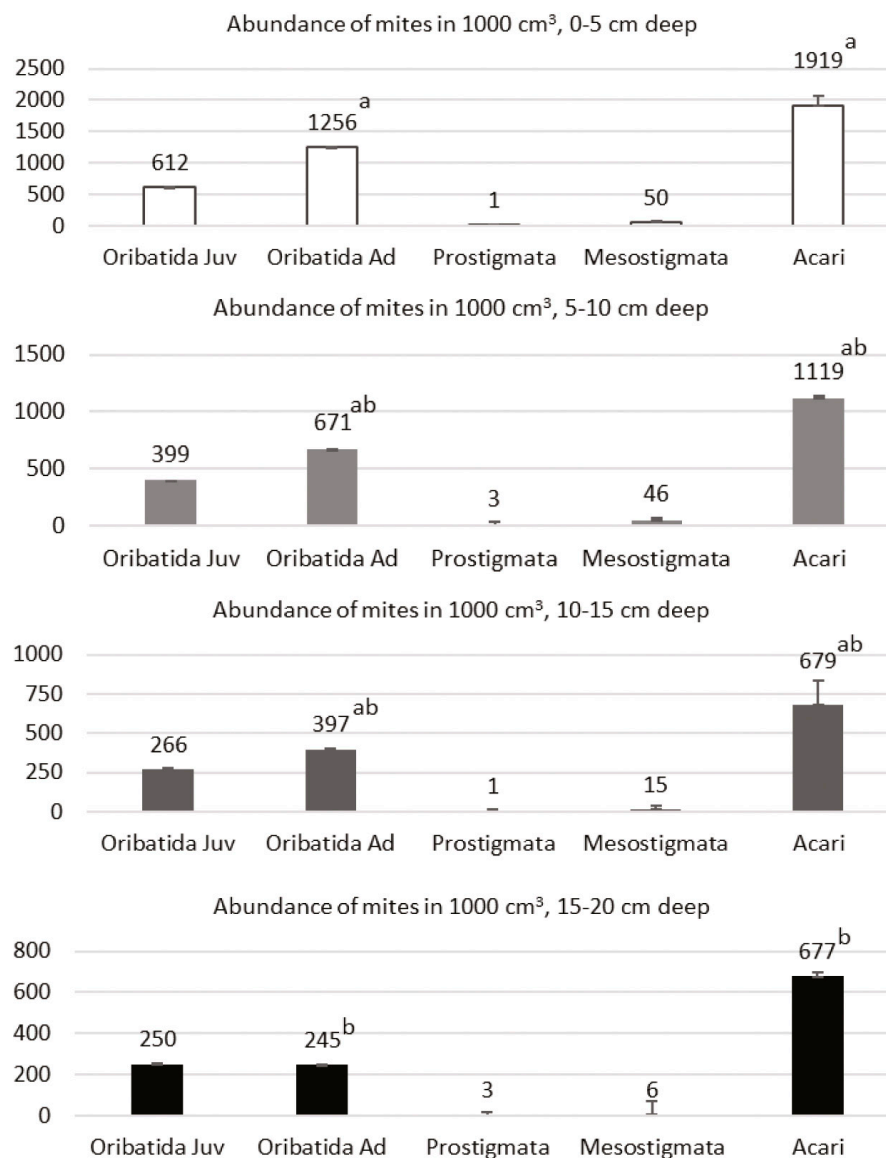

Figure 3. Abundance of mites (in 1000 cm^3) in different layers of *Sphagnum* moss; mean—bars and values above bars; standard deviation—whiskers; Ad—adult; Juv—juvenile; [ab]—different letters indicate significant differences between the means.

