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Free-living mites (Acari) of the Shokalsky Island, off the northern Gyda Peninsula, Kara Sea, High Arctic

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Original research

ABSTRACT

The fauna of free-living mites of the Shokalsky Island, off the Gyda Peninsula, Kara Sea, totals at least 81 species belonging to 36 families. The suborder Prostigmata includes 38 species, *vs* 18 of Oribatida, 17 of Mesostigmata, 5 of Endeostigmata, and 3 of Astigmata. The most species-rich families are Ascidae (9 species), Eupodidae (7), Tarsonemidae (4), and Ceratozetidae (4). However, most genera (77%) are represented by one species only. Among mites identified to the species level, the Holarctic species prevail which show mainly arctic, arctic-montane, and arctic-boreal distribution patterns. The abundance of soil mites varies with 10160–299440 ind./m^2, being the maximum in the soil of both dryad tundra and in a polar fox den on a hillock. Prostigmata are the most diverse mite group throughout, but the dominant species include either prostigmatic or endeostigmatic, or oribatid mites. The rare species, *Charadracarus hurdi* Newell, 1960, hitherto known only from Point Barrow, Alaska, has been found for the first time since its original description. Some features of the acarofauna of the Shokalsky Island are transitional between those characteristics of the polar desert and tundra zones.

Keywords abundance; assemblage structure; distribution range; local fauna; species diversity; polar desert; tundra

Introduction

The soil mite fauna of arctic landscapes is quite species-rich and diverse, including representatives of all main acarine orders (Behan 1978; Danks 1981; Hodkinson *et al.*, 2013).

In terms of species diversity, local polar acarofaunas are comparable to those of insects (Chernov 2004; Coulson *et al.* 2014; Böcher *et al.* 2015; Seniczak *et al.* 2020b), even exceeding them in the northernmost polar desert regions (Makarova 2002a, 2023).

However, the knowledge of free-living mites varies extremely throughout the Arctic depending on either acarine suborder or geographical region. There are only a few areas, such as Greenland, the Svalbard Archipelago, Severnaya Zemlya Archipelago, Franz Josef Land Archipelago, as well as several territories of the Canadian Arctic and Alaska where the mite faunas have been investigated relatively comprehensive (Behan 1978, 1997; Danks 1981; Makarova 2002a, 2015a, 2023; Coulson *et al.* 2014; Seniszak *et al.* 2020b). In the Russian Arctic, oribatid and mesostigmatan checklists have been published for many Eastern European (including Novaya Zemlya and Vaygach Island) and Siberian localities (Grishina 1985; Davydova and Nikolsky 1986; Grishina *et al.* 1998; Makarova 1999, 2002a, b, 2012, 2013; Krivolutsky *et al.* 2003; Malkova 2009; Zenkova *et al.* 2011; Melekhina 2011, 2020; Melekhina and Zinovyeva 2012; Marchenko 2012; Makarova and Rosenfeld 2014; Ryabinin *et al.* 2015; Melekhina *et al.* 2019; Makarova and Bizin 2020, etc.). At the same time, there are virtually no regional studies dealing with other acarine suborders, primarily Prostigmata

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and Endeostigmata. Both are often the most abundant (Prostigmata more diverse as well) taxa in the acarocenoses of tundra and polar deserts (McAlpine 1965; Douce and Crossley 1977; MacLean *et al.* 1978; Hodkinson *et al.* 2013; Makarova 2002a, 2015a, 2023).

Over the vast Siberian Far North, communities of soil mites still remain virtually unexplored (Makarova *et al.* 2015). Several publications have contributed to the knowledge of oribatid and mesostigmatic mite assemblages in some areas of Taymyr (Ananjieva *et al.* 1973, 1979; Bogdanov 1975; Davydova *et al.* 1980; Grishina and Mordkovich 1996; Grishina *et al.* 1998) or Kolyma River delta (MacLean *et al.* 1978, Tolstikov *et al.* 1996). Only a few comprehensive studies on the free-living mites of Severnaya Zemlya and Franz Josef Land include detailed ecological information on all mite taxa (Makarova 1999, 2002a, b, 2023).

