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High Diversity of Mites (Acari: Oribatida, Mesostigmata) Supports the High Conservation Value of a Broadleaf Forest in Eastern Norway

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Abstract: Broadleaf forests are critical habitats for biodiversity and this biodiversity is in turn essential for their proper functioning. Mites (Acari) are a numerous and functionally essential component of these forests. We report the diversity of two important groups, Oribatida and Mesostigmata, in a broadleaf forest in Eastern Norway which is considered to be a biodiversity hotspot. Eighteen samples, each 500 cm^3, were collected from diverse microhabitats (moss on ground, lichens on tree twigs lying on ground, moss on tree trunks at ground level, moss on tree trunks 1.5 m above ground, moss on decaying stump, moss on decaying log, and decaying wood from trees) from which 10,843 specimens and 95 species from 32 families of Oribatida, and 655 specimens of 34 species from 14 families of Mesostigmata were found. Only 30% of the species were previously recorded in broadleaf forests in Western Norway. Oribatid communities on decaying stump and in lichens were distinct from the other communities, while mesostigmatid communities on tree trunks (both at ground level and 1.5 m above ground) and in lichens differed most from other communities. Over 30% of the species were found in only a single microhabitat. Twenty-three species and the genus *Zerconopsis* are reported from Norway for the first time. Six records are also new to Fennoscandia, including (Oribatida) *Coronoquadroppia monstruosa*, *Eueremaeus valkanovi*, *Ramusella furcata*, and (Mesostigmata) *Dendrolaelaps rectus*, *D. multidentatus*, and *D. tenuipilus*. In addition, several rare species were detected, e.g., *Achipteria magna*, *Oribotritia berlesei*, and *Subiasella quadrimaculata*, and two were found in their northernmost locality (*O. berlesei*, *E. valkanovi*). These results confirm the unique character and high conservation value of the studied forest in Norway, Fennoscandia and at a European scale.

Keywords: forest habitats; microhabitats; new species records; Fennoscandia

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1. Introduction

Forests are species-rich habitat types which globally contain over 80% of terrestrial biodiversity. This diversity is essential for their proper functioning, including tree productivity, decomposition, recycling of nutrients, and for resilience of the forest ecosystems [1–4]. In Norway, forests cover nearly one quarter of the land area [5] and are inhabited by approximately 60% of the 44,000 species found in Norwegian terrestrial environments [6,7].

The major species-rich groups found in the forests are insects, arachnids, lichens, mosses, and fungi [6].

Broadleaf forests are rare in Norway and are found mainly in the coastal areas in the west, south, and east which have milder climates. They are exceptional because many of them remain in pristine condition, albeit fragmented, and often are located on rocky slopes which are less attractive for forestry use. These forests are known as the most biodiversity rich terrestrial land habitats in Fennoscandia and are refuges of rare and endangered species of plants and animals. Because of their mild winters, some species, common in Central Europe, have extended their limits to these forests. Thus, these forests have been identified as important biodiversity areas, both nationally and internationally. However, only less than 0.7% of these forests are protected and areas considered as High Conservation Value Forest (HCVF) are threatened by habitat loss and destruction [8]. The first and essential step for preserving these forests is to understand their natural value, also expressed by their biological diversity, including communities below ground that closely interact with diversity above ground [9].

Mites (Acari) are small arachnids (average body length of 0.5 mm) that are very abundant and diverse, particularly the suborder Oribatida and order Mesostigmata, in temperate broadleaf forest ecosystems. Due to their small body size, they often go unnoticed, although they live in diverse forest microhabitats—from deep soils, even 2–3 m underground [10], up to the tops of trees [11]. They are usually most abundant and species-rich in mosses [12–15].

Oribatida are predominantly saprophagous, being very important for decomposition of soil organic matter, but some species feed on plant roots [16], lichens [17], and live animals [18]. In broadleaf forests their densities often exceed 100,000 indiv./m^2 and species richness may be greater than 100 [19–21]. Mesostigmata are mostly predators, and they regulate the densities of small and little-sclerotized taxa, e.g., nematodes or small arthropods, such as juvenile oribatid mites or springtails [20,22]. It is often overlooked that mites, mainly Mesostigmata, are the main groups associated with bark beetles, through phoretic and trophic interactions important for energy flow in the forest ecosystem [23–29]. The proportion of Mesostigmata in the mite communities depends on the density of Oribatida and therefore indirectly on plant cover and climate [14]. For example, in the Arctic tundra in Svalbard, the proportion of Mesostigmata varied greatly (0.3–20.7%) and depended on the form of vegetation [30]. In broadleaf forests this proportion was 4.4–13.9% [14,15,31].

Studies on the invertebrate fauna in old broadleaf forests in Norway are rare [32] and have mainly focused on a specific insect fauna [33–35]. Very few studies on mites from broadleaf forests have been carried out in Norway and they were located mainly in the western part of the country [15,36,37]. Nevertheless, 85 species of Oribatida and 22 of Mesostigmata have been found in those broadleaf forests, and these included 35 new records for Norway and 10 new for Fennoscandia.

This study is a continuation of a species inventory project of rare and rich forest habitats in Norway. So far, only a small group of oribatid mites (ptyctimous mites) have been studied in this part of the country [37]. The aim of this paper is to evaluate the diversity of two large and important mite groups, Oribatida and Mesostigmata, in a diversity of microhabitats in a broadleaf forest in Eastern Norway, considered to be HCVF.

2. Material and Methods

2.1. Study Site

Samples were collected in a plant-rich broadleaf forest located in Kjeøya (59.093° N 11.222° E, 120 m a.s.l.), a peninsula in Viken province, Halden municipality, in Eastern Norway (Figure 1). The study site was characterized by an oceanic climate, with mean annual temperature 6.4 °C and annual precipitation 820 mm [38]. Summer is relatively mild with average temperatures between 16.0–16.7 °C in July and August. In the coldest months (January and February) the average temperatures are between −2.9 °C and −3.8 °C.

The vegetation zone is Boreonemoral and slightly oceanic *sensu* [39]. The bedrock is composed mainly of different gneiss and granite rocks.

Figure 1. Location in Eastern Norway of the broadleaf forest studied (modified from https://www.norgeskart.no and https://faktaark.naturbase.no, accessed on 8 June 2021).

The forest (Figure 2) has an area of 2.32 ha and is considered an important habitat, since many rare species, mainly fungi, have been detected there [40]. Forest was characterized by old and large oak (mostly common oak, *Quercus robur* L.), hollow oaks of 100 years and older (>50 cm dbh) [41], and small-leaved lime (*Tilia cordata* Mill.) trees. Other tree species were hazel (*Corylus avellana* L.), common ash (*Fraxinus excelsior* L.), Norway maple (*Acer platanoides* L.), and some additional European beech (*Fagus sylvatica* L.), Norway spruce [*Picea abies* (L.) H.Karst] and Scots pine (*Pinus sylvestris* L.). The herb vegetation was partly sparse.

Figure 2. Studied forest in Eastern Norway; (**a**) rocks and (**b**) large stones on ground make this type of forest less attractive for forestry use.

2.2. Sampling and Identification

In total, 18 samples, each with a volume of 500 cm^3, were collected on 12 June 2017 from several microhabitats: (1) moss on ground (four samples), (2) lichens on tree twigs lying on ground (three samples), (3) moss on tree trunks at ground level (three samples), (4) moss on tree trunks 1.5 m above ground (two samples), (5) moss on decaying stump (one sample), (6) moss on decaying log (three samples), and (7) decaying wood from trees (two samples).

