


Distribution and population characteristics of the soil mites *Diapterobates notatus* and *Svalbardia paludicola* (Acari: Oribatida: Ceratozetidae) in High Arctic Svalbard (Norway)

Stanisław Seniczak¹  · Anna Seniczak² · Radomir Graczyk² · Hans Tømmervik³ · Stephen J. Coulson^{4,5}

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Abstract The Oribatida of High Arctic Svalbard are faunistically relatively well known, but the distribution, density, stage structure and other population parameters of most species are unknown. Here we focus on two ceratozetid species, *Diapterobates notatus* (Thorell, 1871) and *Svalbardia paludicola* Thor, 1930, and investigate the summer density, stage and sex structure, proportion of gravid females and the body size of these species in 33 locations and 11 vegetation classes of Svalbard. *Diapterobates notatus* occurred in all vegetation classes and at 29 locations, whereas *S. paludicola* occurred in only two vegetation classes and at three locations. The common occurrence of *D. notatus* in Svalbard may be due to: (1) cosmopolitan nature of this species which inhabits all vegetation classes but with a preference for open *Dryas/Carex rupestris* communities, (2) high biological potential (females were more abundant than males and carried 6–7 large eggs) resulting in a high proportion of juveniles, and (3) juvenile morphology which possesses long setae that may enhance passive

dispersal by the wind. Adult body size was found to be greatest in the floristically diverse Arctic meadows. *Svalbardia paludicola* was particularly abundant in the Arctic meadow at Reinsdyrflya where juveniles were more plentiful than the adults. The nymphs of this species have shorter gastronotal setae than those of *D. notatus* which may limit their passive transport by the wind. *Scutozetes clavatosensillus* Ermilov, Martens & Tolstikov, 2013 was found in Mosselbukta (north Spitsbergen); this is the first observation of this species in Svalbard.

Keywords Oribatid mites · Ecology · Stage and sex structure · Body size

Introduction

Oribatid mites are mainly saprophages that play an important role in the decomposition of the soil organic matter (Schuster 1956; Seniczak 1978), including in the Arctic regions. They consume the litter, reducing it to pellets or smaller fragments and hence increasing the surface area available for further microbial decomposition (Schuster 1956; Seniczak 1978). Microbial activity is particularly intensive in the gut tracts of mites (Seniczak and Stefaniak 1978; Stefaniak and Seniczak 1976, 1981), releasing the elements for plants growth. The oribatid mites are usually abundant and rich in species, but these population parameters depend on the type and extent of the vegetation cover and quantity of organic matter (Coulson et al. 2003; Seniczak 1978; Seniczak and Plichta 1978; Seniczak et al. 2014a). Bayartogtokh et al. (2011) listed 81 species of these mites from the Svalbard archipelago, which comprises only 0.8% of the total 10,000 species of recognized oribatid mite species

✉ Stanisław Seniczak
stseni@ukw.edu.pl

¹ Department of Evolutionary Biology, Faculty of Natural Sciences, Kazimierz Wielki University, Ossolińskich 12, 85–092 Bydgoszcz, Poland

² Department of Ecology, UTP University of Science and Technology, Kordeckiego 20, 85–225 Bydgoszcz, Poland

³ Norwegian Institute for Nature Research (NINA), FRAM - High North Centre for Climate and the Environment, No 9296 Tromsø, Norway

⁴ University Centre in Svalbard, P.O. Box 156, 9171 Longyearbyen, Norway

⁵ ArtDatabanken The Swedish Species Information Centre, Swedish University of Agricultural Sciences, Box 7007, 750 07 Uppsala, Sweden

(Behan-Pelletier and Schatz 2010). However, within the Svalbard inventory there is some taxonomic uncertainty regarding the identification of some species (Coulson et al. 2014). Nonetheless, population parameters, such as distribution, density, stage and sex structure of the Svalbard oribatid communities are unknown, except for the four species investigated by Seniczak et al. (2014a, 2015a, b, 2016).

Diapterobates notatus (Thorell, 1871) is common and abundant in the Svalbard archipelago. Seniczak and Plichta (1978) found it to be dominant in moss–lichen tundra at Hornsund (*Saxifraga oppositifolia*, *Cetraria delisei*, *C. delisei*+*Salix polaris* and *Drepanocladus uncinatus*) and juveniles greatly outnumbered adults. In the moss–grass tundra at Petuniabukta and Vestpynten (patches of moss, grasses, moss mixed with grasses, *Cassiope tetragona*, *S. polaris* and bare soil), *D. notatus* was not so abundant (Seniczak et al. 2014a), but the juveniles also dominated the adults. In patches of six vascular plant species (*Luzula confusa*, *Dryas octopetala*, *C. tetragona*, *S. polaris*, *Silene acaulis* and *S. oppositifolia*) investigated by Coulson et al. (2003), the density of *D. notatus* was also lower, but these authors counted only the adults and omitted juveniles. In these three papers, *S. paludicola* Thor, 1930 was absent.

Here we focus on *D. notatus* and *S. paludicola*, which are closely related ceratozetid species occurring in the Svalbard archipelago, but which have dissimilar morphology, ecology and distributions. The former species prefers humid to semi-dry soils covered with mosses, grasses, heath-like vegetation and sometimes willow or birch scrub (Haarlov 1967), with a wide variety of mesic habitats, such as bog, shrub, dry tundra and littoral areas (Behan-Pelletier 1997), whereas the latter species prefers moist to wet habitats (Behan-Pelletier 1985).

We hypothesize that the population density and certain other population parameters of *D. notatus* and *S. paludicola* are related to the type and composition of the vegetation cover, in this paper referred to as “vegetation classes”. The vegetation cover creates the microhabitats for the mite community, integrating various important environmental factors that control the population parameters of these species or can explain absence. A limited number of studies have investigated the distribution of oribatid mites in the Svalbard archipelago (Bayartogtokh et al. 2011; Coulson et al. 2003, 2014; Seniczak et al. 2014a, 2015a, b), but these concerned single regions or omitted the demographically important juvenile stages. Our aim is to compare the density, stage and sex structure, number of gravid females, and the body size of *D. notatus* and *S. paludicola* from diverse vegetation classes and locations in Svalbard.

Material, methods and terminology

Sampling and mite extraction, determination and analyses

We investigated the distribution of *D. notatus* and *S. paludicola* in the Svalbard archipelago (Fig. 1) using 172 samples from 33 locations (Fig. 2). These samples were collected mainly in the rocky coastal zone (1–5 m a. s. l.) except for the vegetated slope in Ringhorndalen (about 100 m a. s. l.), during the polar summer (a period of around 6 weeks from late June to early August) between 2009 and 2014. The number of samples from each location varied between 1 and 12. Soil samples were collected from the typical vegetation communities at each location. Each sample had dimensions of 10 × 10 cm by c. 5 cm deep (the usual maximum depth of the organic soil). The samples (soil and plant cover) were kept cool until being extracted in Tullgren funnels (Burkard Scientific Ltd., Uxbridge, UK) at the University Centre in Svalbard (UNIS) within 5 days of collection. Extracted animals were preserved in 96% ethanol. The density, stage structure and sex ratio, number of gravid females and the body length in very abundant samples on the basis of 30 individuals selected at random was determined for both species.