In August 2016, we carried out a two-week long field survey on the small Shokalsky Island in the southern part of Kara Sea. This island is of interest because (1) it lies very closely to the Gyda Peninsula, adjoining from the north, and its fauna could be considered as the northernmost along the whole West Siberian transect. (2) The island is located within the realm of the arctic tundra subzone (Alexandrova 1980), a transitional belt between the tundra and the polar desert zone. So, the analysis of the Shokalsky Island mite fauna could be useful for delimitation of these two natural zones, since such a subdivision of High Arctic is still in debate (see references in Makarova 2002b; Ermokhina *et al.* 2023). (3) Finally, landscapes of Shokalsky Island and the entire Gyda Peninsula are similar to those of the neighboring Yamal Peninsula, while being much less modified by property development. In this regard, an inventory of the local biodiversity of an environmentally intact area in the West Siberian arctic tundra could be of use for environmental monitoring programs.

Material and methods

Study area

The Shokalsky Island is located in the Kara Sea (72°58′N 74°27′E), east of the Gulf of Ob mouth (Figure 1), 5 km north of the Gyda Peninsula, being separated from the latter by the narrow (5–9 km) and shallow (0.5–6 m) Gydan Strait with pronounced tides, about 0.8 m (Kalyakin *et al.* 1999). The island is small, 30 km × 20 km (428 km^2), and rather flat with only low hills (up to 10 m above sea level; Figure 2). Its surface is mainly composed of sands and almost entirely covered with vegetation (Figure 2; Kalyakin *et al.* 1999). The seasonally thawing layer of the soil varies between 0.9–1.2 m depth.

Due to oceanic impact, the Shokalsky Island has a harsh humid Arctic climate. The frost-free period does not exceed two months per year. During the last decade, the mean annual temperature at the nearest observation point, the M.V. Popov Weather Station (Bely Island, northern Yamal Peninsula), was –8.7 °C, the mean temperature of July amounting to 5.8 °C, and that of January to about –20 °C. Annual precipitation is not more than 300 mm, with about 50% as rains. Relative air humidity is high, almost 90% on average (Weather Archive of M.V. Popov Weather Station 2023).

The dominant soil types are Reductaquic Turbic Cryosols and Histic Reductaquic Turbic Cryosols (Kalyakin *et al.* 1999; IUSS Working Group WRB 2015). Like the northern part of Gyda Peninsula, the Shokalsky Island is located within Yamal-Gyda Subprovince of the European-West Siberian Province of the Arctic Floristic Region (Yurtsev *et al.* 1978).

Sampling

The material was collected on 5–17 August 2016 in the west of the island (Figure 1). Soil samples were cut out using a knife and a plastic frame (5 x 5 cm) in the most typical habitats (Table 1). All cores included the aboveground parts of plants, litter (or turf) and topsoil fragments down to 5 cm. A total of 53 samples were processed.

Figure 1 Map of the Kara Sea region with position of the study area on Shokalsky Island (marked by asterisk).

Four sets of samples were taken on the coastal floodplain in the delta of Pereprava River, the largest river of the island (Table 1). The vegetation cover of this area is the characteristic high-arctic salt marsh influenced by marine tidal inundation. The first series of samples was taken in the zone of low marsh, dominated by the halophilous grasses *Puccinellia phryganodes* (Trin.) Scribn. & Merr. and *Carex subspathacea* Wormsk. ex Hornem. The second series concerned the zone of high marsh with prevalence of *Poa* sp. and *Deschampsia borealis* (Trautv.) Roshev. The third series was a molting place of brants, *Branta bernicla* (Linnaeus, 1758), with *Festuca* sp. and *Phippsia algida* (Soland.) R. Br. In addition, samples of geese

Figure 2 General view of tundra landscape on the Shokalsky Island, Kara Sea (August 2016).

excrements (5 samples, each 125 cm³ in volume) were collected on the molting place (Table 1).

The other habitats studied were located in the inner part of the island. Plots of a cotton-grass bog, of sedge-mossy hummocky tundra, and of dryad tundra, as well as the meadow covering the polar fox den were explored (Table 1).

The samples taken on salt marshes were more numerous than others (Table 1) because of our special interest in the formation of coastal acarocenoses (Bizin *et al.* 2021).

Besides soil samples, mites were collected using pitfall trapping, hand sorting of sod patches and moss cushions, and through mowing herbs and dwarf-shrubs with an insect net (Makarov *et al.* 2018; Nekhaeva 2018).

Mite extraction and identification

The samples were kept in the cold, each sample being wrapped in paper and placed inside a plastic bag for no more than 5–7 days. Microarthropods were extracted into 96% alcohol from the cores in the lab (in Moscow) using Tullgren funnels by drying the samples until their complete desiccation (8–10 days) with neither additional heating nor light. Mites were slide-mounted in Hoyer's medium and identified. The material is currently kept in the collection of the Laboratory of Synecology, Severtsov Institute of Ecology and Evolution RAS, Moscow.