Within the Oribatida, the abundance of adults was significantly affected by depth (permutation test: both on the first axis and all axes, pseudo-F = 17.4, *p* = 0.002, df = 3). The sample depth explained 76.67% of the variability of this group (adjusted explained variation). In contrast, the variability of the abundance of juveniles in relation to depth was not significant (permutation test: both on the first axis and all axes, pseudo-F = 2.7, *p* = 0.092, df = 3), and explained only 24.88% of the variability of this group. As a result of this, the participation of juveniles in the age structure increased with depth. In the upper layer (0–5 cm), the juvenile Oribatida made up 32% of the age structure, while in the three

deeper layers (5–10 cm, 10–15 cm, and 15–20 cm), their participation increased to 37%, 40%, and 50%, respectively (Figure 3).

The CBS index decreased with depth, except for the deepest layer, where it was the highest (Figure 4). When the adult Oribatida were divided into two size groups (smaller or larger than 500 µm), the abundance of both groups decreased with depth (Figure 5). For example, in the upper layer, the abundance of the larger and smaller Oribatida was 689 ($\pm$150) and 567 ($\pm$182) specimens per 1000 cm^3, and in the deepest layer, it was 143 ($\pm$52) and 102 ($\pm$50) specimens per 1000 cm^3, respectively. In particular, the variability of the abundance of the large oribatids was explained by depth (adjusted explained variation 81.65%, permutation test on all axes: pseudo-F = 23.3, p = 0.002, df = 3), and the same was true for the small ones (adjusted explained variation: 67.26%, permutation test on all axes: pseudo-F = 11.3, p = 0.002, df = 3). The number of larger oribatid species was significant in relation to depth (adjusted explained variation: 45.80%, permutation test on all axes: pseudo-F = 5.2, p = 0.028, df = 3), while the number of smaller species was not significant (adjusted explained variation: 0.00%, permutation test on all axes: pseudo-F = 0.9, p = 0.532, df = 3). The important layers were 0–5 cm and 5–10 cm, which explained 42.3% and 13.4% of the variability of the whole community of the adult Oribatida, respectively, even if some species preferred deeper layers.
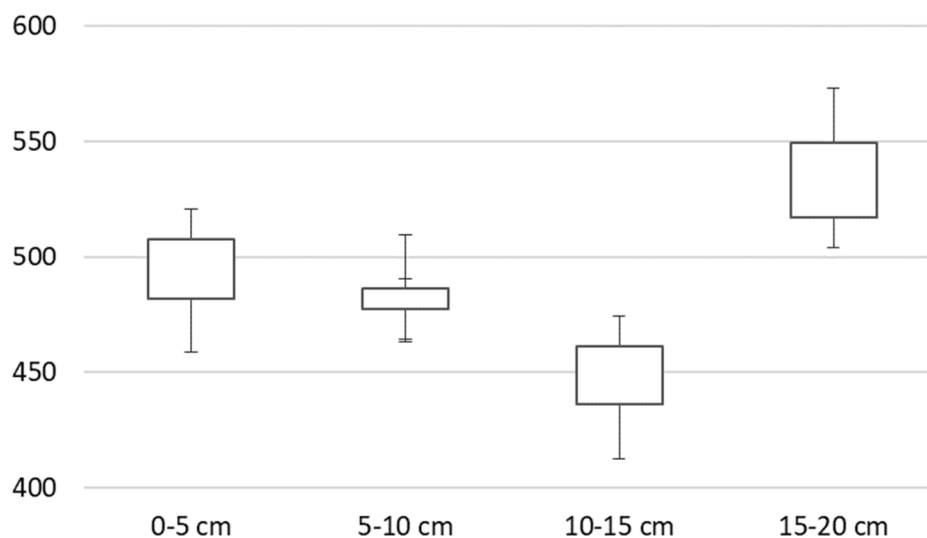

Figure 4. Community body size of adult Oribatida in different layers of *Sphagnum* moss.

The abundance of the Mesostigmata was reduced even more with depth, and in the deepest layer, it made up 12% of the abundance from the uppermost layer (Figure 3). According to the Redundancy Analysis (RDA), the variability of the abundance of the Mesostigmata was not significant in relation to depth (but was close to significant; permutation test: both on the first axis and all axes, pseudo-F = 3.7, p = 0.054, df = 3). Only the abundance of the Prostigmata did not follow any pattern in relation to the sample depth and was insignificant (Figure 3).