Arthropods were extracted using modified Tullgren funnels for 14 days into 90% ethanol and sorted out from the samples under stereomicroscope. Oribatida were mounted on temporary slides with cavity in lactic acid and adult specimens were identified using the keys of [42–45], while juveniles were identified based on [46–61]. The nomenclature of oribatid species follows [62,63] and partly [45,57,58,64]. 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 [65–85]. Full names of species are given in Table 1 while in other tables and figures abbreviations are used. The arrangement of genera in families and the arrangement of species in genera are alphabetized. Specimens representing all species are deposited at the University Museum of Bergen, Norway. Information on other mite groups that were sorted out from the samples will be published later.

Table 1. Total number of individuals (No) and frequency (*F*, in %, proportion of samples) of mites in broadleaf forest in Eastern Norway and occurrence in microhabitats: A—moss on ground, B—lichens on tree twigs lying on ground, C—moss on tree trunks at ground level, D—moss on tree trunks 1.5 m above ground, E—moss on decaying stump, F—moss on decaying log, G—decaying wood from trees; habitat preferences: aquatic (aq), arboricolous (ar), epilithic (el), epiphytic (ep), eurytopic (eu), geophilous (ge), hygrophilous (hy), lichenicolous (li), merocenophilous (mer), mesohygrophilous (mh), muscicolous (mu), praticolous (pr), silvicolous (si), tyrphophilous (ty), xerophilous (xe), xylophilous (xy), unclear (?); in bold—species new to Norway.

Family	Family/Species	Habitat Preferences	No	*F*	Microhabitat
	Oribatida				
Brachychthoniidae	*Liochthonius brevis* (Michael, 1888)	eu (si) el ge	67	22	A C
	***Neobrachychthonius magnus* Moritz, 1976**	si el ge	1	6	A
	Sellnickochthonius immaculatus (Forsslund, 1942)	si ar el ge	14	28	A C
	***S. suecicus* (Forsslund, 1942)**	si ge	2	6	C
	S. zellawaiensis (Sellnick, 1928)	si ge	9	22	A F
Hypochthoniidae	Hypochthonius rufulus C.L. Koch, 1835 †	eu mh el ge	16	17	C F
Oribotritiidae	*Oribotritia berlesei* (Michael, 1898)	? mu ge	1	6	B

Table 1. *Cont.*

Family	Family/Species	Habitat Preferences	No	*F*	Microhabitat
Euphthiracaridae	*Acrotritia duplicata* (Grandjean, 1953) †	si ar ge	10	17	C
	Euphthiracarus cribrarius (Berlese, 1904)	si ar el ge	58	28	A E F G
	E. monodactylus (Willmann, 1919)	si ar el ge	32	17	A F G
Phthiracaridae	*Phthiracarus boresetosus* Jacot, 1930	si ge	4	22	A F G
	P. bryobius Jacot, 1930 †	si ar el ge mu	45	72	A B C D E F G
	P. clavatus Parry, 1979 †	si ge	48	22	A B E G
	P. crinitus (C.L. Koch, 1841) †	si ar el ge mu xy	43	39	A C F G
	P. globosus (C.L. Koch, 1841)	eu (si) ar el ge	21	39	A B C E F G
	P. laevigatus (C.L. Koch, 1844) †	si ar ge mu xy	33	50	A B C E F G
	P. longulus (C.L. Koch, 1841) †	si el ge	221	83	A B C D E F G
	P. nitens (Nicolet, 1855)	si el ge	2	11	B F
Steganacaridae	*Atropacarus striculus* (C.L. Koch, 1835)	si pr ty hy el ge	29	11	A C
	Steganacarus applicatus (Sellnick, 1920)	si ar el ge	104	28	A B
	S. carinatus (C.L. Koch, 1841)	si ge	16	28	A B
Nanhermanniidae	*Nanhermannia coronata* Berlese, 1913 †	eu (ty si) mh ar ge	104	6	C
Nothridae	*Nothrus silvestris* Nicolet, 1855	eu ar ge	28	11	C G
Damaeidae	*Damaeus clavipes* (Hermann, 1804)	eu (si) hy ar ge mu	7	33	A B F
	D. gracilipes (Kulczynski, 1902)	si mh ar ge	1	6	A
	D. onustus C.L. Koch, 1844 †	si pr ar el ge	4	17	A
	Porobelba spinosa (Sellnick, 1920) †	si li ar ge mu xe	169	22	A C D
Caleremaeidae	*Caleremaeus monilipes* (Michael, 1882) †	si ar ep ge	145	39	A C D F G
Eremaeidae	*Eueremaeus oblongus* (C.L. Koch, 1835)	si ar el ep ge mu xe	3	6	E
	E. silvestris (Forsslund, 1956)	si ge	1	6	A
	Eueremaeus sp. 2	?	3	11	A B
	Eueremaeus sp. 3	?	2	6	B
	***E. valkanovi* (Kunst, 1957) †,‡**	si ar ge mu xe	20	28	A B C F
Astegistidae	***Cultroribula bicultrata* (Berlese, 1905)**	si ar el ge	8	6	G
Liacaridae	*Adoristes ovatus* (C.L. Koch, 1839) †	eu ar ep ge	55	39	A B E F
	Liacarus coracinus (C.L. Koch, 1841) †	eu (si pr) ar el ge	82	50	B D E F G
	Xenillus tegeocranus (Hermann, 1804) †	si ar el ge	5	22	B C E F
Carabodidae	*Carabodes areolatus* Berlese, 1916 †	si mh ar el ge mu	64	61	A B C D F G
	C. coriaceus C.L. Koch, 1835	si ar el ep ge	1	6	E
	C. femoralis (Nicolet, 1855) †	si ty ar ge	60	39	A B C F G
	C. labyrinthicus (Michael, 1879) †	eu (si) ar el ep ge li mu	457	67	A B D E F G
	C. marginatus (Michael, 1884) †	si mh ar ge mu	26	33	A B F
	C. ornatus Štorkán, 1925	si ty er ep ge	6	11	B
	C. reticulatus Berlese, 1913 †	si mu ge	26	28	B E F
	C. subarcticus Trägårdh, 1902	si ar ge	2	11	B D
	C. willmanni Bernini, 1975	si ty ar ge	198	17	A B
	Odontocepheus elongatus (Michael, 1879)	si ar ge mu xe	4	11	B F
Autognetidae	*Autogneta longilamellata* (Michael, 1885)	si ar ge	2	6	E
	A. parva Forsslund, 1947	si ar ge	4	6	B
	***Conchogneta dalecarlica* (Forsslund, 1947)**	si ep ge	18	6	C
	C. traegardhi (Forsslund, 1947) †	si ge	27	22	C F G