Table 1 Characteristics of the studied habitats, Shokalsky Island, Kara Sea (August 2016). [1] – five soil samples and five samples of excrements.

Habitat	Code	Coordinates	Landscape position	Dominant plant species	Soil humidity, %	Vegetation cover, %	Number of samples	Number of trap-days
				Coastal area				
Low marsh (*Puccinellia - Carex* marsh)	LM	72°55'16.0"N 74°20'23.3"E	Seaside waterlogged coastal plain in delta of the Pereprava River	*Puccinellia phryganodes*, *Carex subspathacea*, *Phippsia concinna*, *Stellaria humifusa*	43.8	50–95	20	24
High marsh (*Poa* marsh)	HM			*Poa* sp., *Deschampsia borealis*, *Dicranum* sp.	51.1	75–100	8	133
Geese molting place (soil and goose excrements)	MP, GE	72°55'17.0"N 74°20'18.5"E	Flat bank of the Pereprava River's arm	*Festuca* sp., *Phippsia algida*, *Dicranum* sp.	36.4	50–75	5+5[1]	–
				Inner area				
Cotton-grass bog	B	72°56'03.8"N 74°18'38.1"E	Depression between hills	*Arctophila fulva*, *Carex concolor*, *Eriophorum scheuchzeri*, *Poa* sp., *Rhizomnium* sp., *Dicranum* sp., *Sphagnum* sp., *Aulacomnium turgidum*	48.4	75–95	5	160
Sedge-mossy hummocky tundra (zonal community)	SMT	72°56'07.1"N 74°18'34.0"E	Watershed plain	*Carex arctisibirica*, *Poa alpigena*, *Luzula confusa*, *Hylocomium splendens*, *Aulacomnium turgidum*, *Dicranum* sp., *Polytrichum* sp., *Cladonia* spp., *Peltigera rufescens*	29.2	70–90	5	176
Polar fox den	PFD	72°56'38.2"N 74°26'36.5"E	Steep eroded bank of the Pereprava River, small sandy hill	*Salix nummularia*, *Poa alpigena*, *Alopecurus alpinus*, *Festuca* sp., *Bryocaulon divergens*, *Dicranum* sp., *Polytrichum* sp., *Stereocaulon* sp., *Racomitrium lanuginosum*, *Sphaerophorus globosus*, *Parmelia sulcata*, *Parmelia* sp., *Cetrariella delisei*, *Cladonia* sp.	3.5	45	5	97
Dryad tundra	DT	72°56'36.7"N 74°26'32.6"E	Well-drained upper part of the hill slope	*Salix nummularia*, *Dryas punctata*, *Vaccinium vitis-idea*, *Alopecurus alpinus*, *Aulocomnium turgidum*, *Hylocomium splendens*, *Racomitrium lanuginosum*, *Dicranum* sp., *Polytrichum* sp., *Cetraria islandica*, *Flavocetraria cucullata*, *Sphaerophorus globosus*, *Cladonia* spp., *Ochrolechia* sp., *Parmelia* sp., *Pertusaria* sp.	22.6	70–80	5	60

The following publications were mainly used for taxonomic identifications: Chant and Hansell (1971); Ghilarov *et al.* (1975, 1977); Balogh and Mahunka (1983); Behan-Pelletier (1985); Karg (1993); Makarova (2000a, 2015b, c); Chant and McMurtry (2003); Weigmann (2006); Khaustov (2008); Bayartogtokh (2010); Lindquist and Makarova (2011); Makarova and Behan-Pelletier (2015). Immature Oppiidae (impossible to identify) were collected in the dryad tundra only (142 juvenile specimens *vs* 350 adults). They were attributed to species proportionately to the adult ratio and combined with adults in each sample.

Data analysis

The mite density was calculated per m². Quantitative data were previously square-root-transformed prior to analysis.

To determine the efficiency of sampling efforts and to understand if further sampling was likely to reveal more taxa, we used cumulative curve and general sample rarefaction curve.

To examine the assemblage structure, we used the non-metric multidimensional scaling ordination (NMDS) based on Bray-Curtis dissimilarity of species abundance data in separate samples, as well as the principal coordinates analysis (PCoA) of qualitative data based on Jaccard index.

The following common diversity indicators were used: number of mite species per sample and per habitat, the Shannon index, and the Berger-Parker index (Magurran 1988). We tested the differences between total mite density and diversity indicators in various habitats using the Kruskal-Wallis test with pairwise comparisons through the Dunn's test via "dunn.test" package in R software (Dinno 2017; R Core Team 2021).