In total, 62 species of the Oribatida were recorded in this study (Table 1). The largest number of species was noted in the uppermost layer (48), and it decreased with depth to 35 species in the deepest layer. The Shannon species diversity index was also the lowest in the deepest layer.

Across all layers, the most numerous species was *Nanhermannia coronata* Berlese, 1913; it made up 40–55% of all Oribatida (Table 1). In the uppermost layer, the second most abundant was *Tectocepheus velatus* (Michael, 1880), which comprised 15% of the Oribatida. In two other layers (5–10 cm and 15–20 cm), the second most abundant was *Oppiella nova* (Oudemans, 1902), with 9% participation in both layers, and in the deepest layer, the second most abundant was *Quadroppia maritalis* Lions, 1982 (17%).
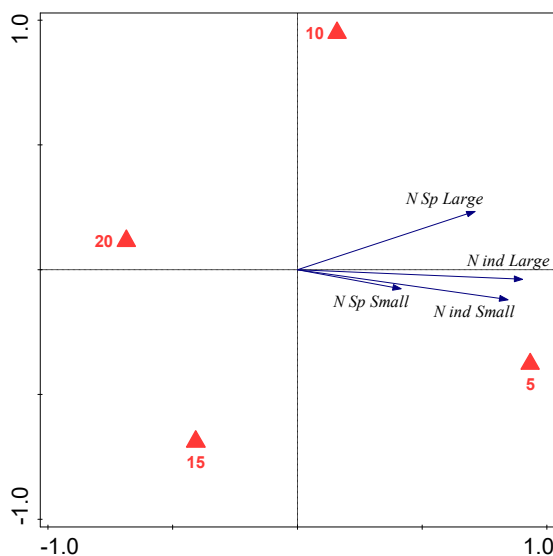
Summary Table:

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.55	0.02	0.01	0.23
Explained variation (cumulative)	55.30	57.21	58.71	81.33
Pseudo-canonical correlation	0.89	0.39	0.51	0.00
Explained fitted variation (cumulative)	94.19	97.45	100.00	

Conditional Term Effects:

| Name	Explains %	pseudo-F	*p*
Sample.5	42.3	10.3	0.004
Sample.10	13.4	3.9	0.018
Sample.20	2.9	0.9	0.46

Figure 5. Results of Redundancy Analysis (RDA) of the variability of the number of specimens and species of adult Oribatida smaller than 500 μm (NindSmall, NSpSmall) and larger than 500 μm (NindLarge, NSpLarge) in relation to the layers (marked with red triangles): 5—0–5 cm, 10—5–10 cm, 15—10–15 cm, 20—15–20 cm.

Twenty-three oribatid species were found across the entire depth gradient studied. Most of them decreased their abundance with depth, as was the case with *Eupelops plicatus* (C.L. Koch, 1835), *Nothrus pratensis* Sellnick, 1928, *Oppiella nova*, and *Tectocepheus velatus* (Table 1). In other species, however, the abundance increased significantly with the sample depth [*Ceratozetes gracilis* (Michael, 1884), *Eulohmannia ribagai* (Berlese, 1910)]. *Quadroppia maritalis* was most abundant at the depth of 10–15 cm. Some species had similar abundance in all studied layers [e.g., *Atropacarus striculus* (C.L. Koch, 1835), *Rhysotritia ardua* (C.L. Koch, 1841), and *Steganacarus magnus* (Nicolet, 1855)].