Table 1. *Cont.*

Family	Family/Species	Habitat Preferences	No	*F*	Microhabitat
Oppiidae	*Dissorhina ornata* (Oudemans, 1900) †	eu si ar el ge	499	61	A B C D E G
	Moritzoppia unicarinata (Paoli, 1908)	si ty ar el ge	37	28	B E F G
	***Oppiella falcata* (Paoli, 1908)**	si mh ar ep ge	2938	78	A B C E F G
	O. nova (Oudemans, 1902) †	eu ar el ep ge li	386	50	A B C E F G
	***Ramusella furcata* (Willmann, 1928)**	pr ty ge	5	6	G
	Rhinoppia subpectinata (Oudemans, 1900)	eu (si) ar ge	112	39	A C D
	***Subiasella quadrimaculata* (Evans, 1952)**	si ge	40	11	B D
Quadroppiidae	***Coronoquadroppia monstruosa* (Hammer, 1979)**	si er ge	232	61	A B C D F
	Q. quadricarinata (Michael, 1885) †	eu ar el ep ge	296	83	A B C E F G D
Suctobelbidae	*Suctobelba regia* Moritz, 1970 †	si ar el li ge	79	67	A B D E F G
	Suctobelbella falcata (Forsslund, 1941)	si ty ar el ge	13	17	B C G
	S. palustris (Forsslund, 1953)	pr ty aq hy ge li	1	6	G
	S. similis (Forsslund, 1941)	si ty ar ge	2	6	G
	S. subcornigera (Forsslund, 1941) †	eu (si) ar el ge	58	56	A B C F G
	S. subtrigona (Oudemans, 1916) †	eu (si) ar ge	8	22	A C
Tectocepheidae	*Tectocepheus velatus* (Michael, 1880) †	eu ar el ep ge	227	50	A B C E F G
Cymbaeremaeidae	*Cymbaeremaeus cymba* (Nicolet, 1855)	xe ar el ge li mu	2	11	D E
Licneremaeidae	*Licneremaeus licnophorus* (Michael, 1882)	si ar el ge	1	6	C
Phenopelopidae	*Eupelops torulosus* (C.L. Koch, 1839) *	si ty ar el ge	3	6	A
Achipteriidae	*Achipteria coleoptrata* (Linnaeus, 1758)	eu ar el ge	4	6	B
	A. magna (Sellnick, 1928)	si ar	107	33	B D F G
	A. nitens (Nicolet, 1855)	si ar ge	1	6	G
	Parachipteria fanzagoi Jacot, 1929	ty si el ge	1741	67	A B C D E F G
Oribatellidae	*Oribatella quadricornuta* Michael, 1880	pr si xe ar el ge	7	17	B D F
	Ophidiotrichus tectus (Michael, 1884) †	si ar ge mu xe	19	22	A C F G
Oribatulidae	*Oribatula exilis* (Nicolet, 1855) †	eu ar bo el ep mu	765	67	A B C D E F
	O. tibialis (Nicolet, 1855)	eu ar el ep ge	3	11	C
	Phauloppia lucorum (C.L. Koch, 1841)	ar el ep li ge xe	2	6	B
	Phauloppia rauschenensis (Sellnick, 1908)	si ar ge el	1	6	E
Parakalummidae	*Neoribates aurantiacus* (Oudemans, 1914)	si pr mh ar el ge	1	6	B
Scheloribatidae	***Scheloribates ascendens* Weigmann et Wunderle, 1990**	eu ar ge el	2	6	B
	S. initialis (Berlese, 1908) †	eu ar el ep ge	53	39	A B E F G
	S. laevigatus (C.L. Koch, 1835) †	eu ar el ep ge	30	17	E F
Ceratozetidae	***Ceratozetella sellnicki* (Rajski, 1958)**	pr ge	13	6	C
	Ceratozetes gracilis (Michael, 1884)	eu ar ge	28	11	A C
	Melanozetes mollicomus (C.L. Koch, 1839) †	si ty ar el ep ge mu	121	33	B E F G
	Sphaerozetes orbicularis (C.L. Koch, 1835) †	si ar el ep ge mu xe	53	50	A B C F G
Chamobatidae	*Chamobates borealis* Trägårdh, 1902 †	eu si ar el ep ge	161	61	A B C E F G
	C. cuspidatus (Michael, 1884) †	eu si ar el ep ge	252	61	A B C E F G
	***C. rastratus* (Hull, 1914)**	si ar ge el	2	11	C E
Euzetidae	*Euzetes globulus* (Nicolet, 1855)	eu ar el ge	7	28	A C G
Punctoribatidae	***Minunthozetes pseudofusiger* (Schweizer, 1922)**	si ar el ep ge li mu xe	216	56	A B C D F G
	M. semirufus (C.L. Koch, 1841)	eu el ep ge	4	11	A B
Galumnidae	*Pergalumna nervosa* (Berlese, 1914)	eu mu ar el ge	3	11	F

Table 1. *Cont.*

Family	Family/Species	Habitat Preferences	No	*F*	Microhabitat
	Mesostigmata				
Microgyniidae	*Microgynium rectangulatum* Trägårdh, 1942	xy, mer, si	2	11	F G
Sejidae	*Sejus togatus* C.L. Koch, 1836	xy, mer, si	7	17	E F G
Epicriidae	*Epicrius mollis* (Kramer, 1876)	mu, si	3	11	C
Zerconidae	*Parazercon radiatus* (Berlese, 1914)	eu, mu, pr, si	15	17	A C G
	Prozercon kochi Sellnick, 1943	eu, mh, mu, xy, si, pr	19	33	A C E F G
	***Zercon berlesei* Sellnick, 1958** *	eu, pr, si, xe	4	11	A F
	Z. triangularis C.L. Koch, 1836	eu, mu, pr, si	56	28	A C F
	Z. zelawaiensis Sellnick, 1944	mu, si, ty	38	39	A C D F
Macrochelidae	*Geholaspis longispinosus* (Kramer, 1876) †	mu, li, pr, xe	6	28	A B F G
	G. mandibularis Berlese, 1904	mu, li, si, xy	1	6	A
Parasitidae	*Holoparasitus inornatus* (Berlese, 1906) †	mu, si	54	61	A B C E F G
	Paragamasus integer (Bhattacharyya, 1963) †	mu, si	10	28	B F G
	P. lapponicus (Trägårdh, 1910) †	mu, si	136	56	A C E F G
	***P. truncus* Schweizer, 1961**	mu, si, pr	105	44	A C F G
	Pergamasus crassipes (Linnaeus, 1758)	mu, xy, pr, si	11	33	A E F
	Vulgarogamasus kraepelini (Berlese, 1905)	mu, xy, si, pr	6	17	A E G
Veigaiidae	*Veigaia cerva* (Kramer, 1876) †,*	mu, si	1	6	E
	V. kochi (Trägårdh, 1901)	mu, si	1	6	A
	V. nemorensis (C.L. Koch, 1839) †	mu, pr, si	29	39	A G E F C
	V. transisalae (Oudemans, 1902) †	mu, hy, ty, si	5	17	E G
Digamasellidae	*Dendrolaelaps cornutulus* Hirschmann, 1960	xy, mer, si	36	22	C F G
	***D. insignis* Hirschmann, 1960**	xy, si	9	6	G
	***D. multidentatus* (Leitner, 1949)**	mer, pr	1	6	E
	***D. rectus* Karg, 1962**	pr	24	17	F G
	***D. spinosus* Hirschmann, 1960**	mer, si	4	6	G
	***D. tenuipilus* Hirschmann, 1960**	mer, si	1	6	E
Ascidae	***Zerconopsis michaeli* Evans et Hyatt, 1960**	mer, si	3	6	E
	***Z. remiger* (Kramer, 1876)**	mu, mh, pr, si	4	6	E
Laelapidae	*Hypoaspis oblonga* (Halbert, 1915)	mu, si	30	6	D
Phytoseiidae	*Amblyseius silvaticus* (Chant, 1959)	ar, si	1	6	B
Trachytidae	*Trachytes aegrota* (C.L. Koch, 1841)	eu, mu, xe, mh, pr, si	10	17	A B G
Urodinychidae	*Dinychus perforatus* Kramer, 1882	eu, xy, pr, si	1	6	G
	***D. woelkei* Hirschmann et Zirngiebl-Nicol, 1969** *	xy, si	1	6	F
Trematuridae	*Trichouropoda ovalis* (C.L. Koch, 1839)	eu, xe, pr, si	17	28	C E F G

*—found only as juvenile forms; †—species known from broadleaf forests in Western Norway; ‡—*Eueremaeus valkanovi* was mentioned as *Eueremaeus* sp. 1 [15].

