

The oribatid mite community of a German peatland in 1987 and 2012 – effects of anthropogenic desiccation and afforestation

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Abstract

Peatlands harbour a large number of specialized plants and animals. In many European countries more than 90% of the peat bogs have been destroyed through drainage for agriculture and forestry. The knowledge on the consequences for soil animals restricted to peatlands is scarce. The current study presents a comparison of the oribatid mite assemblages recorded in 1987 and 2012 from a *Sphagnum* bog being part of a large peatland complex that has suffered from drainage between the two periods. Furthermore, the oribatid mite fauna of the *Sphagnum* bog is compared to the fauna of adjacent peatland habitats of different soil moisture, shadowing and vegetation (*Molinia* meadow, spruce afforestation, birch wood). The study addresses the following questions: 1) which environmental factors determine the oribatid species composition in the peatland complex? 2) how do anthropogenic desiccation and afforestation influence the oribatid mite assemblage? CCAs were calculated using the species abundances recorded in 2012 and the parameters soil moisture, vegetation temperature index, pH, cover of the tree-, herb- and moss layer, cover of herb-leaf-litter and needle litter as well as C/N ratio. In total, 87 oribatid mite species were recorded in the Dubringer Moor in 2012. Species distribution was most closely related to cover of herb-leaf-litter and needle-litter, soil moisture and vegetation temperature index. However, all sampling sites in the spruce forest contained similar sets of common species despite of differences in moisture and vegetation cover. The species composition of the two birch wood sites differed slightly from that of the spruce forest sites. In contrast, the *Sphagnum* bog was characterized by five tyrophilic species (*Pergalumna nervosa*, *Pilogalumna tenuiclava*, *Malaconothrus monodactylus*, *Mainothrus badius*, *Nothrus pratensis*) that occurred almost exclusively here. The *Molinia* meadow as a degenerated part of the *Sphagnum* bog contained almost no species that were characteristic for the *Sphagnum* bog site. However, species richness was higher in the *Molinia* meadow, because a large number of species characteristic for forest habitats occurred. In the *Sphagnum* bog, species richness was heavily reduced from 1987 to 2012 from 37 to 10 species and also density was reduced from 164 individuals/100 cm³ to 9 individuals/100 cm³ due to ongoing desiccation. Several bog-specific species such as *Hoplophthiracarus illinoisensis*, *Trhypochthoniellus longisetus* and *Trhypochthonius nigricans* have apparently disappeared from the *Sphagnum* bog today. Characteristic bog species still occurring in the *Sphagnum* bog in 2012 might be less sensitive to dryer periods and strong water level fluctuations than the species that disappeared since 1987. The results indicate that desiccation in *Sphagnum* sp. reduces oribatid species richness. However, after vegetational changes to, e.g., a *Molinia* meadow, oribatid species richness increases again due to immigrating species that are characteristic for forest habitats and euryoecious species. The oribatid mite community composition and densities of tyrophilic and hygrophilic species appeared to be closely related to *Sphagnum* bog desiccation and peatland habitat characteristics. Oribatid mites therefore obviously offer the opportunity to evaluate the ecological conditions and degeneration of a peatland.

Keywords Acari | Dubringer Moor | drainage | indicator species

1. Introduction

Peatlands harbour a large number of specialized (= tyrphophilic) plants and animals. These species must cope with low pH-values, large temperature and water level fluctuations, high moisture and often also a low nutrient supply. The hydrological conditions and nutrient poverty result in a species poor, but highly specialized flora and fauna (Paje & Mossakowski 1984, Timmermann & Succow 2001, Dapkus 2004, Scott et al. 2006, Spitzer & Danks 2006, van Kleef et al. 2012). Tyrphophilic and tyrphobiotic species are known not only from well-studied taxa such as Carabidae, Lepidoptera or Odonata, but also from the soil animals such as oribatid mites (Tarras-Wahlberg 1961, Popp 1962, Behan-Pelletier & Hill 1986, Ivan et al. 1997, Seniczak 2011).

Globally, peatlands cover an area of about 4 Mio. km² (Maltby & Proctor 1996). Almost 80% of the global peatland area is still in a largely natural state. However, in many European countries more than 90% of the peat bogs have been destroyed through drainage for agriculture and forestry (Joosten 2012). In consequence of drainage, shrinking and peat loss through deflation and mineralization amount up to 2 cm per year (Pfadenhauer & Grootjans 1999). Peatlands have been furthermore damaged or heavily disturbed by former peat extraction and spruce plantation, both combined with drainage. According to Joosten (2012), about 99% of the peatlands in Germany are drained and not growing any more. In consequence, typical peatland plant and animal species are lost. The knowledge on the consequences for soil animals restricted to peatlands is scarce. Oribatid mites are usually the most abundant and diverse soil invertebrates in peatlands (Popp 1962, Silvan et al. 2000) and play an important role as decomposers (Anderson 1975, Norton & Behan-Pelletier 2009). However, little is known about the environmental factors determining their species composition in peatlands and even less studies exist about the reaction of oribatid mite assemblages to increasing dessication of peatlands (but see Markkula 1986, Weigmann 1991, Kehl 1997a,b). As animals closely related to the soil substrate, oribatid mites are appropriate bioindicators for peatland habitat conditions (Weigmann 1991, Borcard 1997, Kehl 1997a,b, van Straalen 1998).

The current study presents a comparison of the oribatid mite assemblages determined in 1987 and 2012 from a *Sphagnum* bog that has suffered from falling groundwater levels between the two periods. Furthermore, the oribatid mite fauna of the *Sphagnum* bog –being part of a large peatland complex– is compared to the fauna of adjacent peatland habitats of different moisture conditions and vegetation cover, including a spruce forest that was afforested on peatland soil after a forest fire in 1965.

In detail, the study addresses the following questions: 1) which environmental factors determine the oribatid species composition in the peatland complex? 2) how do anthropogenic desiccation and afforestation influence the oribatid mite assemblage?

2. Material and methods

2.1. Study area

The Natura 2000 Area ‘Dubringer Moor’ is located in the northeast of Saxony, Germany, and comprises an area of 1,700 ha (Fig. 1A). It is the largest protected wetland in Saxony and forms a patchy, habitat-rich environment including open water sites, *Sphagnum* bogs, fens, reeds and bog woodland. The whole area drops slightly down from about 150 m in the west to about 120 m in the east (SLUG 2010). Water sources for the peatland are precipitation and nutrient-poor groundwater inflow from the northern, western and southern elevations (Vogel 1998). The Dubringer Moor is dominated by podsols with high sulfur contents causing a low pH between 2.5 and 3.