We identified the juveniles of *D. notatus* and *S. paludicola* according to Seniczak (1980, 1993) and Behan-Pelletier (1985). The larva of *D. notatus* has the posterior gastronotal setae (*dp*, *lp* and *h*₁) longer than that of *S. paludicola*, whereas the nymphs of *D. notatus* have the gastronotal setae *c*₂, *da*, *dm*, *la*, *lm* and *h*₂ distinctly longer than those of *S. paludicola* (Figs. 3, 4). Moreover,

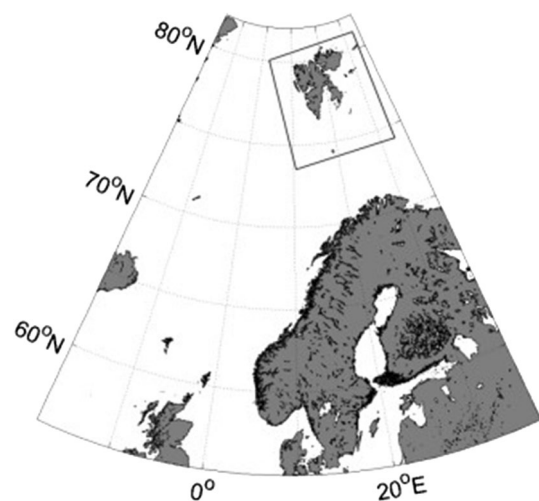


Fig. 1 Location of the Svalbard archipelago (box) in the European High Arctic

Fig. 2 Number of vegetation classes and presence of *Diapterobates notatus* (D) and *Svalbardia paludicola* (S) at sampling locations in the Svalbard archipelago; definitions of the vegetation classes are given in “Material, methods and terminology”

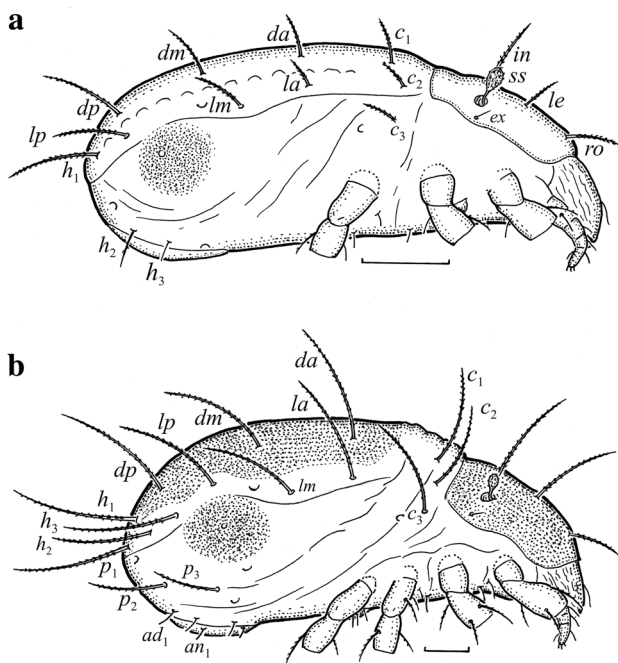
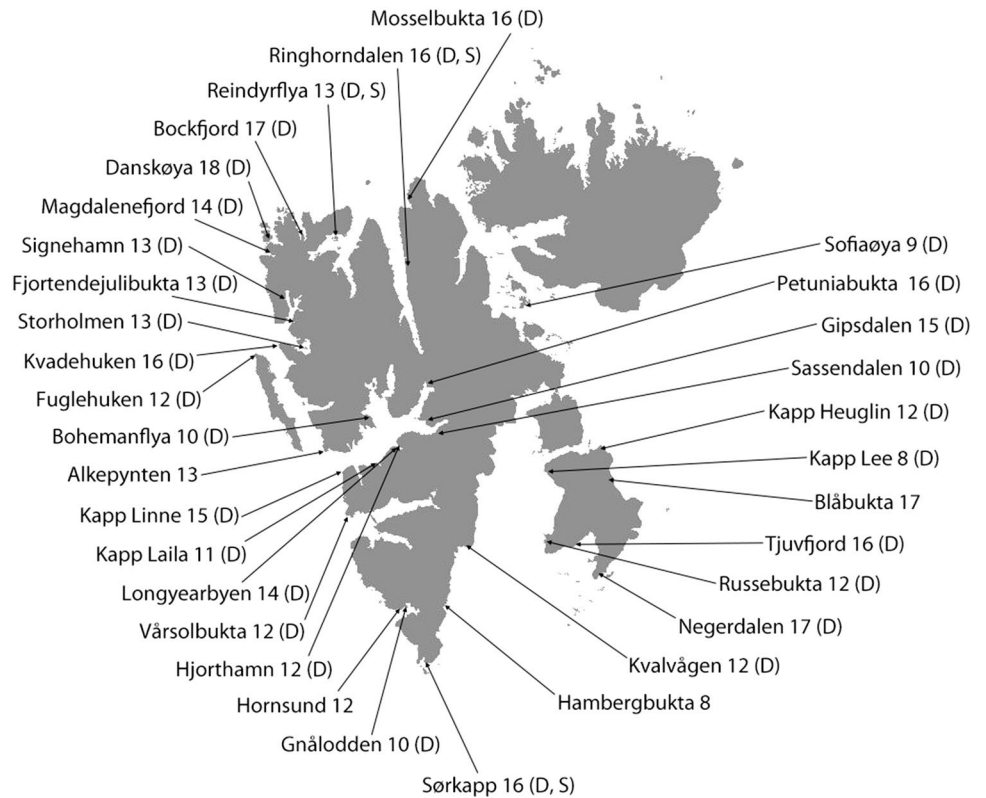


Fig. 3 *Diapterobates notatus*, lateral aspect, legs partially drawn, scale bar 50 µm; **a** larva, **b** tritonymph

the juveniles of *S. paludicola* have a humeral organ (oh) present, whereas those of *D. notatus* do not possess this organ. Species nomenclature follows Subías (2004).