Habitat preferences (Table 1) of oribatid mites are based on [45,86–88], and those of Mesostigmata on [68,70,71,73,74,76–79,81–83,89–92]. These habitats include the following types: aquatic (reproduction and all stages of life cycle in water or at its margins), hygrophilous (living in wet places), mesohygrophilous (preferring high moisture but not wet places), xerophilous (living in dry places), arboricolous (living on trees), epilithic (living on rocks, stones, walls), epiphytic (living on a plant that grows on another plant), geophilous (living in soil), lichenicolous (living on lichens), merocenophilous (living in bark beetle galleries and anthills), muscicolous (living in mosses), xylophilous (living in wood), praticolous (meadow species), silvicolous (forest species), tyrphophilous (bog species) and eurytopic (occurring in more than three habitat types).

The new records of Oribatida for Norway are based on the checklist [93] and later publications [15,37,94] (and references contained in those papers). Those new to Fennoscandia are based on [95,96] and later publications [31,97–108]. The new records of Mesostigmata for Norway are based on [15,36,109–111] and those new to Fennoscandia are based on [91,112].

2.3. Statistical Analyses

Oribatid and mesostigmatid mite populations were quantified as abundance (individuals in 500 cm^3), dominance (D, percentage of specimens of a particular species in the average abundance of Oribatida or Mesostigmata), and frequency (F, percentage of the samples where the species was present), and by the number of species (mean per sample in habitat and total species richness per habitat), and the Shannon (H') diversity index [113]. Categories summarizing the status of occurrence of species (Table 2) follow [114].

The basic statistical descriptors included the mean values and standard deviation and were calculated in MS Excel. The species similarities of the Oribatida and Mesostigmata between microhabitats were analyzed using an unweighted pair group method with arithmetic mean (UPGMA) with Bray-Curtis coefficient [115] using MVSP 3.2 [116]. Chao −1 indices and individual-based rarefaction curves were computed using 100 randomizations in EstimateS for Windows (version 9) [117].

Table 2. Status of occurrence of species new to Norway: Oribatida (Italic font) and Mesostigmata (Italic underlined font) in broadleaf forest in Eastern Norway; *D*—dominance (percentage of specimens of a particular species in the average abundance), *F*—frequency (percentage of the samples where the species was present).

	Very Frequent ($F > 75\%$)	**Frequent (30−75%)**	**Infrequent (15−30%)**	**Very Rare ($F \leq 15\%$)**
Numerous ($20\% < D$)	*O. falcata*			
Abundant ($10 < D \leq 20\%$)		*P. truncus*		
Sparse ($1 < D \leq 10\%$))		*M. pseudofusiger* *C. monstruosa*	*D. rectus*	
Few ($D \leq 1\%$)			*E. valkanovi*	*C. sellnicki* *C. rastratus* *C. dalecarlica* *C. bicultrata* *N. magnus* *R. furcata* *S. ascendens* *S. suecicus* *S. quadrimaculata* *D. insignis* *D. multidentatus* *D. spinosus* *D. tenuipilus* *D. woelkei* *Z. berlesei* *Z. michaeli* *Z. remiger*

3. Results

In total, 10,843 specimens (including 1694 juveniles) of Oribatida and 655 specimens (including 250 juveniles) of Mesostigmata were found. Oribatida were represented by 95 species from 32 families and Mesostigmata by 34 species from 14 families (Table 1). Rarefaction curves for both groups are presented in Figure 3. The mean Chao −1 index for Oribatida was 99.09 (±SD = 3.6, with 95% confidence limits 95.93–113.02) and for Mesostigmata it was 48.98 (±SD = 13.23, 95% confidence limits 37.92–102.01).

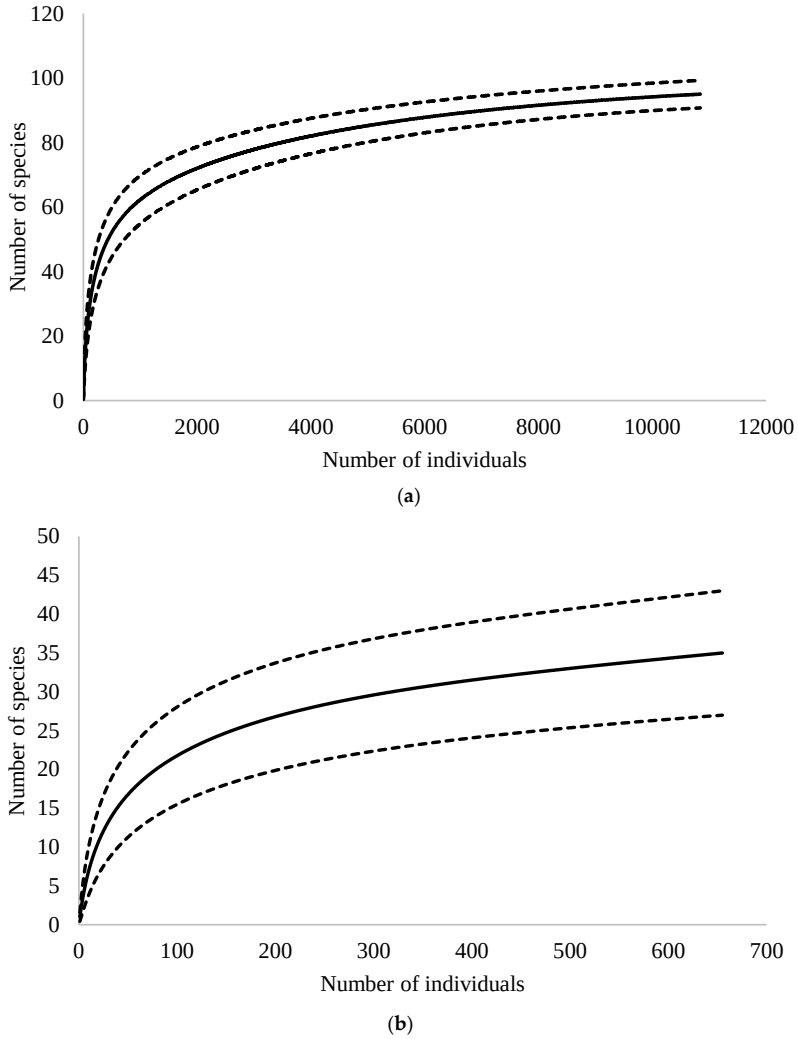

Figure 3. Rarefaction curves for Oribatida (**a**) and Mesostigmata (**b**) in broadleaf forest in Eastern Norway (continuous lines) with 95% confidence limits (broken lines).

Species diversity measured with Shannon index (H') was 2.97 for Oribatida and 2.74 for Mesostigmata. Only 30% of species (35 spp. of Oribatida and 7 spp. of Mesostigmata) were found in the broadleaf forests previously studied in Western Norway (Table 1), after [15]. Most of the species found in this study were silvicolous, but about 30% of Oribatida and 17% of Mesostigmata were eurytopic and several species were characteristic of ecosystems other than forests (Table 1).

The most abundant and frequent oribatid species was *Oppiella falcata* (Paoli, 1908). This species represented 27% of all Oribatida specimens and was found in 78% of the samples (Table 1). The second most abundant and frequent species was *Parachipteria fanzagoi* Jacot, 1929 which made up 16% of Oribatida specimens and was present in 67% of the samples. Among Mesostigmata, *Paragamasus lapponicus* (Trägårdh, 1910) dominated (22% of the specimens) in the mite community and was present in 56% of the samples. The second most abundant mesostigmatid species was *P. truncus* Schweizer, 1961, which made up 12% of the specimens and was found in 44% of the samples.