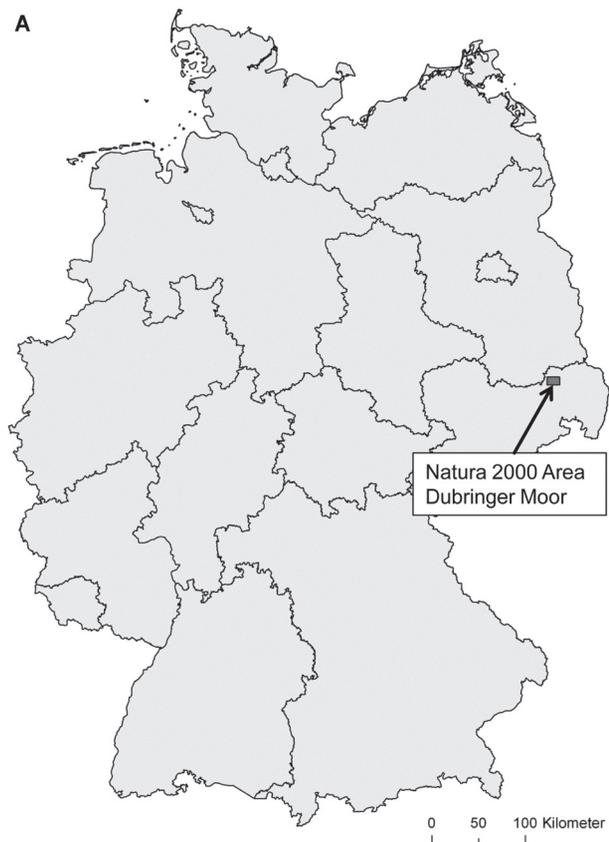


Figure 1A: Position of the Natura 2000 Area Dubringer Moor in Germany.

Maximum peat depth is 5.8 m, peat depth decreases from west to east (SLUG 2010). Eastern Saxony is characterized by continental climate, but the high water supply in the study site leads to high humidity and therefore to a so called pseudoatlantic local climate (Pietsch 1990). The mean annual temperature is 8.5°C, and mean annual precipitation is 662 mm (Vogel 1998).

In the last decades, the 'Dubringer Moor' suffered from different anthropogenic disturbances. Brown-coal mining in the vicinity required lowering of the groundwater level by up to 10 m (SLUG 2010). Furthermore the specific area was drained in connection with forestry, agriculture and water power production (Karneth 1990). Additionally, after a forest fire in 1965, an area of about 8 ha was afforested with spruce trees, which constitute a barrier between the different peatland habitats and further enhance dehydration. Unfortunately, the local groundwater level has never been recorded, but several scientists involved in investigations of the Dubringer Moor in the 1980ies and in 2012 confirm the ongoing desiccation, which is visible by a loss of water-filled hollows at the peat bog. Furthermore, changes in the dominance structure of spider species strongly

indicate these moisture changes (Haase & Balkenhol, submitted). At least no industrial peat-digging occurred in the Dubringer Moor, so that *Sphagnum* bogs with a characteristic hummock-hollow-complex still exist. Only small-scale peat-digging by local farmers left several water-filled peat-cut sites.

2.2. Sampling 2012

Eight sampling sites in four different habitat types were chosen in the Dubringer Moor concerning soil moisture, shadowing and vegetation (Fig. 1B):

Sphagnum bog (about 2 ha)

- *Sphagnum* bog (bog) (N 51,39775°; E 14,16409°) – cover of the moss layer amounts to 92% (Tab. 1), *Sphagnum papillosum* Lindb. on hummocks, *Sphagnum fallax* H. Klinggr. in hollows; herb layer dominated by the dwarf shrubs *Erica tetralix* L. and *Calluna vulgaris* Hull; contains characteristic species of nutrient-poor bogs such as *Eriophorum angustifolium* Honck., *Drosera rotundifolia* L., *Rhynchospora fusca* Vahl in the

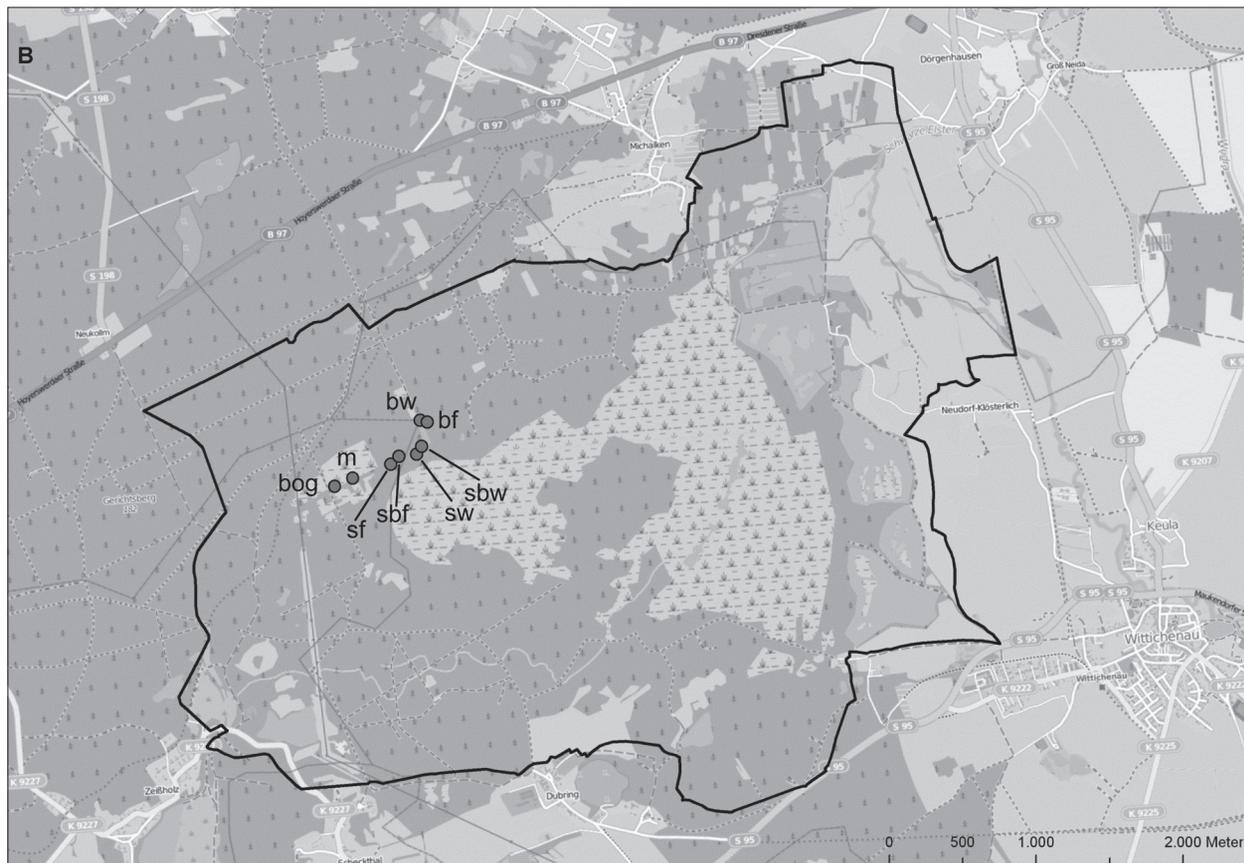


Figure 1B. Position of the sampling sites in the Natura 2000 Area Dubringer Moor. **bog** – *Sphagnum* bog, **m** – *Molinia* meadow, **sf** – dense fresh spruce forest, **sw** – dense wet spruce forest, **sbf** – open fresh spruce-birch forest, **sbw** – open wet spruce-birch forest, **bw** – wet birch wood; **bf**: fresh birch wood.