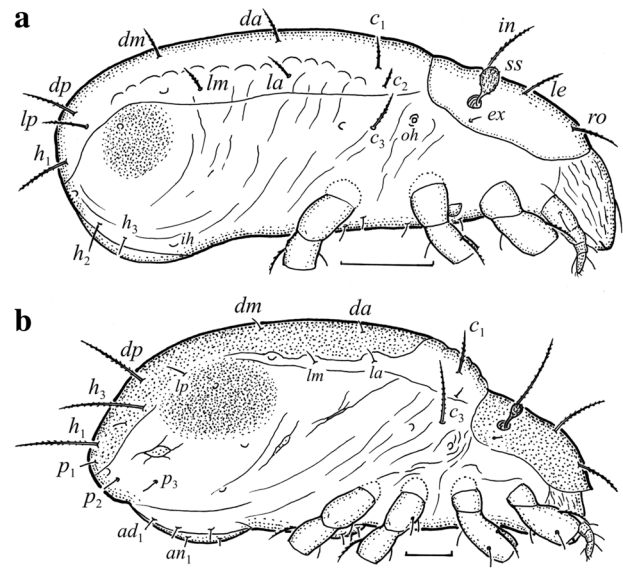


Fig. 4 *Svalbardia paludicola*, lateral aspect, legs partially drawn, scale bar 50 µm; **a** larva, **b** tritonymph

Identified material is deposited as alcohol samples in the Department of Evolutionary Biology, Kazimierz Wielki University in Bydgoszcz (Poland).

Statistical analysis of the density of *D. notatus* was performed only for locations with five or more replicates.

We compared the density and stage structure of *D. notatus* between vegetation classes using Euclidean distances. The resemblance matrices were produced using a cluster analysis and employing an unweighted pair-group method with arithmetic averaging (UPGMA) (Jongman et al. 1987; Piernik 2008). Normality was examined by the Kolmogorov–Smirnov test and homogeneity of variance with the Levene’s test. As the assumptions of variance analysis were not met, nonparametric tests were used. Kruskal–Wallis was to inspect the raw data and in the case of significant differences between means, a multiple comparison test on ranks was employed (Stanisz 2006). The level of significance for all statistical tests was accepted at $\alpha=0.05$. Data were analyzed using MS Excel 2007, Statistica 10.0 and MVSP 3.2 (Kovach Computing Services 2010).

Vegetation and land cover types

The distribution of *D. notatus* and *S. paludicola* was determined in revised vegetation classes of the Svalbard vegetation map (Johansen et al. 2012) and given in Fig. 2:

- Pioneer vegetation on wet vegetated flats, beaches, slopes and river fans (class 8), with some exposed *Dryas* dominated vegetation and graminoids *Luzula* sp.
- Moderate snowbed and snowflush communities (class 9), with snow protection during winter, plant composition from moss-rich communities to tussock flats, and *Deschampsia alpina*, *Poa alpina*, *S. polaris*, *Equisetum arvense* and moss.
- Swamps, hygrophilous vegetation and wet moss tundra (class 10), including bird cliffs or bird manured areas, with moss and *Arctophila fulva*, *Carex subphatacea*, *Eriophorum triste*, *Dupontia psilosantha* and *Ranunculus hyperboreus*.
- Moss tundra (class 11), occurs in areas with moderate snow cover during winter.
- Rich moss tundra and bird cliff vegetation (class 12), with moist moss *Tomentypnum nitens*, grasses (*Alopecurus ovatus*, *Dupontia fisheri*, *Dupontia pelligera* and *Eriophorum scheuchzeri*) and sedges (*Carex parallela* and *Carex saxatilis*).
- Arctic meadows—rich vegetation (class 13), with grasses and sedges and in the drier parts of *Dupontia* meadows. This class includes bird cliff vegetation communities, with grasses (*P. alpina*, *Festuca rubra richardsonii*, *Festuca baffinensis* and *Trisetum spicatum*) and forbs (*Taraxacum brachyceras* and *Cochlearia groenlandica*).
- Open dry-grass communities (class 14), comprise open, extremely dry communities characterized by grass, sedge and rush species and lichens, High Arctic steppe vegetation.
- Open *Dryas/Carex rupestris* communities (class 15), with *Carex rupestris*, *Carex nardina*, *S. oppositifolia* and scattered stands of *D. octopetala*.
- Established dense *Dryas* heaths (class 16), with a significant winter snow cover and is dominated by species such as *D. octopetala*, *C. tetragona*, *S. oppositifolia*, and *Papaver dahlianum*.
- Luzula* vegetation—sparse graminoid vegetation (class 17), is composed of *Luzula* sp., moss *Racomitrium lanuginosum* and lichens (*Flavocetraria nivalis*, *Cladonia mitis* and *C. delisei*).
- Gravel barren communities (class 18), with barren gravel communities constitute none-to-sparsely vegetated gravel-boulders, block fields and large periglacial polygons.

Results

Distribution, density and stage structure of species of *Diapterobates notatus* and *Svalbardia paludicola*

Diapterobates notatus was present in 133 samples (Table 1) from a total 172 total samples investigated, so the constancy of species was high (77% of all samples). Only at Alkepynten (moss tundra), Hornsund (rich moss tundra), Blåbukta and Hambergbukta (*Luzula* vegetation) was this species absent. *Diapterobates notatus* occurred in all 11 vegetation classes, but the highest mean density (5759 ± 7155.4 ind m^{-2}) was achieved in open *Dryas/Carex rupestris* communities (Table 1). A relatively great mean density occurred in moderate snowbed communities, 4450 ± 6010.4 ind m^{-2}) but lower densities (150–312 ind m^{-2}) were noted in pioneer vegetation, moss tundra, open dry-grass communities and gravel barren communities. In other vegetation classes the mean densities were 1836–2856 ind m^{-2} .

The stage structure of the *D. notatus* population was determined from a total of 1962 juveniles and 1275 adults. In most vegetation classes the juveniles dominated the adults. Juveniles comprised between 51.3% (rich moss tundra) and 100% (gravel barren communities) of the population, except for pioneer vegetation where the proportion declined to 33.3% (Table 1). In most vegetation classes the larvae or protonymphs dominated the other juvenile stages and the proportion of subsequent nymphs (protonymph to tritonymph), usually decreased. The density of juveniles and adults of *D. notatus* was the highest in open *Dryas/Carex rupestris* communities, as compared to that in moss tundra and open dry-grass communities (Fig. 5).