Twenty-three species are reported for the first time from Norway, including 13 Oribatida and 10 Mesostigmata species. Two of these species, *O. falcata*, and *P. truncus*, were abundant and frequent, but the large majority occurred in very low numbers (Table 2). We report here the first record of the genus *Zerconopsis* Hull, 1918 in Norway, which was found in moss on a tree stump. Six of the new records are also new to Fennoscandia, including (Oribatida) *Coronoquadroppia monstruosa* (Hammer, 1979), *Eueremaeus valkanovi*

(Kunst, 1957), *Ramusella furcata* (Willmann, 1928), and (Mesostigmata) *Dendrolaelaps rectus* Karg, 1962, *D. multidentatus* (Leitner, 1949), and *D. tenuipilus* Hirschmann, 1960.

The abundance and diversity of mites varied between the microhabitats studied (Figure 4). The average abundance of Oribatida ranged from about 300 individuals in lichens up to nearly 1200 individuals in moss on decaying log. The lowest mean number of oribatid species per sample (15) was found on tree trunks 1.5 m above ground, and the highest (31) was found in moss on decaying stump. The Shannon diversity index ranged from 1.97 in moss on decaying log to 2.61 in decaying wood. Many oribatid species had low dominance ($D \leq 5\%$) in the majority of microhabitats but in moss on tree trunks 1.5 m above ground there were fewer species, but they had higher dominance (Figure 5). Mesostigmata were the least abundant (only three individuals) and the least species rich in lichens. They were the most abundant (82 individuals) and species richest in decaying wood. In moss on tree trunks 1.5 m above ground the species richness was as low as in lichens and species diversity was lowest ($H' = 0.30$). The highest species diversity ($H' = 2.25$) was in moss on the ground surface. In most microhabitats there were many species with low dominance but some species occurring in lichens and on trees had higher dominance (Figure 5). Overall, 44 species of mites were found in only one microhabitat (Table 1) and 14 of these are new records for Norway. Most of these species (nine) were recorded from moss on decaying stump, while only one was found on tree trunks 1.5 m above ground.

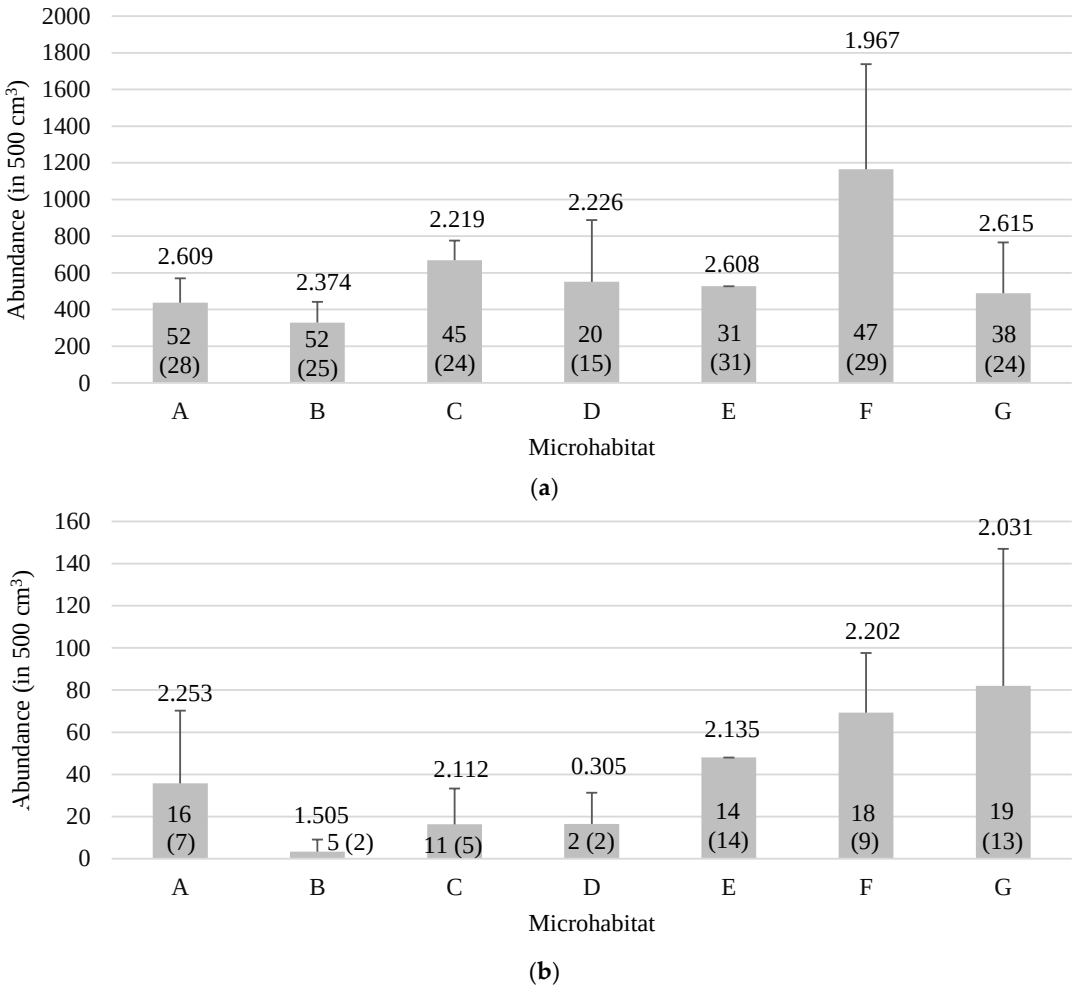

Figure 4. Average abundance (in 500 cm^3) of Oribatida (**a**) and Mesostigmata (**b**) (bars) with standard deviation (whiskers), Shannon index (above bars) and number of species (total and in brackets mean number per sample, in bars) in microhabitats of broadleaf forest in Eastern Norway: A—moss on ground, B—lichens on tree twigs lying on ground, C—moss on tree trunks at ground level, D—moss on tree trunks 1.5 m above ground, E—moss on decaying stump, F—moss on decaying log, G—decaying wood from trees.