dense carpet of *S. fallax*; a wet site with high sun exposure; classified as Northern Atlantic wet heath with *Erica tetralix* (4010; European Union Habitats Directive, Annex I)

Molinia meadow (about 0.5 ha)

- *Molinia* meadow (m) (N 51,39817°; E 14,16590°) – drier part of the *Sphagnum* bog dominated by a dense moor grass vegetation (*Molinia caerulea* (L.) Moench; up to 90% cover); minor hummock-hollow structure, only *Sphagnum fallax*; trees selectively removed by hand between 2004 and 2009; in comparison to the rest of the *Sphagnum* bog slightly elevated and drier (Tab. 1), high sun exposure

50-year old spruce afforestation on peat substrates (about 8 ha)

- dense fresh spruce forest (sf) (N 51,39885°; E 14,16968°) & dense wet spruce forest (sw) (N 51,39935°; E 14,17226°) – dense spruce afforestation (*Picea abies* (L.) Karst) on fresh and wet (due to local re-wetting measures) soil (Tab. 1); no herb layer, only sporadic moss layer (e.g. *Hypnum cupressiforme* Hedw., *Plagiothecium denticulatum* W. P. Schimp.), thick layer of coniferous litter; no sun exposure
- fresh spruce-birch forest (sbf) (N 51,39929°; E 14,17054°) & wet spruce-birch forest (sbw) (N 51,39979°; E 14,17281°) – open spruce afforestation with interspersed birches (*Betula pendula* Roth) on fresh and wet soil (Tab. 1); moderately developed herb layer dominated by *Molinia caerulea*, *Pteridium aquilinum* (L.) Kuhn, moderately developed moss layer (e.g. *Pohlia nutans* Lindb., *Dicranella heteromalla* [Renauld & Cardot] Kindb.); medium sun exposure

birch wood on peat substrates (about 100 ha)

- wet birch wood (bw) (N 51,40137°; E 14,17285°) – wet birch wood (*Betula pubescens* Ehrh., *B. pendula*; Tab. 1) close to an open water area (peat-cutting site); partial open-reed character (*Phragmites australis* [Cav.] Steud., *Calamagrostis canescens* [Weber] Roth), herb layer contains several grasses like *Deschampsia cespitosa* (L.) P. Beauv., *Calamagrostis epigejos* (L.) Roth, *Carex rostrata* Stokes, *C. canescens* L. and *Juncus effusus* L., moss layer dominated by *Sphagnum squarrosum* Crome; high sun exposure
- fresh birch wood (bf) (N 51,401251°; E 14,173539°) – former bog woodland, now drained; birch wood (*B. pubescens*, *B. pendula*) with a dense herb layer dominated by *Pteridium aquilinum*, also abundant are *M. caerulea*, *Moehringia trinerva* (L.) Clairv., *Poa trivialis* L., *D. cespitosa* and *C. epigejos*,

distinct moss layer of *Atrichum undulatum* P. Beauv. and *Brachythecium rutabulum* W. P. Schimp.; high sun exposure (Tab. 1)

In every sampling site five soil cores were taken in about 5 m distance from each other at 17 October 2012. The soil cores had a diameter of 4 cm and were taken to a depth of 10 cm (vegetation removed, litter layer included; volume = 125.7 cm³). Soil cores were separated in two portions of 0 to 5 cm and 5 to 10 cm depth and transported in cylinders of same size closed on the top and the bottom with plastic caps. MacFadyen-extraction was started one day after sampling and the soil cores were kept cool until then (transport in cooling box, storage over night in fridge at 6°C). Determination of Oribatida followed Weigmann (2006).

Five soil cores per sampling site were also taken for soil analyses at the same time and in the same manner as the soil cores for animal extraction. The soil moisture (Tab. 1) of each sample was determined in the laboratory as the difference between the fresh and dry weight (dried at 110°C) relative to the fresh weight. From three soil cores per sampling site, pH values (Tab. 1) were measured in 0.1 M KCl- solution according to VDLUFA (1991) and DIN 10390. Only for the *Sphagnum* bog site (bog) the pH value was measured close to the water edge of three small peat-cutting sites in about 3 cm water depth. Soil carbon and nitrogen contents as well as C/N ratios (Tab. 1) were determined spectrometrically from 3 soil cores per sampling site following DIN 10694 in a Vario Pyro Cube analyzer.

At every sampling site, five vegetation surveys according to Braun-Blanquet (1964) were carried out within 16-m² plots, where the central point represented the soil core for oribatid mite sampling. *Sphagnum*-samples were taken for later determination. From the vegetation surveys temperature indices (Tab. 1) were derived based on Ellenberg et al. (1992). Furthermore, the cover of the moss-, herb-, shrub- and tree layer in each of the 16-m² plots was estimated as well as the cover of herb- and leaf-litter (herb-leaf-litter) and the cover of needle-litter (Tab. 1).

2.3. Sampling 1987

In 1987, Jürgen Schulz (State Museum of Natural History Görlitz) collected a large number of samples by hand from *Sphagnum*-hummocks in the *Sphagnum* bog site (bog) and extracted the soil mesofauna in a Berlese-apparatus. All extracted oribatid mites were stored in the museum collection as undetermined material. During the current investigation, the oribatid mites from five samples taken on 22 August 1987 were determined.

Table 1. Mean environmental and soil parameters of the eight sampling sites in the Dubringer Moor. **bog** – *Sphagnum* bog, **m** – *Molinia* meadow, **sf** – dense fresh spruce forest, **sw** – dense wet spruce forest, **sbf** – open fresh spruce-birch-forest, **sbw** – open wet spruce-birch-forest, **bw** – wet birch wood, **bf** – fresh birch wood.

	bog	m	sf	sw	sbf	sbw	bw	bf
soil moisture [%]	90.9	81.5	48.5	73.1	57	67.6	66.2	60.3
temperature index	4.9	5.1	3	3.4	3.6	4	5	5
pH	4	4.4	3.4	3.7	2.9	3.0	3.6	3.0
cover tree layer [%]	0	0	91	77	63	47.5	35	49
cover herb layer [%]	46.2	58	0	2	56	29	88	81
cover moss layer [%]	92	9	6	2	13	19	12	26
cover herb-leaf-litter [%]	18	80	0	0	0	0	70	78
cover needle-litter [%]	0	0	95	93	80	91	0	0
C/N	31.3	21.4	21.1	19.6	21.6	21.2	21.2	22.6

Each sample consisted of seven subsamples taken by hand of about 50 cm³ each. These subsamples had been mixed together after Berlese-extraction so that for the present investigation every sample from 1987 comprised about 350 cm³. No environmental parameters had been measured.