According to the RDA (Figure 6), the variability of the oribatid community (adults + juveniles) was significantly affected by the sample depth (permutation test: on the first axis, pseudo-F = 1.8, *p* = 0.002, and on all axes, pseudo-F = 2.8, *p* = 0.004, df = 3) that explained 26.82% of the variability of this group. Most species preferred the upper layer of *Sphagnum*. Only *Suctobelbella acutidens* (Forsslund, 1941) and *Carabodes femoralis* (Nicolet, 1855) preferred the deeper layer (5–10 cm). *Quadroppia maritalis* showed preference towards the 10–15 cm layer, while *Eulohmannia ribagai* and *Ceratozetes gracilis* preferred the deepest layer. In populations of several species, the juveniles dominated in the age structure (Figure 7). Both adults and juveniles of the same species showed a preference for the same layer (Figure 6).

Most oribatid species, which are known as intermediate hosts of tapeworms (Table 1), except *Ceratozetes gracilis*, were found to be the most abundant in the uppermost layer [*Adoristes ovatus* (C.L. Koch, 1839), *Carabodes* spp., *Galumna obvia* (Berlese, 1914), *Oppiella nova*, *Platynothrus peltifer* (C.L. Koch, 1839)], so they can potentially transmit parasites onto other animals, including those grazing in the forest bog.
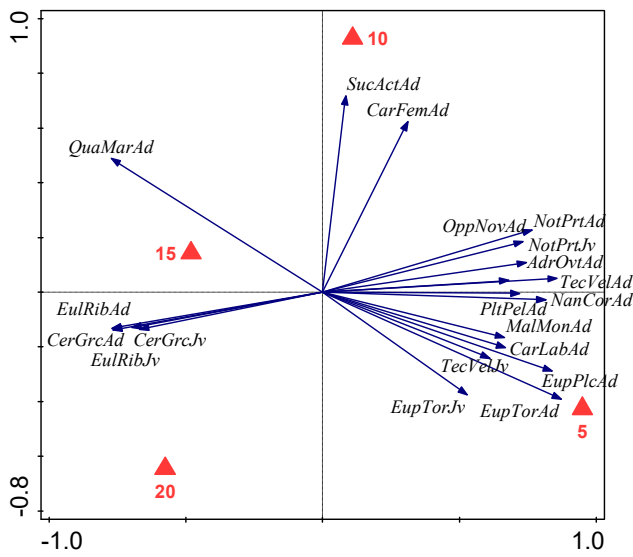
Summary Table:

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.31	0.08	0.03	0.26
Explained variation (cumulative)	31.19	38.84	41.45	67.89
Pseudo-canonical correlation	0.92	0.94	0.68	0.00
Explained fitted variation (cumulative)	75.23	93.69	100.00	