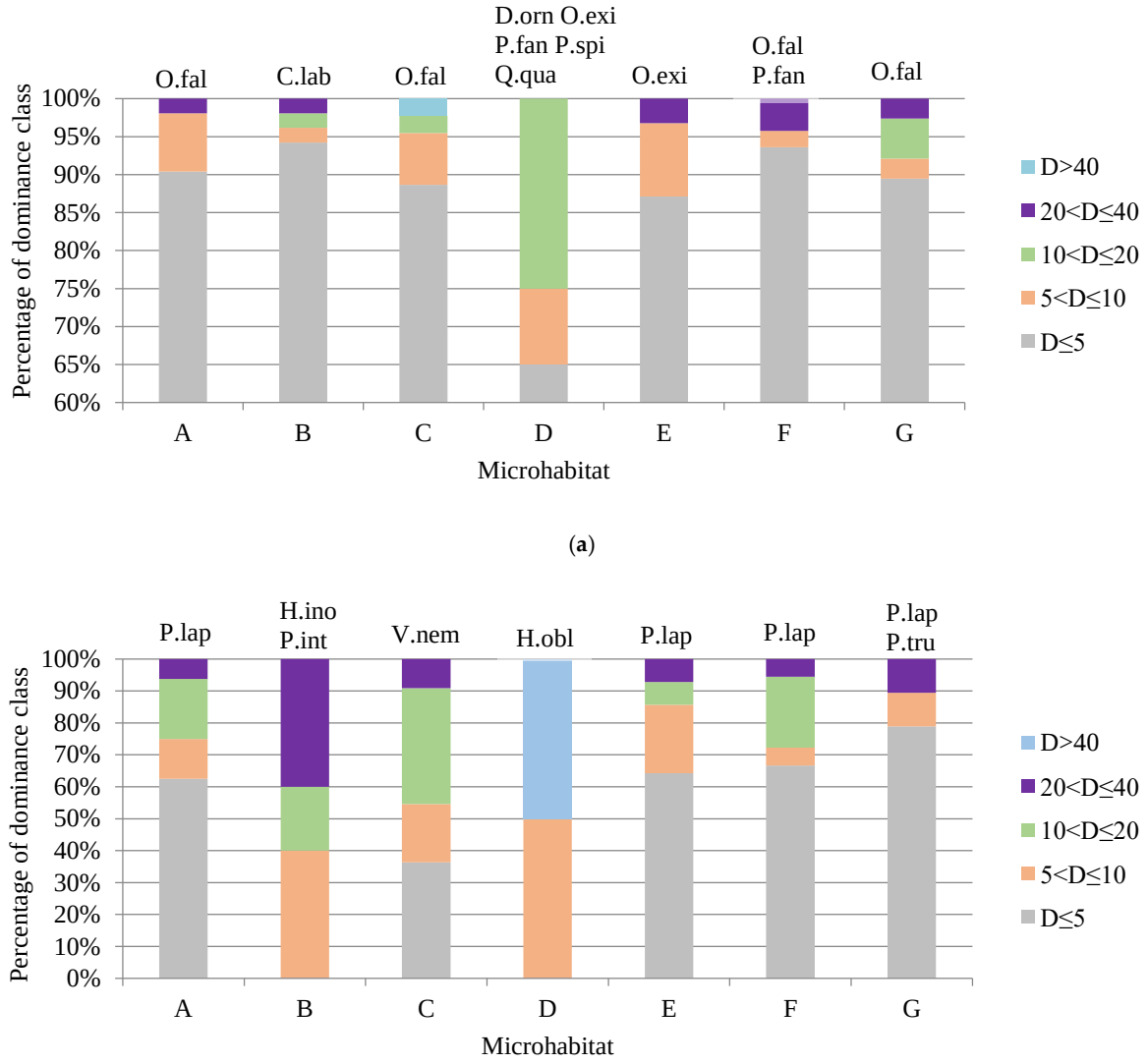

Figure 5. Dominance of Oribatida (**a**) and Mesostigmata (**b**) species in different microhabitats of broadleaf forest in Eastern Norway: A—moss on ground, B—lichens on tree twigs lying on ground, C—moss on tree trunks at ground level, D—moss on tree trunks 1.5 m above ground, E—moss on decaying stump, F—moss on decaying log, G—decaying wood from trees; most abundant species: C.lab—*C. labyrinthicus*, D.orn—*D. ornata*, O.fal—*O. falcata*, O.exi—*O. exilis*, P.fan—*P. fanzagoi*, P.spi—*P. spinosa*, Q.qua—*Q. quadricarinata*, H.ino—*H. inornatus*, H.obl—*H. oblonga*, P.int—*P. integer*, P.lap—*P. lapponicus*, P.tru—*P. truncus*, and V.nem—*V. nemorensis*.

In general, the species composition of oribatid and mesostigmatid communities varied differently between microhabitats. However, communities of both taxa were most similar in moss on ground and in moss on decaying log (Figure 6). The communities of Oribatida in moss on decaying stump and in lichens were distinct from other mite communities. On decaying stump, *Oribatula exilis* (Nicolet, 1855) was the most abundant oribatid species, in lichens, *Carabodes labyrinthicus* (Michael, 1879), while in other microhabitats, *O. falcata* was dominant (Figure 5). Mesostigmatid communities on tree trunks (at ground level and 1.5 m above ground) and in lichens were distinct from other mite communities. *Hypoaspis oblonga* (Halbert, 1915) was dominant on tree trunks 1.5 m above ground (Figure 5), *Holoparasitus inornatus* (Berlese, 1906) and *Paragamasus integer* (Bhattacharyya, 1963) were abundant in lichens, and *Veigaia nemorensis* (C.L. Koch, 1839) was dominant

on tree trunks at ground level, while in the other microhabitats, *Paragamasus lapponicus* (Trägårdh, 1910) was the most abundant.