2.4. Statistical analyses

To analyze the influence of different environmental parameters on the species composition of oribatid mites, canonical correspondence analyses (CCA) were carried out using Canoco 5 (Lepš & Šmilauer 2012). Only species of which at least three individuals had been determined were included. CCAs were calculated using the mean species abundances of all five samples taken at one sampling site. In a first comprehensive CCA, all environmental parameters listed in table 1 were included. In a second shortened CCA, several heavily correlated parameters and parameters with a weak influence on the species composition were eliminated and only soil moisture, cover of moss layer, cover of herb-leaf-litter, cover of needle-litter and C/N ratio were included. Furthermore, five species were eliminated which clearly separated broadly from all other species in the comprehensive CCA and had led to all other species agglomerating together. To validate the CCAs, the corresponding detrended correspondence analyses (DCA) without environmental parameters were also calculated. Another DCA was calculated with the species abundances of 2012 and 1987 to compare the species composition of both years. A CCA could not be calculated with the data from 1987 because no environmental parameters were available.

3. Results

In total, the soil cores taken in autumn 2012 contained 3512 individuals from 87 oribatid mite species (Tab. 2). The largest number of species was collected in the fresh birch wood (bf) with 42 species, whereas in the *Sphagnum* bog (bog) only 10 species were registered. Mean oribatid mite densities ranged from 115 individuals/100 cm³ in the fresh spruce-birch-forest (sbf) to 9 individuals/100 cm³ in the *Sphagnum* bog (bog) in 2012 (Tab. 2). From the *Sphagnum* bog samples taken in autumn 1987, 3639 individuals from 37 species were determined (Tab. 2). In 1987, the mean oribatid mite density in the *Sphagnum* bog was much higher with 164 individuals/100 cm³.

The distribution of species along axis 1 of the comprehensive CCA (Eigenvalues: axis 1 = 0.762, axis 2 = 0.42; figure not shown) is best explained by vegetation temperature index, cover of herb layer and tree layer as well as cover of herb-leaf-litter and needle-litter. The species distribution along axis 2 can be explained by the C/N-ratio, cover of moss layer, soil moisture and weakly also by pH. The cover of the herb layer was positively correlated with the cover of the herb-leaf litter and the temperature index. The three parameters were negatively correlated with the cover of needle litter and the cover of the tree layer. C/N-ratio, cover of moss layer and soil moisture were positively correlated with each other. The species distribution in the corresponding DCA (Eigenvalues: axis 1 = 0.762; axis 2 = 0.25; figure not shown) was quite similar to the comprehensive CCA, especially along axis 2. Along axis 1, species ordinate more widely in the DCA than in the CCA.

Table 2. Mean number of individuals per 100 cm³ soil substrate calculated from five soil cores per sampling site. Abbreviations (abbr.) are only given, if the species was included to the CCA or DCA (Fig. 2A, 2B, 3). **bog** – *Sphagnum* bog, **m** – *Molinia* meadow, **sf** – dense fresh spruce forest, **sw** – dense wet spruce forest, **sbf** – open fresh spruce-birch-forest, **sbw** – open wet spruce-birch-forest, **bw** – wet birch wood, **bf** – fresh birch wood.

abbr.	species	22.08.1987	04.10.2012							
		bog 87	bog	dhm	sf	sbf	sw	sbw	bw	bf
Ach col	<i>Achipteria coleoptrata</i>						1.6			
Acr lon	<i>Acrogalumna longipluma</i>		0.2		0.2	0.2	0.2	0.6		
	<i>Banksinoma lanceolata</i>	0.6								
Ber hau	<i>Berniella hauseri</i>									2.7
Ber sp	<i>Berniella</i> sp.					7.8		0.6		0.2
	<i>Camisia spinifer</i>									0.2
	<i>Carabodes aerolatus</i>							0.2		
Car cor	<i>Carabodes coriaceus</i>						0.2			0.5
Car orn	<i>Carabodes ornatus</i>					0.2			0.3	0.2
	<i>Cepheus cepheiformis</i>								0.2	
Cer med	<i>Ceratozetes mediocris</i>									2.2
Cer min	<i>Ceratozetes minimus</i>				3.2			0.3		
	<i>Ceratozetoides maximus</i>							0.2		
	<i>Chamobates borealis</i>				0.3					
Cha cus	<i>Chamobates cuspidatus</i>			0.5	1.0	2.2	2.7	2.0		0.8
Cha voi	<i>Chamobates voigtsi</i>					0.8				
Cul bic	<i>Cultroribula bicultrata</i>			0.5		1.8		0.5		
	<i>Damaeobelba minutissima</i>							0.3		
Dis orn	<i>Dissorhina ornata</i>			0.5	0.8	0.3			0.6	2.5
	<i>Eupelops acromios</i>							0.3		
Eu hirt	<i>Eupelops hirtus</i>				0.2			0.3		
Eu pli	<i>Eupelops plicatus</i>	0.6		0.8		0.2		0.5		0.2
Eu tor	<i>Eupelops torulosus</i>			0.2	0.2		0.2			
	<i>Furcoribula furcillata</i>							0.2		
Gal lan	<i>Galumna lanceata</i>				0.3	0.2		0.2	0.2	0.3
Gal obv	<i>Galumna obvia</i>	0.3							0.6	1.5
Gus mic	<i>Gustavia microcephala</i>								1.1	3.5
Hop ill	<i>Hoplophthiracarus illinoisensis</i>	3.5								
Hyd lac	<i>Hydrozetes lacustris</i>	0.2								
Hyp ruf	<i>Hypochthonius rufulus</i>	2.3		0.2		0.3		4.4	1.5	2.7
Lim cil	<i>Limnozetes ciliatus</i>	0.4								

Lim rug	<i>Limnozetes rugosus</i>	0.2							
Mai bad	<i>Mainothrus badius</i>	3.5	1.6	0.2					
Mal mon	<i>Malaconothrus monodactylus</i>	4.7	0.5	0.2					
Met pul	<i>Metabelba pulverosa</i>								0.5
	<i>Metabelba sphagni</i>	0.3							
Microp	<i>Microppia minus</i>		0.3	15.9	2.7	0.2	6.5		0.6
Microt	<i>Microtritia minima</i>			2.4	1.8	0.2	6.5		0.3
Min sem	<i>Minunthozetes semirufus</i>			5.0	33.9	4.0	2.5		25.1
Nan cor	<i>Nanhermannia cf. coronata</i>	1.6	0.2						
Nan nan	<i>Nanhermannia nana</i>			1.1	5.5				3.8
Not pal	<i>Nothrus palustris</i>							0.6	0.6
Not pra	<i>Nothrus pratensis</i>	1.3	2.2						
Not sil	<i>Nothrus silvestris</i>		0.2	0.6	2.4		7.8	0.6	0.8
Op fal	<i>Oppiella fallax</i>		0.2	1.8			0.3	0.3	
Op nov	<i>Oppiella nova</i>	0.2	0.3	3.8					
Op pro	<i>Oppiella propinqua</i>	22.7	0.2	0.5	6.5	28.3	3.5	22.8	0.8
	<i>Oppiella subpectinata</i>				0.2				
Op ul	<i>Oppiella uliginosa</i>	4.6		0.5					
	<i>Oribatella calcarata</i>				0.2				
Ori tib	<i>Oribatula tibialis</i>		0.2	0.5	0.6	0.2	2.7		
	<i>Pantelozetes paolii</i>								0.2
	<i>Peloptulus montanus</i>	0.2							
Per ner	<i>Pergalumna nervosa</i>		0.3					0.3	
Per will	<i>Pergalumna willmanni</i>	0.9							
Ph bor	<i>Phthiracarus boresetosus</i>			0.2	0.2			0.3	
Ph cri	<i>Phthiracarus crinitus</i>							0.2	0.3
Ph lae	<i>Phthiracarus laevigatus</i>		0.2			0.2			0.2
Pil ten	<i>Pilogalumna tenuiclava</i>	0.6	1.0						
Pla pel	<i>Platynothrus peltifer</i>		0.3	2.2	0.6		0.5	0.2	3.2
Por spi	<i>Porobelba spinosa</i>	0.6		0.2	1.3		0.8		0.3
Pun sel	<i>Punctoribates sellnicki</i>	0.9							
Qua ham	<i>Quadroppia hammerae</i>	0.2			0.8		3.7		0.2
	<i>Ramusella furcata</i>	0.2							
Rhy ar	<i>Rhysotritia ardua</i>	0.6							0.3