Figure 6. Results of Redundancy Analysis (RDA) of the variability of the best fitted species of Oribatida to the layers (marked with red triangles): 5—0–5 cm; 10—5–10 cm; 15—10–15 cm; 20—15–20 cm; Ad—adult; Juv—juvenile; abbreviations of species names are in Table 1.
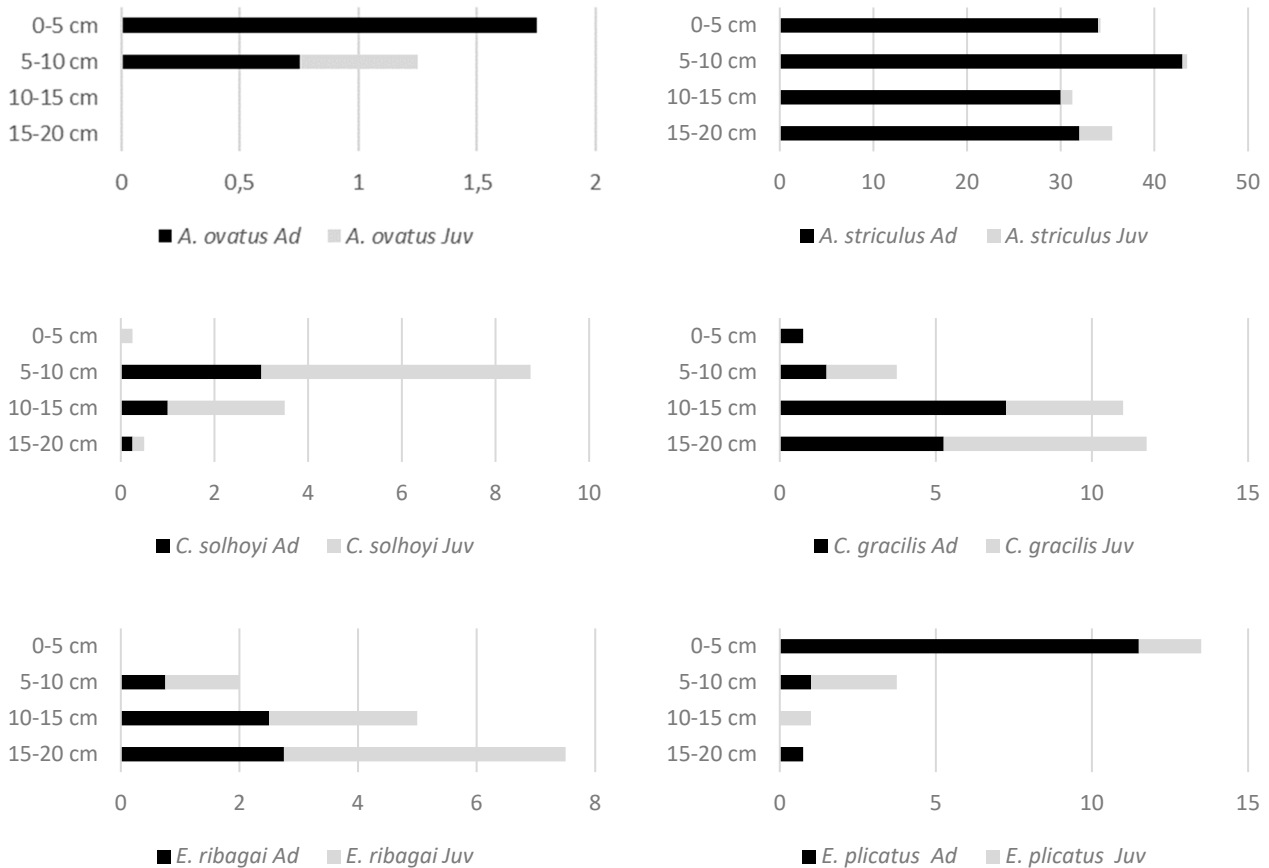
Figure 7. *Cont.*
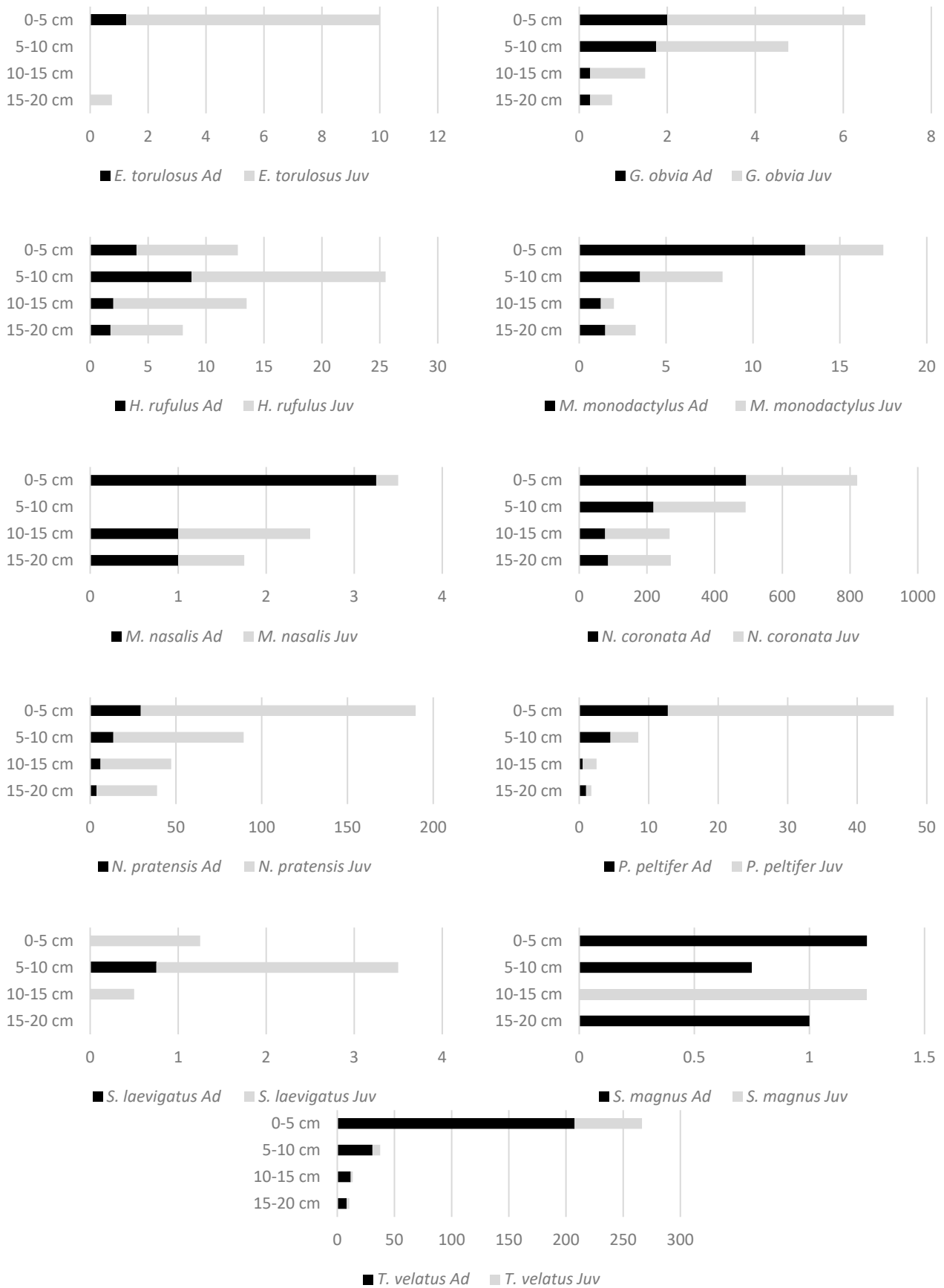
Figure 7. Mean abundance (in 1000 cm^3) of Oribatida species which were represented in samples by both adults and juveniles, in different layers of *Sphagnum*.