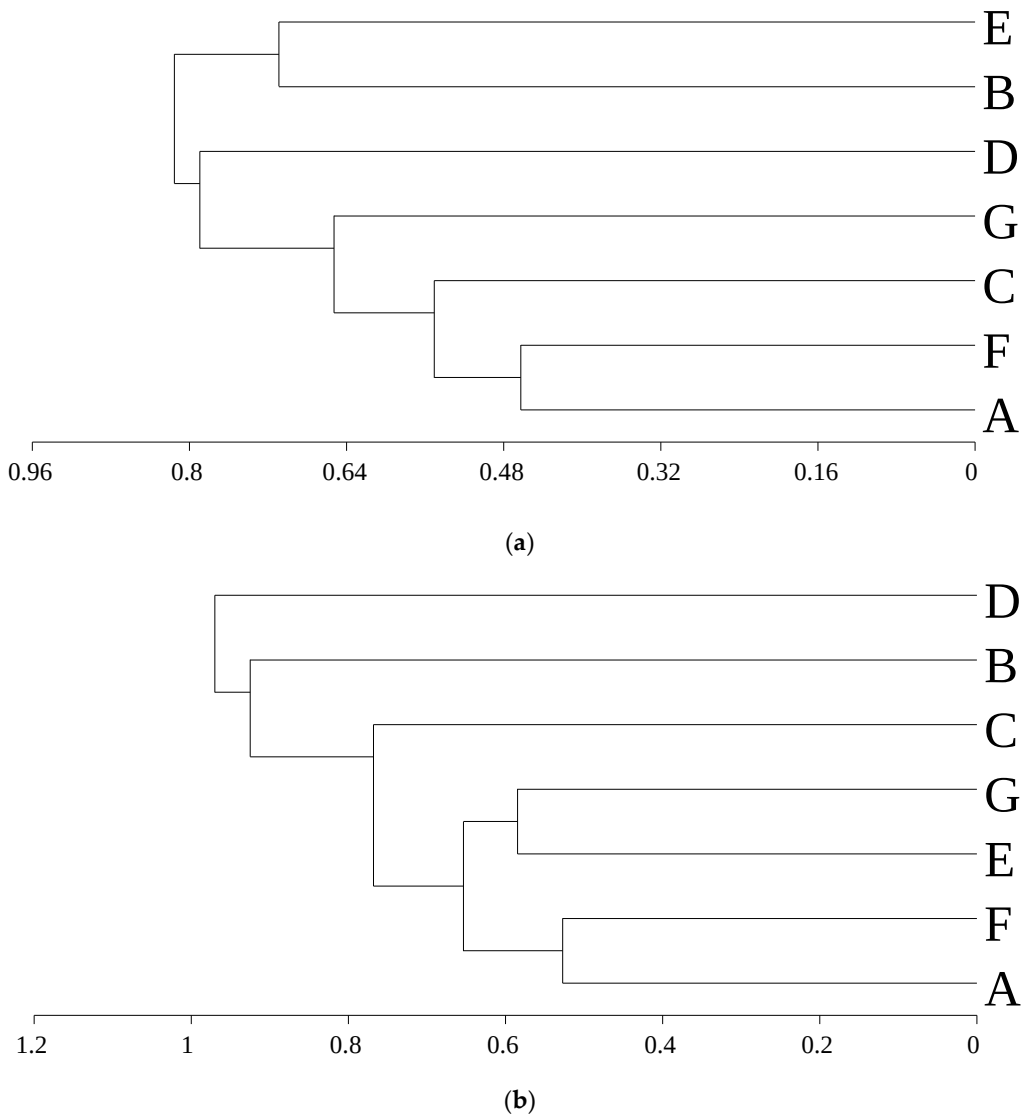

Figure 6. Bray–Curtis dissimilarity of Oribatida (**a**) and Mesostigmata (**b**) in microhabitats of broadleaf forest in Eastern Norway: A—moss on ground, B—lichens on tree twigs lying on ground, C—moss on tree trunks at ground level, D—moss on tree trunks 1.5 m above ground, E—moss on decaying stump, F—moss on decaying log, G—decaying wood from trees.

The majority of the Oribatida recovered were adults, which made up 89% of total specimens (Figure 7), and their proportional abundance varied from 67% in moss on decaying log to almost 100% in moss on stump. Adult Mesostigmata represented 59% of the specimens in this group but juveniles dominated in moss on tree trunks 1.5 m above ground (58%). Four mite species were represented only by their juvenile forms, including two Mesostigmata (*Dinychus woelkei* Hirschmann et Zirngiebl-Nicol, 1969 and *Zercon berlesei* Sellnick, 1958) which are new records to Norway.

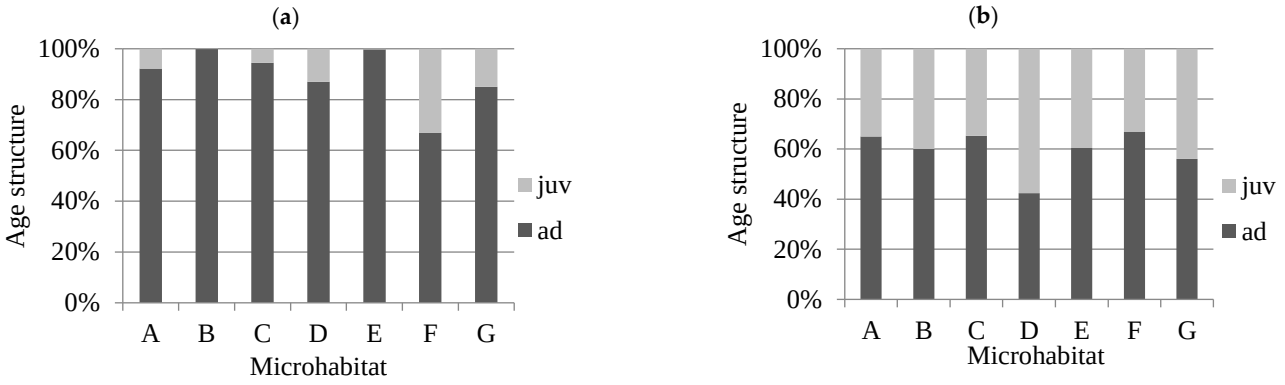

Figure 7. Age structure of Oribatida (**a**) and Mesostigmata (**b**) in microhabitats of broadleaf forest in Eastern Norway: A—moss on ground, B—lichens on tree twigs lying on ground, C—moss on tree trunks at ground level, D—moss on tree trunks 1.5 m above ground, E—moss on decaying stump, F—moss on decaying log, G—decaying wood from trees: ad—adults, juv—juveniles.

4. Discussion

The forest in Kjeøya is very species rich in Oribatida and Mesostigmata which supports earlier results from vegetation, showing that this forest type is important for biodiversity [40]. Both the density and diversity of mites were higher here than in a broadleaf forest studied in Western Norway [15] (see Table 3 for comparison). This observation is in accordance with a well-known pattern that species richness is higher in Eastern Norway than in Western Norway, which was also seen in other groups of arthropods [118–120], including some Oribatida (ptyctimous mites) [37], and in plants [121]. This pattern is likely to be related to either the delayed post-glacial migration from east to west due to the geographical barrier of the Scandes Mountains [122] or to climate, since the lower summer temperature and higher precipitation in Western Norway are critical to some taxa. A good example is the European spruce bark beetle (*Ips typographus* L.) which requires dry and warm summers and does not occur in Western Norway [118]. In case of mites, a forest type might be the most important factor if only sites with milder climate are compared [37,123], but when climatic differences are large, then regional differences become more significant [27,124].

Earlier studies on ptyctimous Oribatida demonstrated that Norwegian broadleaf forests, including the forest studied here [37], are very rich in these mites, even richer than Białowieża Primeval Forest (Poland) which is famous worldwide for its high biological diversity [114]. Therefore, we were not surprised by the high diversity of Oribatida and Mesostigmata discovered in a single forest, which is comparable to, or even higher, than the richness found in much more extensive studies in other broadleaf forests in Europe. A similar study (Table 3) carried out in a beech forest nature reserve in northern Poland [14] had much higher numbers of samples (42) and several-fold higher numbers of individuals identified (over 71,000 specimens of Oribatida and 3300 Mesostigmata) and although the number Mesostigmata species found was higher there (66) than in the present study (35), only 79 oribatid species were recorded there (vs. 95 in this study). However, the species richness of both groups was lower there (H' = 2.20 for Oribatida and H' = 1.70 for Mesostigmata) than in the present study (H' = 2.97 for Oribatida and H' = 1.90 for Mesostigmata). Because of varying methodologies, other studies in Europe may not be directly comparable to our study, but a review of these studies gives a general overview of expected mite diversity. For example, a high number of oribatid species (120) was found in a beech forest in southern Germany [125], which was higher than in many other forests (where it ranged 61–89), but the study lasted for two years and was based on eight sampling events, many samples, and two sampling methods in different microhabitats. Another extensive study was carried out in ten broadleaf forests in Ireland, where two forest types, nine microhabitats and two sampling methods were applied, but despite

higher sampling effort the number of mite species (Oribatida and Mesostigmata) was lower there and varied between 18–75 per forest [126]. When only the soil microhabitat was sampled [123,124,127], the number of species of Oribatida per 500 cm^3 sample was lower than in our study, which underscores the importance of sampling different microhabitats for biodiversity assessment [12,15,21,37,128–130].

Table 3. Abundance and diversity of mites in broadleaf forests studied in Europe; O—Oribatida, M—Mesostigmata; Na—data not available.