Table 2 (continued).

abbr.	species	22.08.1987	04.10.2012							
		bog 87	bog	dhm	sf	sbf	sw	sbw	bw	bf
Rhy du	<i>Rhysotritia duplicata</i>			0.3	0.3	1.3		0.6		0.8
	<i>Schelorbates pallidulus</i>		0.3							
S quin	<i>Schelorbates quintus</i>			0.5						
	<i>Sellnickochthonius formosus</i>				0.3					
Sel im	<i>Sellnickochthonius immaculatus</i>				1.3					
Sel sue	<i>Sellnickochthonius suecicus</i>				3.8					
	<i>Spatiodamaeus boreus</i>					0.2				
Spa ver	<i>Spatiodamaeus verticillipes</i>							0.2	0.2	0.2
Ste car	<i>Steganacarus carinatus</i>								1.0	3.2
	<i>Suctobelbella forsslundi</i>				0.2					
	<i>Suctobelbella latirostris</i>	0.6								
Suc mor	<i>Suctobelbella moritzi</i>				0.6					
	<i>Suctobelbella nasalis</i>							0.2		
Suc pal	<i>Suctobelbella palustris</i>	2.7			0.2					0.3
Suc per	<i>Suctobelbella perforata</i>				1.0					
Suc sar	<i>Suctobelbella sarekensis</i>	0.6			6.8	0.2	0.3	1.1		
	<i>Suctobelbella similis</i>				0.2					
Suc scg	<i>Suctobelbella subcornigera</i>	0.6		1.5	1.7	6.4	1.0	0.8		1.3
Suc str	<i>Suctobelbella subtrigona</i>	0.6						0.3		0.3
	<i>Suctobelbella tuberculata</i>			0.2						
	<i>Suctobelbella vera</i>				0.2					
Tec min	<i>Tectocephus minor</i>				0.5	2.5				
Tec vel	<i>Tectocephus velatus</i>	14.9			0.2	2.7	1.1	3.2	0.2	2.0
Tr long	<i>Trhypochthoniellus longisetus</i>	1.9								
Tr nig	<i>Trhypochthonius nigricans</i>	0.8								
	<i>Trhypochthonius tectorum</i>									0.3
	<i>Xenillus tegeocranus</i>				0.2					
	<i>Zygoribates exilis</i>									0.2
	Juvenile	87.0	2.7	2.5	12.7	9.5	8.0	3.2	4.0	19.9
number of species		37	10	24	40	30	16	38	15	42
mean number of individuals/100 cm³		163.5	9.2	13.4	81	115.2	23.8	78.1	12.3	86.2
mean number of individuals/m²		-	6526	10823	156295	103931	15757	98520	8276	65415

In both analyses, a group of five species (*Pergalumna nervosa* (Berlese, 1914), *Pilogalumna tenuiclava* (Berlese, 1908), *Malaconothrus monodactylus* (Michael, 1888), *Mainothrus badius* (Berlese, 1905), *Nothrus pratensis* Sellnick, 1928) clearly separated from all other species. Those five species almost exclusively occurred in the *Sphagnum* bog. All other species agglomerate

together along axis 1, so that no further information was visible in the comprehensive CCA.

In the shortened CCA with the reduced set of species (Eigenvalues: axis 1 = 0.418; axis 2 = 0.257; Fig. 2A, B), the species distribution along axis 1 was explained best by the vegetation temperature index and the cover of the two litter types. Along axis 2,