4. Discussion

In the bog on Neshalvøya, the abundance of mites and the Oribatida was significantly higher in the upper *Sphagnum* layer and decreased with depth, which is consistent with the results from some other bogs [1,19] and other types of soil [8,16,58–61]. Our results differ, however, from earlier findings in Norway, where the adult Oribatida were most abundant in the deeper layer (5–10 cm) [20]. These differences can be explained by different seasons of sampling; we collected samples in late spring (28 May, at 18.7 °C) while in another study [20], samples were collected during winter (11 March, temperature not given). Based on the available temperature data from the nearest weather station (Fivelsdal) that refer to the later period (1995–2023), the mean temperature on 11 March ranged from −3.8 °C to 9.2 °C (https://www.yr.no/, accessed on 8 February 2024); therefore, it was evidently lower than in our study. The vertical distribution of Oribatida in raised bogs is strongly influenced by the season [19,21]. In spring, most mites (60–90%) accumulate in the surface layer (5–7 cm), 30% are found in lower parts of *Sphagnum*, and only 10% feed in the peat soil below. In autumn, most Oribatida (50–80%) migrate down to the *Sphagnum* hummocks, below the depth of 7 cm, while the percentage of mites in peat remains low (3.5%) [19]. In contrast, in bog microhabitats with a high water table, the seasonal migration of Oribatida is less pronounced, and many mites also stay in the upper layer in winter, because waterlogged and anaerobic conditions in the deeper layers are unsuitable for their overwintering [19,21–23].