Locality/Forest Type	Number and Volume of Samples	Number of Samplings	Microhabitat Sampled	Abundance on Ground (indiv. /m^2)	Diversity Measures (indiv./spp./H')	Diversity Measures (indiv./spp.) per 500 cm^3	Reference
Eastern Norway/ rich broadleaf forest	18 × 500 cm^3	1	Moss, lichens, decaying wood	O: 44,000 M: 3600	O: 10,843/95/2.97 M: 655/35/2.74	O: 602/5.3 M: 36/1.9	Present study
Western Norway/ low-herb broadleaf forest	14 × 500 cm^3	1	Moss, decaying wood	O: 32,700 M: 5400	O: 6350/67/2.54 M: 559/22/1.52	O: 453/4.8 M: 39/1.6	[15]
Northern Poland/beech forest (nature reserve)	42 × 500 cm^3	1	Soil litter, moss, decaying wood, tree bark	O: 82,300 M: 7000	O: 71,124/79/2.20 M: 3309/66/1.70	O: 1693/1.9 M: 79/1.6	[14]
Northern Spain/ 18 forests, 5 types, different regions	54 × 2000 cm^3	3 (3 years.)	Soil	Na	O: 50,307/260/-	O: 233/1.2	[123]
Ireland/5 oak forests, different regions	45 (different volume)	1	Moss and tree bark from canopy, moss from ground, soil	Na	O + M: 5906/59/-	na	[126]
Ireland/5 ash forests, different regions	45 (different volume)	1	Moss and tree bark from canopy, moss from ground, soil	Na	O + M: 2863/32/-	na	[126]
Germany/3 beech forests in different regions	24 × 157 cm^3	1	Soil	O: 30,000 *,†	O: -/15–20/- *,‡	O: -/2.0–2.6 *,‡	[124]
Southern Poland/beech forest (nature reserve)	1080 × 135 cm^3	36 (3 years.)	Soil	O: 20,000 *	O: -/77/- *	O: -/0.3 *	[127]
Southern Germany/beech forest	Over 100 (different volume)	8 (2 years.)	Soil litter, moss, decaying wood, tree bark	O: 61,500 *,†	O: -/119/-	na	[125]

*—litter/soil since moss was not sampled; †—only adults included; ‡—without Suctobelbidae and Brachychthoniidae.

Many new species records for Norway come from specific microhabitats which illustrates the importance of sampling a broad range of microhabitats in studies of faunal inventories and diversity assessment. Over 30% of species were found in just one microhabitat, and the highest number of unique species was found in moss growing on decaying stump, even though only one sample was collected there. This is consistent with [131] who concluded that stumps are important sources of oribatid diversity and not sampling these can lead to the omission of 30% of the mite diversity. Two oribatid species that were found exclusively on decaying stump, *Autogneta longilamellata* (Michael, 1885) and *Eueremaeus oblongus* (C.L. Koch, 1835), were also found on stumps in Poland, so they seem to be characteristic of this microhabitat. Among Mesostigmata, *Dendrolaelaps* species were found mainly in microhabitats associated with decaying wood, which agrees with earlier findings [31,132]. The relatively large numbers of mite species in moss on stumps and rotting wood was also observed in other studies [14,31] and it demonstrates the positive influence of decaying wood on species diversity in broadleaf forests and landscapes [21,133,134].

In turn, Mesostigmata communities on tree trunks were very distinct from communities of these mites in other microhabitats, which shows that mesostigmatids are not species-rich on tree bark, and the few species occurring there are very little overlapping with the communities on ground, as already observed by other authors [13,31].

Lichens seem to be a special habitat for both Oribatida and Mesostigmata as their communities differed considerably from other communities. One species, *Carabodes labyrinthicus*, was found in nearly all microhabitats but was only really abundant in lichens. It occurs abundantly in lichens growing on tree bark in lower sections of trees (up to a height of 8 m) and its juveniles develop inside lichen thalli [135] where they feed [27]. *Phauloppia lucorum* (C.L. Koch, 1841) also feeds on lichens [27] and in our study was found exclusively in this habitat. *Scheloribates ascendens* Weigmann et Wunderle, 1990 that was found only in lichens is an arboreal species; it was also found in lichens on limestone walls in Sweden [102]. In contrast, Mesostigmata occurred in such low numbers on lichens that their presence seems rather accidental.

The forest fauna included many rare species, e.g., among Oribatida, *Achipteria magna* (Sellnick, 1928), *Oribotritia berlesei* (Michael, 1898), and *Subiasella quadrimaculata* (Evans, 1952) [87,88]. For some species, this forest is also their northernmost locality (*O. berlesei*, *R. furcata*). *Oribotritia berlesei* is a Palearctic species and has so far been recorded in some countries of western, central, and southern Europe, the south European part of Russia, and the Far East [64] before it was found in the forest in Kjeøya [37]. *Ramusella furcata* is a European species, often found on meadows and in peatlands, while here it was found in decaying wood, albeit not abundantly. *Eueremaeus valkanovi* has been previously known only from central Europe and Japan [63]. The species has also been found in broadleaf forests in Western Norway [15] but was mentioned there as *Eueremaeus* sp. 1. All these examples support the unique character and high biological diversity of a rich broadleaf forest in Kjeøya. Similarly, among Mesostigmata rare species have been found, and they usually occurred in low densities. For example, *Microgynium rectangulatum* Trägårdh, 1942 and *Sejus togatus* C.L. Koch, 1836 have Palearctic distribution and are mainly found in decaying wood and in bark beetle galleries, including these of the European spruce bark beetle [23–26,78]. Other rare species have European distribution, e.g., *Dinychus woelkei* Hirschmann et Zirngiebl-Nicol, 1969 and *Zercon berlesei* Sellnick, 1958 [67,69,70,80,81,89,91], and representatives of the genus *Zerconopsis*: *Z. michaeli* Evans et Hyatt, 1960 and *Z. apodius* Karg, 1969. The two latter species can be found in soil and litter of broadleaf forests, as well as in decaying wood and in nests of the European red wood ant (*Formica polyctena* Förster) [77,82,83]. It is also worth noting the relatively high species diversity of the representatives of the genus *Dendrolaelaps*, which are mostly ecologically associated with merocenoses of decaying wood, bark beetles' galleries, and ant nests [23–26,73].

Studies in forests have contributed markedly to the knowledge of the acarofauna in different countries. For example, in Finland, 82 species of Oribatida were found in mesic broadleaf forests, which accounts for some 25% of the total number of oribatid species known to that country [104]. Similarly, in Poland, some 20% of the country's oribatid diversity was found in three types of forests, including 15 species new to Poland and 3 new to science [127]. In Germany, in just one type of broadleaf forest about 15% of the total species diversity of the country was discovered [125]. In our study we found 30% of the total number of Oribatida known to Norway (i.e., 95 out of ca. 320) and 13% of the total number of Mesostigmata known to Norway (i.e., 34 out of 265 species). The global diversity of Oribatida includes more than 11,000 species [63] and there are similarly more than 11,000 species of Mesostigmata described [136]. In forests the richness of both groups seems comparable, and in more extensive studies the diversity Mesostigmata was nearly as high as that of Oribatida (e.g., 75 spp. vs. 96 spp. were found in Finland [31]; 66 spp. vs. 79 spp., in Poland, [14]). As indicated by the rarefaction curve and Chao −1 index, about 50% of mesostigmatid species are still left to be discovered in studied forest. Because Mesostigmata are mostly predators and use larger areas, they would require more sampling in future studies to discover their full diversity in broadleaf forests.

It needs to be emphasized that even a small forest such as the one studied here (with an area of only ca. 2 ha) can harbour a very large diversity of mites and, in particular that it hosts predominantly silvicolous mite species. If this fragmented forest is treated as a habitat island, its oribatid diversity is comparable with true islands that are several orders of magnitude larger in area and occur in latitudes extending from the Arctic and Antarctic to the tropics [137]. Even if the land-based islands, such as forest fragments, cannot be directly compared with true islands [138], this study shows just how important they are in supporting biodiversity at both regional and wider scales.

Author Contributions: A.S., S.S., S.R. and B.H.J. planned the study, A.S., S.R. and P.D. carried out the fieldwork, J.S., S.S. and A.S. identified Oribatida, S.K. identified Mesostigmata, J.K. sorted mites, A.S. and T.B. wrote the manuscript with support of all authors. All authors have read and agreed to the published version of the manuscript.

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