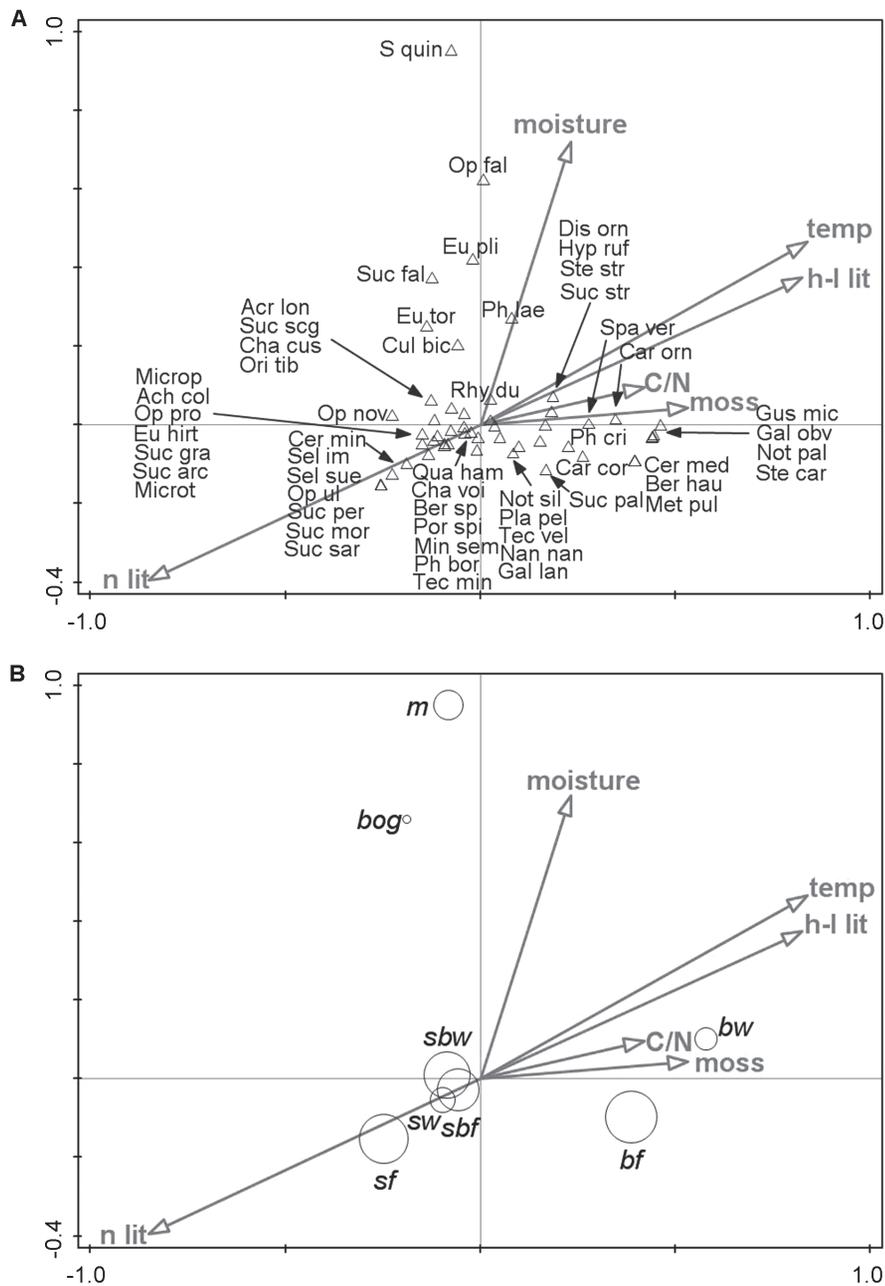


Figure 2A. The shortened CCA of the oribatid mites sampled on 04 October 2012. For species abbreviations see table 2. The following environmental parameters were included: soil moisture (moisture), temperature number (temp), cover of herb-leaf-litter (h-l lit), C/N ratio (C/N), cover of moss layer (moss) and cover of needle-litter (n lit). Eigenvalues: axis 1 = 0.418; axis 2 = 0.257.

Figure 2B. Distribution of sampling sites in the shortened CCA of the oribatid mites sampled on 04 October 2012. The following environmental parameters were included: soil moisture (moisture), vegetation temperature index (temp), cover of herb-leaf litter (h-l lit), C/N ratio (C/N), cover of moss layer (moss) and cover of needle litter (n lit). **bog** – *Sphagnum* bog, **m** – *Molinia* meadow, **sf** – dense fresh spruce forest, **sw** – dense wet spruce forest, **sbf** – open fresh spruce-birch-forest, **bw** – wet birch wood, **bf** – fresh birch wood. Eigenvalues: axis 1 = 0.418; axis 2 = 0.257.

species ordinated along differences in soil moisture. All sampling sites in the spruce forest (sf, sw, sbf and sbw) lay close together near the origin of the diagram (Fig. 2B) and therefore contained similar sets of common species. The two birch wood sites (bf and bw) ordinate to the right of the coordinate system (quadrants I and IV). Their species composition accordingly differed slightly from that of the spruce forest sites. The *Molinia* meadow (m) and the wet *Sphagnum* bog (bog) ordinate in the upper part of the coordinate system (quadrant II), being characterized by only a small number of oribatid species (not included in the shortened CCA: *M. badius*, *M. monodactylus*; included: *Oppiella fallax* (Paoli, 1908). The most common species in the spruce forest sites was *Oppiella propinqua* Mahunka & Mahunka-

Papp, 2000 [It remains uncertain and requires further investigation whether *O. propinqua* is a unique species or simply a morphospecies of *O. nova* (Oudemans, 1902)]. Further characteristic species of the spruce forest were *Minunthozetes semirufus* (C. L. Koch, 1841), *Microppia minus* (Paoli, 1908), *Microtritia minima* (Berlese, 1904), *Chamobates cuspidatus* (Michael, 1884), *Oribatula tibialis* (Nicolet, 1855), *Tectocephus velatus* (Michael, 1880), *Acrogalumna longipluma* (Berlese, 1904) and several Suctobelbidae (Fig. 2A).

The two birch wood sites were characterized by *Galumna obvia* (Berlese, 1915), *Gustavia microcephala* (Nicolet, 1855), *Nothrus palustris* C. L. Koch, 1839 and *Steganacarus carinatus* (C. L. Koch, 1841) (Fig. 2A). In the fresh birch wood, species richness was higher than

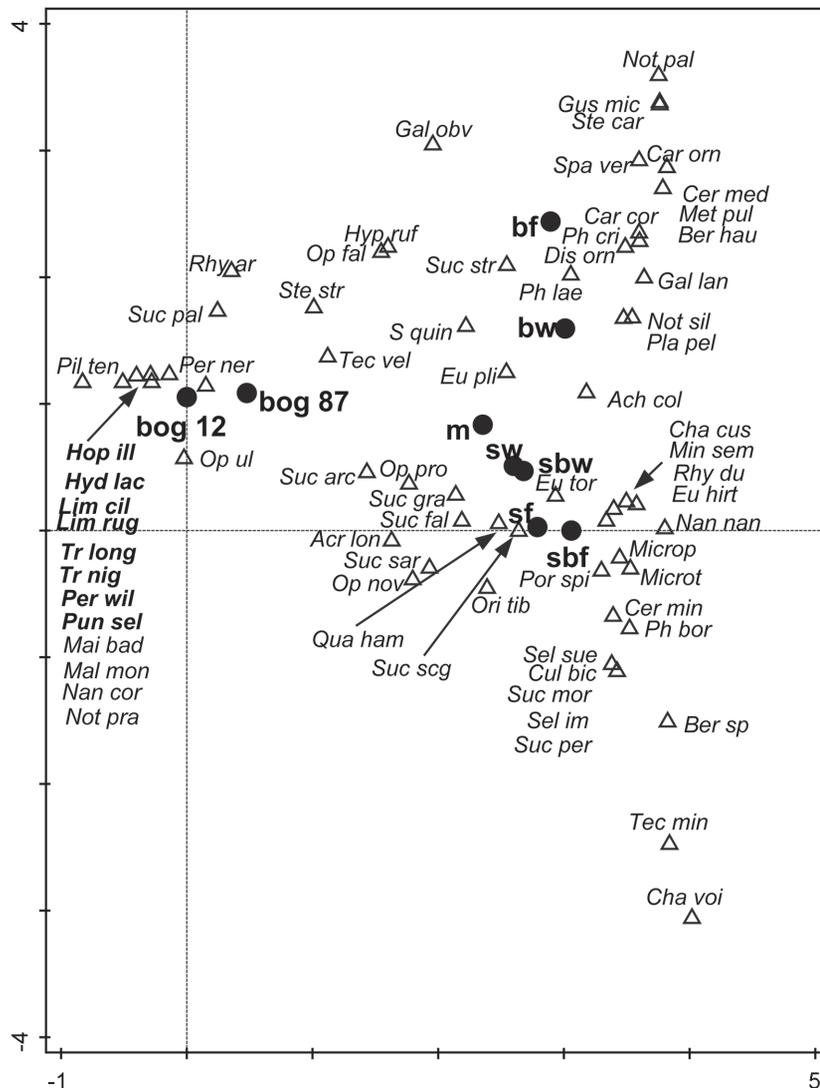


Figure 3. DCA of oribatid mites collected on 22 August 1987 and 04 October 2012. For species abbreviations see table 2. Species abbreviations in bold represent species that were only found in 1987. **bog 87** – *Sphagnum* bog sampled in 1987, **bog 12** – *Sphagnum* bog sampled in 2012, **m** – *Molinia* meadow, **sf** – dense fresh spruce forest, **sw** – dense wet spruce forest, **sbf** – open fresh spruce-birch-forest, **sbw** – open wet spruce-birch-forest, **bw** – wet birch wood, **bf** – fresh birch wood. Eigenvalues: axis 1 = 0.599; axis 2 = 0.311.

in the wet birch wood due to additional species such as *Minunthozetes semirufus*, *Berniella hauseri* (Mahunka, 1974) and *Ceratozetes mediocris* Berlese, 1908 (Tab. 2). *Minunthozetes semirufus* was the most common species in the fresh birch wood and also occurred regularly in the spruce forest.