Table 1 Mean density of *Diapterobates notatus* (ind dm⁻², ±SD and range) in vegetation classes in Svalbard

Vegetation classes	Regions (replications)	L	PN	DN	TN	Tot JUV	%	AD	Tot	Ind m ⁻²
Pioneer vegetation on wet vegetated flats, beaches, slopes and river fans	Kapp Lee (2)	0	0	0.5±0.7 0–1	0	0.5±0.7 0–1	33.3	1.0±1.4 0–2	1.5±0.7 1–2	150±70.7 100–200
Moderate snowbed and snow-flush communities	Sofiaøya (2)	19.0±26.9 0–38	3.0±4.2 0–6	3.0±2.8 1–5	6.5±9.2 0–13	31.5±43.1 1–62	70.8	13.0±17.0 1–25	44.5±60.1 2–87	4450.0±6010.4 200–8700
Swamps, hygrophilous vegetation and wet moss tundra	Bohemianfya (2), Gnålodden (4), Sassendalen (8)	1.8±3.2 0–11	4.7±7.5 0–24	4.0±7.6 0–26	1.7±3.0 0–9	12.3±20.2 0–70	66.8	6.1±6.6 0–17	18.4±25.4 1–86	1836.4±2544.5 100–8600
Moss tundra	Kapp Laila (10)	0.6±1.2 0–3	0.6±0.7 0–2	0.3±0.5 0–1	0.1±0.4 0–1	1.6±1.5 0–5	69.6	0.6±1.1 0–3	2.3±1.4 1–5	225.0±138.9 100–500
Rich moss tundra and bird cliff vegetation	Hiorthamn (6), Kapp Heuglin (1), Kvalvågen (3), Russebukta (12), Vårsolbukta (3)	3.6±6.1 0–21	2.8±4.1 0–17	2.8±5.1 0–22	4.2±10.7 0–45	13.4±24.7 0–105	51.3	12.7±27.1 0–124	26.1±47.3 1–185	2609.5±4728.2 100–18,500
Arctic meadows (rich vegetation)	Fjortendejuitbukta (10), Fugleluken (6), Reinsdyrflya (6), Storholmen (6), Signehamn (3)	6.8±8.7 0–29	4.1±7.4 0–37	2.3±3.3 0–13	1.5±2.0 0–8	14.7±16.5 1–77	59.5	10.1±11.9 0–57	24.7±26.9 2–134	2474.1±2694.8 200–13,400
Open dry-grass communities	Longyearbyen (7), Magdalenefjord (3)	0.6±0.9 0–2	1.4±2.3 0–6	0.6±0.9 0–2	0	2.6±3.2 0–8	83.9	0.5±0.5 0–1	3.1±3.0 1–8	312.5±304.4 100–800
Open <i>Dryas/Carex rupestris</i> communities	Gipsdaten (6), Kapp Linné (2)	7.3±5.6 0–14	10.1±11.0 0–33	11.0±17.7 1–52	5.9±10.3 0–27	34.3±42.1 1–124	59.7	23.3±29.9 0–89	57.5±71.6 1–213	5759.0±7155.4 100–21,300
Established dense <i>Dryas</i> heaths	Kvadehøken (2), Mosselbukta (3), Petuniabukta (12), Ringhornsdalen (9), Sørkapp (13), Tjuvfjord (6)	8.4±12.9 0–52	4.1±6.4 0–32	3.3±4.6 0–22	2.8±4.3 0–20	18.4±21.5 0–74	64.3	10.1±13.0 0–50	28.6±31.8 1–124	2856.8±3177.7 100–12,400
<i>Luzula</i> vegetation—sparse graminoid vegetation	Bockfjord (8), Negerdalen (2)	3.8±7.1 0–21	1.8±3.0 0–9	3.5±4.3 0–13	2.5±3.0 0–9	11.5±16.9 0–52	56.1	9.0±8.9 1–25	20.5±24.7 1–77	2050.0±2467.5 100–7700
Gravel barren communities	Danskeøya (3)	3	0	0	0	3	100	0	3	300
Mean		5.5±9.3 0–52	3.7±6.3 0–37	3.1±6.3 0–52	2.5±5.8 0–45	14.8±22.0 0–124	60.9	9.6±16.4 0–124	24.3±35.9 1–213	2433.8±3589.4 100–21,300
Total	Anova rang Kruskal–Wallis	728	488	415	331	1962	60.6	1275	3237	323,700
	<i>H</i>	21.688	14.002	17.605	17.293	23.967	–	31.442	28.982	28.982
	<i>P</i>	0.017	0.173	0.062	0.068	0.008	–	0.001	0.001	0.001

L larva, PN protonymph, DN deutonymph, TN tritonymph, AD adult, Tot total

Diapterobates notatus displayed significant variations in density between vegetation classes (Table 2). For example, in Arctic meadows the mean density of this species was significantly greater for larvae, juveniles, adults and all life stages than in moss tundra. In the former vegetation class, the mean density of *D. notatus* was also significantly greater than in open dry-grass communities but this was due to the large numbers of both juveniles and adults. In open *Dryas/Carex rupestris* communities, the mean density of *D. notatus* was significantly greater than in moss tundra and open dry-grass communities due to large numbers of larvae, deutonymphs, all juveniles, adults and all life stages (moss tundra) or adults and all instars (open dry – grass communities). In established *Dryas* heaths,

the mean density of *D. notatus* was significantly greater than in moss tundra and open dry-grass communities due to the large numbers of adults and all instars (moss tundra) and tritonymphs, adults and all instars (open dry-grass communities).

The preferences of *D. notatus* to particular vegetation classes are clear from the cluster analysis (Fig. 6), which separates open *Dryas/Carex rupestris* communities, with the greatest density of this species (Table 2), from the other plant classes. Moss tundra and open dry-grass communities cluster together due to their low densities.

Svalbardia palludicola was noted in only two vegetation classes, but only in Arctic meadows was this species abundant (Table 3) and the juveniles were more abundant than

Fig. 5 Structure of the mean density of adults (AD) and juveniles (JUV) of *Diapterobates notatus* in 11 vegetation classes (the names of vegetation classes are given in “Material, methods and terminology”)

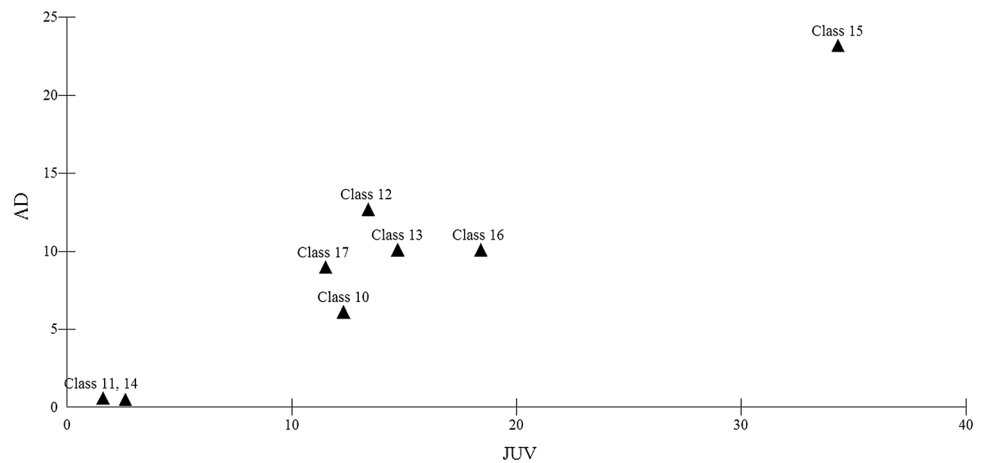


Table 2 Significant differences in densities of *D. notatus* at $P \leq 0.05$ between vegetation classes in Svalbard