The results concerning the Mesostigmata and Prostigmata are similar to those obtained in other habitats, e.g., in grassland, where the abundance of the Mesostigmata was the highest in the upper layer and decreased with depth, while the abundance of the Prostigmata was similar across all soil layers [13]. Many Mesostigmata species are hemiedaphic (i.e., living partly within the soil and partly on the surface). Changes in the vertical distribution of prostigmatid mites were observed after the drainage of a forest bog [23]; hence, this group seems to be sensitive to water conditions.

The analyses of the Oribatida at the species level revealed their different preferences towards the vertical layers of *Sphagnum*, similar to earlier observations [1]. One of the species that occurred abundantly in the upper layer and significantly decreased its abundance with depth was *Nothrus pratensis.* For comparison, throughout winter, this species was found solely in the middle layer of *Sphagnum* [20]. *Nothrus pratensis* was considered a thermophilous species, which quickly migrates vertically, even in response to diurnal changes in the temperature [21]. It is a primary decomposer, i.e., it feeds mainly off litter material [62], and as demonstrated with the stable isotopes, the specimens collected from different layers of *Sphagnum* use the same food sources [63]. So, it is rather the temperature than food that affects the vertical distribution of *N. pratensis* in peatlands.

Also, *Hypochthonius rufulus* C.L. Koch, 1835, is considered thermophilous [21] and it was more abundant in the upper layer of bogs in Switzerland [1]. In our study, no significant differences in the abundance of this species were observed, but in the deepest layer, its abundance made only ca. 60% or less of that in the higher layers, while in winter, it was found only in the middle layer of the *Sphagnum* [20]. The trophic status of *Hypochthonius rufulus* is unclear. Its gut content included springtails, mites [64], and bacteria mixed with finer, unidentified organic fragments [65], while carbohydrase activity suggested that it is omnivorous [66], and stable isotope results indicated that it has a narrow trophic range [63].

The significant decrease in the abundance of *Eupelops plicatus* with depth can be explained by its feeding preferences. It is considered a primary decomposer of litter, similar to *Nothrus. pratensis* [67]. The vertical distribution of *Oppiella nova* and *Tectocepheus velatus* is difficult to explain, since both species are eurytopic [32] and show wide tolerance to many ecological factors, e.g., humidity [23,68]. *Oppiella nova* is fungivorous [69], and *Tectocepheus velatus* has wide feeding preferences.

Nanhermannia coronata was the most abundant species in this study and occurred in all *Sphagnum* layers, confirming the results from other studies [1,20]. This species occurs abundantly in bogs and has wide preferences for bog microhabitats, e.g., hummocks, lawns,

and hollows [42]. In two bogs in Trøndelag (Norway), the adults dominated in the age structure at the end of June (making up on average 65% of populations of this species), larvae made up 4%, protonymphs 10%, deutonymphs 12%, and tritonymphs 10%. Also, in the present study, the adults dominated in the surface layer, but in the deeper layers, the juveniles were more abundant than adults.

Quadroppia maritalis was found only in adult form, and juveniles of the entire family Quadroppiidae remain unknown [48,49]. Despite this species being considered rare [70], it was abundant in our study (in total, 739 specimens were found) and occurred across all layers. It clearly preferred the depth of 10–15 cm, where 62% of the specimens were found. Little is known about the ecology of *Q. maritalis*. It is considered praticolous and silvicolous [70,71], and has also been found in the upper layer (0–5 cm) of bogs [72,73], but in lower quantities. It was also found in low abundances in post-smelting areas, heavily contaminated with heavy metals [74], and in the soil under *Silene acaulis* cushions in high alpine Sweden [75]. This species is possibly more common but occurs in deeper soil layers, which were omitted in sampling.