The *Molinia* meadow (m) contained almost no species that were determined to be characteristic for the *Sphagnum* bog site (bog; *P. nervosa*, *P. tenuiclava*, *M. monodactylus*, *M. badius*, *N. pratensis*; Tab. 2). Only *M. badius* and *M. monodactylus* were also detected in the *Molinia* meadow albeit in much smaller densities than in the *Sphagnum* bog. However, species richness in the *Molinia* meadow was higher than in the *Sphagnum* bog due to species such as *Chamobates cuspidatus*, *Cultroribula bicultrata* (Berlese, 1905), *Dissorhina ornata* (Oudemans, 1900), *Eupelops plicatus* (C. L. Koch, 1836), *Micropoppia minus*, *Platynothrus peltifer* (C. L. Koch, 1839) and *Suctobelbella subcornigera* (Forslund, 1941). These species were also detected in the spruce forest sites.

The DCA calculated from oribatid mite abundances sampled in 1987 and 2012 showed that the species composition in the *Sphagnum* bog in 2012 is still closer to the *Sphagnum* bog composition in 1987 than to the other sites sampled in 2012 (Fig. 3). However, several changes occurred due to a loss of species. In total, 14 species detected in 1987 were not found in 2012 at all (Tab. 2, Fig. 3). Further species such as *M. badius*, *M. monodactylus* and *Nanhermannia* cf. *coronata* Berlese, 1913 were detected in much lower densities. Some of the species that had been registered in the *Sphagnum* bog in 1987 were sporadically found in quite different habitats in 2012, for example *Oppiella uliginosa* in the spruce forest (sf) and *Suctobelbella palustris* in the spruce forest (sf) and the fresh birch wood (bf) (Tab. 2).

4. Discussion

The patchy environment of the Dubringer Moor and the large number of habitat types that lie in close proximity to one another leads to a high overall species richness, which is also visible in the oribatid mite fauna of the present investigation. Despite different anthropogenic influences, 87 oribatid mite species were detected in 2012, supporting the fact that the Dubringer Moor is a well-chosen part of the Natura 2000 network. Taking more habitat types into account would most likely still increase total species richness.

Although all investigated habitat types were part of the same peatland, species richness and composition differed

between the *Sphagnum* bog, the *Molinia* meadow, the spruce afforestation and the birch wood and only *Oppiella propinqua* was detected in every sampling site. Therefore, peat substrates are obviously not the determinant factor for the formation of a characteristic species assemblage. The highest species richness was recorded in the fresh birch wood with 42 species. The species composition in the spruce afforestation slightly differed from the birch wood, but species richness was comparably high with up to 40 species. In contrast, only 10 species were found in the *Sphagnum* bog. Oribatid densities were highest in the fresh spruce forest sites with up to 156,000 individuals/m² in the dense fresh spruce forest. Mean oribatid densities between 100,000 and 300,000 individuals/m² are usual in temperate forests on mor soil (Petersen & Luxton 1982). Compared to temperate deciduous forests on mull soil exhibiting between 20,000 and 50,000 individuals/m² (Petersen & Luxton 1982), mean oribatid density in the fresh birch wood was quite high (65,000 individuals/m²). In the present study, lowest oribatid densities were recorded in the wet *Sphagnum* bog (6500 individuals/m²). In mountainous *Sphagnum* bogs in Romania, Ivan et al. (1997) recorded equally low densities between 7,600 and 8,600 individuals/m² and in a raised peat bog in Russia, Zaitsev (2013) found about 7250 individuals/m². However, in floating *Sphagnum* mats species densities of up to 165,000 individuals/m² (Seniczak et al. 2006 in Seniczak 2011) and even 281,000 individuals/m² (Seniczak 2011) are possible.

Species composition of the different habitat types revealed that the species distribution was primarily influenced by the cover of herb-leaf-litter and needle-litter, by temperature, by soil moisture and by the C/N value. In contrast to earlier studies (Luff & Hutson 1977, van Straalen & Verhoef 1992, van Straalen 1997), pH seems to have only a weak influence on the species composition in the current investigation. However, all eight sampling sites were quite acidic (pH 2.9 to 4.0) and the range was most likely too small to allow an influential gradient. From the differences between the CCAs and DCAs it can be concluded that the present study did not consider all environmental parameters determining the oribatid species composition.

Due to pronounced correlations between the environmental parameters, recognizing the actually determinant parameters is difficult. A strong herb- and tree layer is closely related to a heavy litter layer. The cover of the tree layer is also related to shadowing and therefore to the mean temperature of a given site. Hence, the spruce forest sites are much cooler than the birch wood and the *Sphagnum* bog.

The differences in species composition between the spruce forest and the birch wood seems to be influenced by

litter type. The composition and richness of the litter layer can affect soil fauna by shaping the microenvironment and by providing a range of different food resources (Hättenschwiler et al. 2005). Food quality of the litter differs in terms of leaf toughness, nitrogen, lignin, and polyphenol concentrations, the carbon/nitrogen and lignin/nitrogen ratios and their consequences for microbial activity and substrate utilization (Berg et al. 1993, Cadish & Giller 1997, Perez-Harguindeguy et al. 2000). As decomposer oribatids feed directly on litter, but also on microorganisms colonizing the litter, e.g. fungi (Anderson 1975, Behan-Pelletier & Hill 1983, Maraun et al. 1998). Especially species of the Oppiidae, which were very numerous in the spruce forest sites, and also *Chamobates* are known to be fungivores (Anderson 1975, Kaneko et al. 1998, Beck 2000). Furthermore, litter composition influences the oribatid mites through habitat richness and patchiness. The larger the number of litter producing plant species, the better structured the microhabitat and the higher the oribatid species richness (Hansen & Coleman 1998, Kaneko & Salamanca 1999). Hence, species number is highest in the fresh birch wood, where beside the trees several herbs and mosses contribute to the litter layer. However, also in the dense fresh spruce forest without any herbs and pure needle litter, species richness was high. Concerning Walter & Proctor (1999) needle litter contains a large number of small pores (between the needles) and is therefore an ideal microhabitat for oribatid mites.

Species composition of oribatid mites is also influenced by soil moisture (Strenzke 1952; Weigmann 1991, 1997). Although many species prefer fresh sites, they seem to avoid waterlogged areas, since in the birch wood as well as in the dense spruce forest, the wet sampling site was species poorer than the fresh sampling site. This conforms with Strenzke (1952), according to whom the highest oribatid species richness occurs at mean moisture, high organic content, low pH and a medium litter cover. The *Sphagnum* bog with the highest soil moisture of all sampling sites was characterized by a low species number of only ten species in the present study (2012 sampling). Beside the water content, this is likely a consequence of the low nutrient supply and the high temperature fluctuations resulting from the lack of a herb and tree layer.