Vegetation class	Class 13	Class 14	Class 15
Moss tundra	L, JUV, AD, Tot	–	L, JUV, AD, Tot
Arctic meadows (rich vegetation)	–	AD, Tot	–
Open dry-grass communities	–	–	AD, Tot

L larva, PN protonymph, DN deutonymph, TN tritonymph, AD adult, Tot total

Fig. 6 Cluster analysis of the density of *Diapterobates notatus* in the vegetation classes (Euclidean distances) (definitions of the vegetation classes are given in “Material, methods and terminology”)

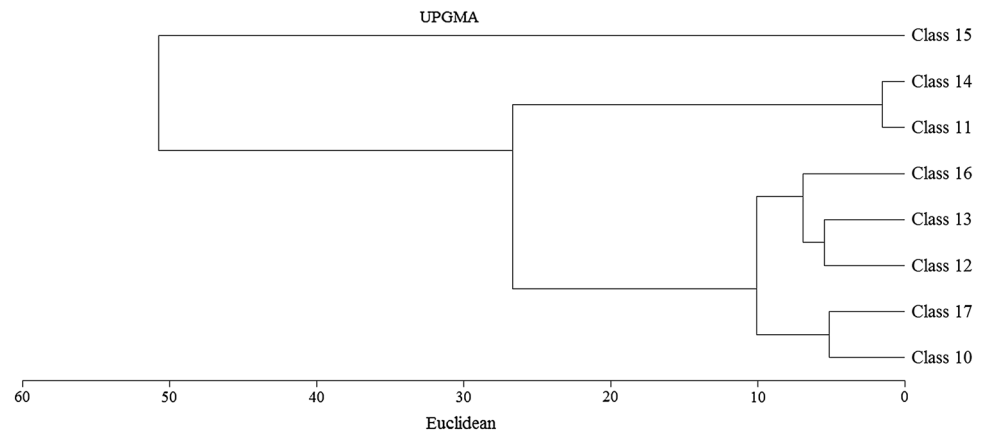


Table 3 Stage structure and sex ratio of *Svalbardia palludicola* in Svalbard

Class of vegetation	Region	Rep	Juveniles						AD	Tot	Per 1 m ²	Sex		
			L	PN	DN	TN	Tot	%				♀	♂	Sex ratio
Arctic meadows (rich vegetation)	Reinsdyrflya	b	28	7	9	35	79	61	51	130	13,000	24 (21)	29	1:1.2
		e	0	0	0	1	1	50	1	2	200	0	1	–
Established dense <i>Dryas</i> heaths	Ringhorndalen	a	7	4	1	0	12	71	4	17	1700	1	0	–
	Sørkapp	e	0	0	0	1	1	100	0	1	100	–	–	–

Rep replications, L larva, PN protonymph, DN deutonymph, TN tritonymph, AD adult, Tot total, ♀ female (gravid females), ♂ male

Table 4 Sex ratio of *Diapterobates notatus* and number of gravid females in chosen vegetation classes in Svalbard

Plant class, regions and samples	♀(gravid)/♂	Sex ratio ^a		Gravid♀		
		Mean	Range	$\bar{X} \pm SD$	Range	%
Moderate snowbed and snowflush communities						
Sofiaøya						
♀	12 (7)	1:0.9	–	7.0 ^b	–	58.3
♂	11			–	–	–
Swamps, hygrophilous vegetation and wet moss tundra						
Gnålodden, Sassendalen						
♀	29 (26)	1:0.9	1:0.7–1:1.4	6.5 ± 1.3	5–8	89.7
♂	27			–	–	–
Rich mosstundra and bird cliff vegetation						
Hiorthamn, Kapp Heuglin, Russebukta						
♀	86 (76)	1:0.4	1:0.3–1:1.4	9.5 ± 6.7	3–23	88.4
♂	37			–	–	–
Arctic meadows (rich vegetation)						
Fjortendejulibukta, Fuglehuken, Reinsdyrflya, Storholmen, Signehamn						
♀	157 (95)	1:0.5	1:0.1–1:2.5	7.3 ± 5.5	2–18	60.5
♂	83			–	–	–
Open <i>Dryas/Carex rupestris</i> communities						
Gipsdalen, Kapp Linné						
♀	62 (59)	1:0.6	1:0.2–1:2.5	9.8 ± 7.9	2–21	95.1
♂	37			–	–	–
Established dense <i>Dryas</i> heaths						
Mosselbukta, Petuniabukta, Sørkapp, Tjuvfjord						
♀	146 (95)	1:1.0	1:0.1–1:7.5	5.0 ± 3.2	1–12	65.1
♂	148			–	–	–
<i>Luzula</i> vegetation—sparse graminoid vegetation						
Bockfjord, Negerdalen						
♀	29 (23)	1:0.9	1:0.7–1:1.4	7.7 ± 3.8	5–12	79.3
♂	25			–	–	–
Total						
♀	521 (381)	1:0.7	1:0.1–1:7.5	7.1 ± 5.1	1–23	73.1
♂	368			–	–	–
ANOVA rang Kruskal–Wallis						
♀	$H=2.735; P=0.841$			$H=5.292; P=0.507$		
♂	$H=4.516; P=0.607$			–		

♀ females, ♂ males

^aNumber of ♀/♂

^bNumber of gravid ♀ ± SD and range

Table 5 Comparison of average body length of females and males of *D. notatus* in some vegetation classes in Svalbard

Plant classes	Regions	Sex	Individuals	$\bar{X} \pm \text{SD}$	Range
Moderate snowbed and snowflush communities	Sofiaøya	♀	12	103.9±3.8	95–109
		♂	11	96.2±4.6	88–103
Swamps, hygrophilous vegetation and wet moss tundra	Sassendalen, Gnålodden	♀	29	102.0±2.9	96–108
		♂	27	97.7±2.3	92–102
Rich mosstundra and bird cliff vegetation	Hiorthamn, Kapp Heuglin, Russebukta	♀	87	103.0±2.7	96–110
		♂	37	98.6±2.7	94–104
Arctic meadows (rich vegetation)	Fjortendejulibukta, Fuglehuken, Reinsdyrflya	♀	157	105.5±3.0 ^{ab}	93–113
		♂	74	97.8±10.9	10–106
Open <i>Dryas/Carex rupestris</i> communities	Gipsdalen, Kapp Linné	♀	62	104.2±2.3	97–108
		♂	46	97.8±2.9	92–104
Established dense <i>Dryas</i> heaths	Mosselbukta, Petuniabukta, Tjuvfjord, Sørkapp	♀	146	103.0±3.3 ^c	94–111
		♂	148	97.8±3.1	87–105
<i>Luzula</i> vegetation—sparse graminoid vegetation	Bockfjord, Negerdalen	♀	29	104.5±3.0	97–110
		♂	25	97.4±3.4	90–103
Total		♀	521	103.8±3.2	93–113
		♂	368	97.8±5.6	10–106
ANOVA rang Kruskal–Wallis		♀	$H=60.342; P=0.000$		
		♂	$H=10.593; P=0.102$		

Significantly different between: ^aswamps, hygrophilous vegetation and wet moss tundra and certain classes; ^brich mosstundra and bird cliff vegetation and certain classes; ^cArctic meadows (rich vegetation) and certain classes

the adults. In one sample from Reinsdyrflya this species successfully competed with *D. notatus* and was dominant.