Some species, like *Ceratozetes gracilis* and *Eulohmannia ribagai,* preferred the deepest layer of *Sphagnum*. Concerning *Ceratozetes gracilis,* similar results were obtained in aspen woodland soil, where this species showed a significantly positive correlation with the depth of organic matter and was predominant in the fermentation and humus organic horizons [76]. *Ceratozetes gracilis* is panphytophagous, i.e., it feeds on dead plant material and living microflora [38]. The results of *Eulohmannia ribagai* are consistent with Solhøy [20], who found this species confined to the lower layer of the bog. *Eulohmannia ribagai* inhabits fine humus, usually beneath the forest litter and epigeic mosses [77]. Its narrow and well-articulated body is a perfect match to move inside small pore spaces. The species feeds on litter-derived particles and associated bacterial films, which explains why it lives in moist microhabitats [77], like deeper layers of the forest bog on Neshalvøya.

Similarly, the vertical distribution of the aquatic Oribatida, e.g., *Limnozetes ciliatus* (Schrank, 1803), is strongly affected by the water conditions [23], not by the temperature, due to being eurythermic [21]. In our study, aquatic species [*Limnozetes ciliatus, Hydrozetes lacustris* (Michael, 1882), *Tyrphonothrus foveolatus* (Willmann, 1931), *T. maior* (Berlese, 1910)] were not abundant, and most occurred only in the deepest layer of the bog. Only *Limnozetes rugosus* (Sellnick, 1923) occurred both in the upper and bottom layers. In contrast, Lehmitz and Maraun [63] found both, *Limnozetes ciliatus* and *Tyrphonothrus maior* in different layers of *Sphagnum*, which was probably caused by more moist conditions in the bogs they studied.

Among the Oribatida, a significant decline in the abundance was observed only in adults, but not in juveniles. Earlier studies in peatlands showed that the inclusion of the juvenile Sarcoptiformes, to which the Oribatida belong, had less impact on the results than in the case of the Mesostigmata and the Trombidiformes [6]. The different stages of the same species were located at the same depths in most cases, similar to observations in the Swiss Jura [1].

In mineral soils with humus and litter, larger Oribatida are usually more abundant on the surface than the small ones [16,78,79], which was also observed in peatlands sampled to a depth of 7 cm [1]. In our study, the CBS index generally decreased with depth, confirming the latter results [1], and only in the deepest layer (15–20 cm) was it higher. This was because of the abundant occurrence of *Nanhermannia coronata* in this layer. The species has a body length of 480–570 μm; however, it has a narrow, cylindrical body, with a mere width of 228–260 μm [42], so it can easily migrate to deeper layers of *Sphagnum* bogs. *Nanhermannia coronata* belongs to secondary decomposers, i.e., predominantly feeding on fungi, and partly on litter [80], so it can use different food resources at different depths.

In the current study, we found eleven species of Oribatida that are listed as intermediate hosts of tapeworms [26], and most of them occurred in the upper layer. The most abundant was *Oppiella nova,* which is known as an intermediate host of *Moniezia* spp. that infest sheep and cattle. Another abundant species was *Platynothrus peltifer*, which is an intermediate host of four tapeworm species that are parasites of horses, sheep, cattle, and

voles. The most frequent oribatid species that acts as an intermediate host of tapeworms (14 species of anoplocephalids were found in this mite) is *Scheloribates laevigatus* (C.L. Koch, 1835) [28], which was also found in our study but was not abundant.

In this study, fourteen oribatid species (i.e., over 20% of the total) were absent from the upper layer but were present in the deeper layers. Similarly, sampling during different seasons in peatlands contributes to the evaluation of their diversity [69], as does the inclusion of different developmental instars [6,25].

5. Conclusions

In the upper layer, the mites were the most abundant and most diverse. Most oribatid species that are known as intermediate hosts of tapeworms occurred in the upper layer creating potential risk to farm animals grazing on the studied bog. However, some Oribatida species were found only at deeper layers. Sampling these layers contributes considerably to the evaluation of the species diversity, andshould be considered in studying the biological diversity of naturally valuable areas, like the Neshalvøya peninsula studied herein.

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