Although species poverty is typical for *Sphagnum* bogs (Popp 1962, Kuriki 1995, Seniczak 2011) with only 10 species the *Sphagnum* bog in the Dubringer Moor is even species poorer than found in other studies. From a *Sphagnum* bog in Poland, Seniczak (2011) reported 36 oribatid species. In Romania, two peat bogs in 900 and 1200 m a.s.l. contained 20 and 39 oribatid species, respectively (Ivan et al. 1997). The species poverty

of the *Sphagnum* bog in the Dubringer Moor most likely results from the increasing desiccation, since species richness was much higher in 1987 (37 species). Several tyrophilic species such as *Hoplophthiracarus illinoisensis* (Ewing, 1909), *Trhypochthoniellus longisetus* (Berlese, 1904), *Trhypochthonius nigricans* Willmann, 1928, *Ramusella furcata* (Willmann, 1928) and *Metabelba sphagni* Strenzke, 1950 have apparently disappeared from the *Sphagnum* bog today. However, more samples are necessary to validate this preliminary result. *R. furcata* and *M. sphagni* were already rare in 1987, but low abundances may be typical for these species since they were also detected in small numbers in bogs of other areas (Tarras-Wahlberg 1961, Seniczak 2011). In contrast, *H. illinoisensis* was quite abundant (3.5 individuals/100 cm³) in the *Sphagnum* bog in 1987. The species typically occurs in wet peat bogs with *Sphagnum* sp. (Tarras-Wahlberg 1961, Popp 1962, Ivan et al. 1997, Weigmann 2006). *T. longisetus* and *T. nigricans* are also known to be characteristic for wet peat bogs and *Sphagnum*-mosses (Kehl 1997b, Weigmann 2006, Seniczak 2011). *Punctoribates sellnicki* Willmann, 1928 as a stenotopic species of wet peat bogs and meadows (Weigmann 2001, 2006) has also apparently disappeared from the *Sphagnum* bog. *Hydrozetes lacustris* (Michael, 1882), *Limnozetes ciliatus* (Schrank, 1803) and *L. rugosus* (Sellnick, 1923) were also not detected in 2012, but this may be due to methodical reasons. They prefer submerged vegetation, which was probably sampled in 1987, but could not be incorporated by the sampling method used in 2012. Single specimens of *Oppiella uliginosa* and *Suctobelbella palustris* that were abundant in the *Sphagnum* bog in 1987 were detected in other, adjacent habitat types in 2012. Hence, renaturation measures for hydrological stabilization in the early future may enable a re-immigration of those species and the redevelopment of a bog-specific oribatid community might still be possible.

Despite the low species number the *Sphagnum* bog is an important part of the Dubringer Moor that highly deserves protection due to a number of specialists it exhibits. Characteristic bog species still occurring here in 2012 were *Nothrus pratensis*, *Mainothrus badius*, *Pilogalumna tenuiclava*, *Malaconothrus monodactylus* and *Pergalumna nervosa* (Strenzke 1952, Tarras-Wahlberg 1961, Popp 1962, Weigmann 2006, Seniczak 2011). Those species still occurring in the *Sphagnum* bog today might be less sensitive to dryer periods and strong water level fluctuations than the species that disappeared since 1987. *M. badius* and *P. tenuiclava* are regarded as character species of wet and floating bogs (Strenzke 1952, Tarras-Wahlberg 1961, Popp 1962, Seniczak 2011). *M. monodactylus* is a less stenotopic bog species that also occurs in reed beds, wet meadows and eutrophic

fen woods (Strenzke 1952), although it was not found in forest habitats in the present study. The omnivorous species feeds on fungal hyphae, plant debris, fungal spores, conifer pollen and even arthropods (Behan-Pelletier & Hill 1983) and is flexible concerning pH (Strenzke 1952). *N. pratensis* is also less stenotopic than *M. badius* and *P. tenuiclava*. Its main habitat are bogs (Popp 1962, Ivan et al. 1997, Weigmann 2006), but it also prefers moist substrates in general (Strenzke 1952). The *Sphagnum* bog and therefore also those bog specialists are endangered by ongoing desiccation. If the water level drops to a point where *Sphagnum* species cannot grow any more, tree species invade the bog area and the bog evolves toward an acid forest that has lost most of its typical bog fauna (Borcard 1997). Such a development can already be observed in the *Molinia* meadow. The *Molinia* meadow can be regarded as a degenerated part of the *Sphagnum* bog and in case of ongoing desiccation the whole *Sphagnum* bog might first develop into a *Molinia* meadow and later into a forest. This *Molinia* meadow – although still holding remains of *Sphagnum fallax* – contains almost no species characteristic for the *Sphagnum* bog. Only *M. badius* and *M. monodactylus* were detected here, but in smaller abundances than in the *Sphagnum* bog. However, species richness increases from the *Sphagnum* bog to the *Molinia* meadow. Instead of bog species, several species characteristic for forest habitats occur in the *Molinia* meadow, for example *Chamobates cuspidatus*, *Cultroribula bicultrata*, *Dissorhina ornata*, *Microppia minus* and *Suctobelbella subcornigera* as well as the euryoecious *Platynothrus peltifer*. All those species were also captured in the spruce forest. Hence, the present study confirms that ongoing bog degeneration leads to a typical bog species community changing to a community of habitat generalists and species preferring drier environments like forests (Markkula 1986). The change of the oribatid bog species community towards a more forest-like community in connection with a permanent lowering of the water table is already known from vegetational changes, the rapidity of which depends on the nutrient status, the original wetness of the site and the extent of the change in the water level (Laine & Vanha-Majamaa 1992, Laine et al. 1995). Species density was also higher in the drier *Molinia* meadow than in the *Sphagnum* bog. This agrees to Silvan et al. (2000) who found an increase in oribatid abundance and a significant positive correlation with the depth of the site water level in a drainage continuum of peatland sites in Finnish pine fens.

The loss of tyrophilic species and the decreasing abundances of hygrophilic species are the results of the unstable water supply and the water deficiency especially during summer in the Dubringer Moor (SLUG 2010),

caused by drainage and spruce afforestation. In the present study, the oribatid mite community composition and densities of tyrophilic and hygrophilic species were closely related to *Sphagnum* bog desiccation and habitat characteristics like litter type, vegetation cover, soil moisture and temperature. The results indicate that in the beginning of desiccation when *Sphagnum* mosses are still abundant, oribatid species richness and density decreases due to a loss of bog specialists. In later phases of desiccation, when the vegetation changes from a *Sphagnum* dominated composition to, e.g., a *Molinia* dominated meadow oribatid species richness increases again due to immigrating species being characteristic for forest habitats and euryoecious species. Oribatid mites therefore obviously offer the opportunity to evaluate the ecological conditions and degeneration of a *Sphagnum* bog.

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