Sex structure, number of gravid females and body length of *Diapterobates notatus* and *Svalbardia paludicola*

The mean sex ratio (females to males) of *D. notatus* was 1:0.7, but this varied between vegetation classes from 1:0.4 to 1:1.0 (Table 4) (no statistically significant differences, $P>0.05$). In all vegetation classes, the sex ratio varied greatly between samples, especially in established dense *Dryas* heaths (1:0.1–1:7.5). For *S. palludicola* the males were more abundant than females (sex ratio 1:1.2), but the estimate was based from only one sample. The occurrence of gravid females of *D. notatus* was generally high (58–95%) and the differences between vegetation classes were insignificant (Table 4). The gravid females carried 6–7 large eggs, rarely eight eggs, in all vegetation classes.

Females of *D. notatus* were usually larger than the males (Table 5), but the body length of the mites varied between vegetation classes. However, in Arctic meadows females were significantly larger than those in swamps, hygrophilous vegetation, rich moss tundra Arctic meadows and established *Dryas* heaths. In all vegetation classes, the range of both female and male body length was large and the values overlapped.

New finding for Svalbard

We found two females of *Scutozetes clavatosensillus* Ermilov, Martens & Tolstikov, 2013 in Mosselbukta (north Spitsbergen, established *Dryas* heaths). This is a first record for Svalbard.

Discussion

This study demonstrates that *D. notatus* and *S. paludicola* are typical components of the oribatid mite fauna of the Svalbard archipelago. The former species is distinctly more common than the latter species. In Svalbard it prefers the open *Dryas/Carex rupestris* communities, with *S. oppositifolia*, in which the density of *D. notatus* is usually high (Coulson et al. 2003; Seniczak and Plichta 1978). However, in this study the mean density of *D. notatus* is relatively low (5759 ind m⁻²) compared to previous reports. For example, in patches of *S. oppositifolia* at Hornsund this species achieved a density of 64,410 ind m⁻² and comprised 82.5% of all oribatid mites (Seniczak and Plichta 1978). In other plant patches with *C. delisei*, *C. delisei*+*S. polaris*, and *D. uncinatus*, the density was lower (9635–17,434 ind m⁻²), but *D. notatus* still dominated, forming 65–91% of the oribatid mite community. In all plant patches, the larvae and protonymphs comprised more than 50% of all individuals of this species. Intriguingly, the

lowest percent of *D. notatus* was observed in patches of *D. uncinatus*, where the density of Mesostigmata was the greatest. The latter group of mites predate oribatid mites (Karg 1993; Ruf and Beck 2005) and reduces their density. Similarly, in patches of moss + grasses at Vestpynten (Longyearbyen, Adventfjord), *D. notatus* was also abundant (37,600 ind m⁻²), but was not a dominant (Seniczak et al. 2014a). In five vascular plant species investigated by Coulson et al. (2003), the mean density of adult *D. notatus* in *Dryas* patches was clearly lower (4.4 ind m⁻²) than in *Saxifraga* patches (35.8 ind m⁻²). Relatively low mean density of *D. notatus* in the open *Dryas/Carex rupestris* communities can be explained by sampling the most representative areas of this vegetation class, not in plant patches of *S. oppositifolia*.

In other vegetation classes, the density of *D. notatus* was lower or low, and significant differences in mean values were noted between vegetation classes, but there are no data in the literature on how vegetation may influence the population density of *D. notatus*. A low density of *D. notatus* in pioneer vegetation can be explained by the type of vegetation, that of open dry-grass communities, by the extremely arid communities, and that of in gravel barren communities, by the sparsely vegetated and mobile gravel, all of which provide poor habitats for oribatid mites. Behan-Pelletier (1997) also found *D. notatus* to be rare in barren habitats. Although a more open vegetation may allow the ground to achieve greater summer temperatures (Coulson et al. 1993) and the early melt of the thin snow that accumulates along ridge crests results in a longer snow free summer period (Ávila-Jiménez and Coulson 2011), these environmental benefits of pioneer and open vegetation may not offset the reduced development of organic soils and lack of suitable microhabitats. However, in vegetation classes with low densities, the juveniles of *D. notatus* were present suggesting the development of this species here despite the potentially extremely demanding living conditions. The wide variance of *D. notatus* densities in the various vegetation classes could be due to the mosaic pattern of distribution of plant species (Coulson et al. 2003; Jónsdóttir 2005; Seniczak and Plichta 1978; Seniczak et al. 2014a) or the heterogeneous distribution of the oribatid mites that often occur in clusters.

The common occurrence of *D. notatus* in Svalbard appears to be mainly due to the wide ecological tolerance of this species, its high reproductive potential, the large proportion of juveniles, and the presence of long setae in the juvenile stages. This species is a generalist, but prefers vegetation communities with a low diversity of plant species, a characteristic of most vegetation classes in Svalbard (Coulson et al. 2003; Seniczak and Plichta 1978; Seniczak et al. 2014a). Female *D. notatus* were more abundant than the males and the majority were gravid resulting in a high

proportion of juveniles in the populations. A closely related species, *Diapterobates humeralis* (Hermann, 1804), is abundant and common on the lichen-covered bark of young Scots pine (*Pinus sylvestris*) and larch (*Larix decidua*) in Poland. In the spring and early summer, the juveniles dominate the adults, achieving proportions of 79.6% and 74.3% of all individuals, respectively (Seniczak 1974), and the juveniles also have long setae, as those of *D. notatus*.

Relatively high density of *D. notatus* in the open *Dryas/Carex rupestris* communities was achieved partly due to the juveniles, which were the most abundant there, especially the protonymphs and deutonymphs. However, the percent of juveniles in the population was not high and may suggest the stability of the population, compared to the less abundant populations of *D. notatus* with higher proportions of juveniles which often indicates the growth phase of a population. Generally, a large proportion of juveniles in the population of *D. notatus* may enhance dispersal and colonization success in the Arctic ecosystem since the juveniles are poorly sclerotized, weigh less than the adults, and have long prodorsal and gastronotal setae that enlarge their body dimensions and enhance passive dispersal by the wind. Transport of juveniles and adults of *D. notatus* by birds (Krivolutsky and Lebedeva 2004) and insects (Coulson 2009) may also be important for in potential long-distance dispersal distribution of this species in Svalbard. However, the juveniles are believed to be more sensitive to adverse environmental conditions than adults (Seniczak 1978; Seniczak and Plichta 1978; Seniczak et al. 2014a). Mite mortality is also a result of predation; for example, from gamasid mites (Karg 1993; Ruf and Beck 2005), especially on the juvenile stages. These predators were present in the samples, and while they were not investigated here, may typically occur at approximately 1000 ind m⁻² (Gwiazdowicz and Coulson 2011).

The sex ratio of oribatid mites varies between the species and the number of eggs carried by gravid females generally depends on body size and season. For example, the mean sex ratio of *D. notatus* was 1:0.7 and in the polar summer the medium-sized gravid females (about 675 µm) usually carried 6–8 eggs, suggesting the high developmental potential of this species. In a slightly smaller species, for example, *Mycobates sarekensis* (Trägårdh, 1910), males usually dominated (mean sex ratio 1:1.3) and gravid females usually carried 6–7 eggs (Seniczak et al. 2015b). In abundant populations of the distinctly smaller Arctic species, *Oribatella arctica* (Thor 1930), the males also dominated (sex ratio 1:0.9–1:1.8), but the proportion of gravid females was low (14%), and these (body length about 440 µm) usually carried only one or two large eggs (Seniczak et al. 2015a).

By contrast, *S. paludicola* was not common, which is consistent with the observations of Thor (1930). This species was the most abundant in the Arctic meadows

at Reinsdyrflya which is rich in plant species, including *Dupontia* sp., and which is consistent with Behan-Pelletier (1985). The reduced dispersal of *S. paludicola* to other Arctic meadows and other vegetation classes than *D. notatus* may be partly the result of the morphology of its juveniles; they have shorter gastronotal setae and are less suitable for anemochory than *D. notatus*. Interestingly, *S. paludicola* successfully competed with *D. notatus* in one sample from Reinsdyrflya. This suggests that more studies on the population biology of this species are required to determine the factors restricting abundances in the other samples and vegetation classes.

In High Arctic Svalbard, the body size of *D. notatus* depends on the vegetation class being the largest in rich vegetation of Arctic meadows, and the smallest in the poorer vegetation of hygrophilous vegetation and wet moss tundra. In other species of Oribatida, the body size also depends on microhabitat. For example, on Olympus Mtn. (Greece) the largest adults of *Eueremaes oblongus* (C. L. Koch, 1835) were recorded from moss patches and the smallest from dead wood (Seniczak et al. 2014b). In the Mediterranean region, the largest adults of *Oppia denticulata* (R. & G. Canestrini, 1882) were found in pine litter in Vodice (Croatia), and the smallest in pine litter in Bilbao (northern Spain) (Seniczak et al. 2013).

The question arises about the population consequences of the small body size of *D. notatus*. Smaller gravid females carry a lower number of eggs, but it does not appear to limit the density of a species. The small Arctic species *O. arctica* achieves distinctly greater densities in Svalbard (Seniczak et al. 2015a) than *D. notatus*. The smaller body size may also influence the vertical distribution in the soil profile, which partly depends on the soil pores and interstitial spaces that get smaller with the soil depth (Seniczak 1978). The lack of suitable soil pores and cavities for oribatid mites to inhabit was suggested by Coulson et al. (2015) as a possible explanation for the lack of oribatid mites in the imported soils at the abandoned mining settlement of Pyramided in Svalbard. Smaller individuals of *D. notatus* may penetrate deeper soil horizons and obtain access to additional resources, but this distribution limits their passive dispersal by the wind to surrounding areas. These examples indicate the complicated consequences of the smaller body size on the interactions between environment and mite.

In this project, two females of *S. clavatosensillus* were obtained from established *Dryas* heaths at Mosselbukta (north Spitsbergen). This is a new species record for Svalbard, and is especially interesting as it was recently described from Nepal (Ermilov et al. 2013) and its wider distribution is unknown. It is, therefore, difficult to explain the history of this species in Svalbard.

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References

- Ávila-Jiménez ML, Coulson SJ (2011) Can snow depth predict the distribution of the high Arctic aphid *Acyrtosiphon svalbardicum* (Hemiptera: Aphididae) on Spitsbergen? *BMC Ecol* 11:25. doi:10.1186/1472-6785-11-25
- Bayartogtokh B, Schatz H, Ekrem T (2011) Distribution and diversity of the soil mites of Svalbard, with redescription of three known species (Acari: Oribatida). *Int J Acarol* 37:467–484. doi:10.1080/01647954.2010.525525
- Behan-Pelletier VM (1985) Ceratozetidae of the Western North American Arctic. *Can Entomol* 117:1287–1366. doi:10.4039/Ent1171287-11
- Behan-Pelletier VM (1997) Oribatid mites (Acari: Oribatida) of the Yukon. In: Danks HV, Downes JA (eds) *Insects of the Yukon*. Biological Survey of Canada (Terrestrial Arthropods). Ottawa, pp 115–149
- Behan-Pelletier VM, Schatz H (2008) Global diversity of oribatids (Oribatida: Acari: Arachnida). *Hydrobiologia* 595:323–328. doi:10.1007/s10750-007-9027-z
- Coulson SJ (2009) Association of the soil mite *Diapterobates notatus* (Thorell, 1871) (Acari, Oribatidae) with *Cynomys mortuorum* (Linnaeus, 1761) (Calliphoridae, Calliphorinae): implications for the dispersal of oribatid mites. *Int J Acarol* 35:175–177
- Coulson SJ, Hodkinson ID, Strathdee AT, Bale JS, Block W, Worland MR, Webb NR (1993) Simulated climate change: the interaction between vegetation type and microhabitat temperatures at Ny Ålesund, Svalbard. *Polar Biol* 13:67–70. doi:10.1007/BF00236585
- Coulson SJ, Hodkinson ID, Webb NR (2003) Microscale distribution patterns in High Arctic soil microarthropod communities: the influence of plant species within the vegetation mosaic. *Ecography* 26:801–809. doi:10.1111/j.0906-7590.2003.03646.x
- Coulson SJ, Convey P, Aakra K, Aarvik L, Ávila-Jiménez ML, Babenko A, Biersma EM, Boström S, Brittain JE, Carlsson AM, Christoffersen K, De Smet WH, Ekrem T, Fjellberg A, Füreder L, Gustafsson D, Gwiazdowicz DJ, Hansen LO, Holmstrup M, Hullé M, Kaczmarek Ł, Kolicka M, Kuklin V, Lakka HK, Lebedeva N, Makarova O, Maraldo K, Melekhina E, Ødegaard F, Pilskog HE, Simon JC, Sohlenius B, Solhøy T, Sjøli G, Stur E, Tanasevitch A, Taskaeva A, Velle G, Zawierucha K, Zmudczyńska-Skarbek K (2014) The terrestrial and freshwater invertebrate biodiversity of the archipelagoes of the Barents Sea; Svalbard, Franz Josef Land and Novaya Zemlya. *Soil Biol Biochem* 68:440–470. doi:10.1016/j.soilbio.2013.10.006

- Coulson SJ, Fjellberg A, Melekhina EN, Taskaeva AA, Lebedeva NV, Belkina O, Seniczak S, Seniczak A, Gwiazdowicz DJ (2015) Microarthropod communities of disturbed or imported soils in the High Arctic; the abandoned coal mining town of Pyramiden, Svalbard. *Biodivers Conserv* 24:1671–1690. doi:10.1007/s10531-015-0885-9
- Ermilov SG, Martens J, Tolstikov AV (2013) New species of oribatid mites of the genera *Lepidozetes* and *Scutozetes* (Acari, Oribatida, Tegoribatidae) from Nepal. *Zookeys* 339:55–65. doi:10.3897/zookeys.339.6199
- Gwiazdowicz DJ, Coulson SJ (2011) High Arctic gamasid mites (Acari, Mesostigmata); community composition on Spitsbergen, Svalbard. *Polar Res* 30:1–7. doi:10.3402/polar.v30i0.8311
- Haarlov N (1967) Arthropoda (Acarina, Diptera) from subfossil layers in West Greenland. *Medd Grön* 184:1–17
- Johansen BE, Karlsen SR, Tømmervik H (2012) Vegetation mapping of Svalbard utilising Landsat TM/ETM + data. *Polar Rec* 48:47–63. doi:10.1017/S003224741100064747
- Jongman RHG, ter Braak CJF, van Tongeren DFR (1987) Data analysis in community and landscape ecology. Pudoc, Wageningen
- Jónsdóttir IS (2005) Terrestrial ecosystems on Svalbard: heterogeneity, complexity and fragility from an Arctic island perspective. *P R Irish Acad* 105:155–165
- Karg W (1993) Acari (Acarina), Milben Parasitiformes (Anactinochaeta) Cohors Gamasina Leach. *Raubmilben. Die Tierwelt Deutschlands* 59:1–523
- Krivolutsky DA, Lebedeva NV (2004) Oribatid mites (Oribatei, Acariformes) in bird feathers: nonpasserines. *Acta Zool Lith* 14:26–47
- Piernik A (2008) Numerical methods in ecology. Wyd Nauk UMK. Toruń (in Polish)
- Ruf A, Beck L (2005) The use of predatory soil mites in ecological soil classification and assessment concepts, with perspectives for oribatid mites. *Ecotox Environ Safe* 62:290–299
- Schuster R (1956) *Ergänzender Beitrag zur steirischen Bodenmilbenfauna (Oribatei)*. Mitt naturwiss Ver Steiermark 86:96–101
- Seniczak S (1974) Ecological characteristic of chosen arboreal oribatid mites (Acarina, Oribatei) in two young kind of forest. *Pr Kom Nauk Roln I Kom Nauk Leśn PTPN Poznań* 37:183–198 (in Polish)
- Seniczak S (1978) Juvenile stages of oribatid mites (Acari, Oribatei) as an essential part of communities of these mites transforming the soil organic matter. *Rozprawy UMK, Toruń*, pp 1–171 (in Polish)
- Seniczak S (1980) The morphology of juvenile stages of moss mites of the subfamily Trichoribatinae (Acari: Oribatei), II. *Ann Zool* 35:221–231
- Seniczak S (1993) The morphology of juvenile stages of moss mites of the subfamily Trichoribatinae (Acari, Oribatida). *V Zool Anz* 230:153–168
- Seniczak S, Plichta W (1978) Structural dependence of moss mites populations (Acari: Oribatei) on patchiness of vegetation in moss-lichen tundra at the north coast of Hornsund, West Spitsbergen. *Pedobiologia* 18:145–152
- Seniczak S, Stefaniak O (1978) The microflora of the alimentary canal of *Oppia nitens* (Acarina, Oribatei). *Pedobiologia* 18:110–119
- Seniczak A, Seniczak S, Szczukowska H (2013) External morphology of Oppiidae (Acari: Oribatida) in the light of the ontogeny of three species and genera. *Int J Acarol* 40:52–80. doi:10.1080/01647954.2013.872185
- Seniczak S, Seniczak A, Gwiazdowicz DJ, Coulson SJ (2014a) Community structure of oribatid and gamasid mites (Acari) in moss-grass tundra in Svalbard (Spitsbergen, Norway). *Arct Antarct Alp Res* 46:591–599. doi:10.1657/1938-4246-46.3.591
- Seniczak S, Seniczak A, Kaczmarek S, Słowikowska M (2014b) Variability of external morphology of *Eueremaus* Mihelčič, 1963 (Acari, Oribatida, Eremaeidae) in the light of ontogeny of three species. *Int J Acarol* 40:81–108. doi:10.1080/01647954.2013.878393
- Seniczak S, Seniczak A, Coulson SJ (2015a) Morphology, distribution and certain population parameters of the Arctic mite species, *Oribatella arctica* (Acari: Oribatida: Oribatellidae). *Int J Acarol* 41:395–414. doi:10.1080/01647954.2015.1048727
- Seniczak S, Seniczak A, Coulson SJ (2015b) Morphology, distribution and biology of *Mycobates sarekensis* (Acari: Oribatida: Punctoribatidae). *Int J Acarol* 41:663–675. doi:10.1080/01647954.2015.1102968
- Seniczak S, Seniczak A, Coulson SJ (2016) Morphological ontogeny, distribution, and descriptive population parameters of *Hermannia reticulata* (Acari: Oribatida: Hermannidae), with comments on Crotonioidea. *Int J Acarol*. doi:10.1080/01647954.2016.1229812
- Stanisz A (2006) Easy course of statistic using Statistica PL and medicine examples. 1. Basic statistic. StatSoft Polska, Kraków (in Polish)
- Stefaniak O, Seniczak S (1976) The microflora of the alimentary canal of *Achipteria coleoptrata* (Acarina, Oribatei). *Pedobiologia* 16:185–194
- Stefaniak O, Seniczak S (1981) The effect of fungal diet on the development of *Oppia nitens* (Acar, Oribatei) and on the microflora of its alimentary tract. *Pedobiologia* 21:202–210
- Subías LS (2004) Listado sistemático, sinonímico y biogeográfico de los Ácaros Oribátidos (Acariformes, Oribatida) del mundo (1758–2002). *Graellsia* 60:3–305. doi:10.3989/graeellsia.2004.v60.iextra.218
- Thor S (1930) Beiträge zur Kenntnis der Invertebratenfauna von Svalbard. *Skr Svalb og Ishavet Oslo* 27:1–156