Rarefaction curve and both ordinations (NMDS, PCoA) were carried out in PAST software vers. 4.02 (Hammer *et al.* 2001).

Results

A total of 13,343 specimens were examined, including immature stages. In soil samples, we identified 77 species belonging to all major orders of mites. Additionally, four species, namely *Melichares parvanalis* (Thor, 1930) (Mesostigmata), *Neomolgus* sp., *Eupodes* cf. *voxencollinus* Thor, 1934, and *Penthaleus* cf. *major* (Dugès, 1834) (Prostigmata), were found in pitfall material. In total, 81 free-living mite species representing 36 families are presently known to occur in the Shokalsky Island (Table 2).

The suborder Prostigmata was especially diverse (43–68% of the species list in a separate habitat; Figure 3A), being represented by 38 species (31 genera, 15 families). *Cyta latirostris* (Hermann, 1804), *Claveupodes delicatus* Strandtmann & Prasse, 1977, *Eupodes* cf. *voxencollinus*, and *Poecilophysis* cf. *saxonica* (Willmann, 1934) were recorded from the Russian Arctic at first time. The species, *Charadracarus hurdi* Newell, 1960 (Johnstonianidae), identified by J. Mąkol (Wroclaw University of Environmental and Life Sciences), was found to occur in Russia at first time.

The suborder Oribatida amounted to 18 species (13 genera, 9 families), Mesostigmata included 17 species (13 genera, 7 families), while Endeostigmata (5 species, 3 genera, 3 families) and Astigmata (3 species, 2 genera, 2 families) were less diverse. The most species-rich families were Ascidae (9 species), Eupodidae (7), Tarsonemidae (4), and Ceratozetidae (4) comprising about a third of the total checklist. Most genera (77%) were represented by one species only, whereas *Arctoseius*, *Zercon* (Mesostigmata), *Neoprotereunetes* (Prostigmata), *Alicorhagia* (Endeostigmata), *Liochthonius,* and *Moritzoppia* (Oribatida) contained from 3 to 9 species each (Table 2).

Of the 58 securely identified species (Table 2), at least seven are distributed worldwide (cosmopolitan or subcosmopolitan), and 19 are polyzonal. At the same time, 24 identified species (41%) showed circumpolar or similar distribution patterns (Holarctic arctic or Holarctic

Table 2 Distribution and abundance (ind./m^2) of free-living mite species in the studied habitats (Shokalsky Island, Kara Sea; August 2016). Species found only in pitfall traps are marked by a plus (+). [1] – this species was previously reported as *Centrotrombidium* sp. (Danks 1981; Bizin *et al.* 2021). Distribution patterns: Ln, longitudinal characteristics – S, Siberian; P, Palaearctic; WP, West Palaearctic; EP, East Palaearctic; H, Holarctic; Or, Oriental; C, cosmopolitan; sC, subcosmopolitan; Lt, latitudinal characteristics – A, arctic; AB, arctic-boreal; AM, arctic-montane; ABM, arctic-boreal-montane; Pz, polyzonal; n.d. – no data.

Taxon	Distribution pattern		Coastal marsh			Cotton-grass bog	Sedge-mossy hummocky tundra	Polar fox den	Dryad tundra
	Ln	Lt	Low marsh	Geese molting place (soil; goose excrements)	High marsh				
PARASITIFORMES									
MESOSTIGMATA									
Uropodidae									
Dinychus micropunctatus Evans, 1955	H	A	–	–	–	80	5280	–	240
Zerconidae									
Zercon cf. *bajkalensis* Blaszak, 1979	S	ABM	–	–	–	–	–	15600	640
Z. forsslundi Sellnick, 1956	WP	AB	–	–	–	2960	1280	–	–
Z. michaeli Halašková, 1977	H	AM	–	–	–	–	–	640	640
Halolaelapidae									
Halolaelaps cf. *gerlachi* Hirschmann, 1966	H	A	20	–	–	–	–	–	–
Ascidae									
Arctoseius babenkoi Makarova, 2000	H	A	–	–	–	–	–	480	–
A. haarlovi Lindquist & Makarova, 2011	H	A	–	–	–	–	–	160	–
A. idiodactylus Lindquist, 1961	H	AM	60	–	–	–	–	–	–
A. minor Lindquist, 1961	H	A	–	–	–	–	–	80	–
A. multidentatus Evans, 1955	H	A	20	720; –	3250	–	240	–	–
A. ornatus Lindquist, 1961	H	ABM	660	1360; –	50	2080	–	–	–
A. productus Makarova, 2000	S	A	–	–	–	–	160	80	–
A. semiscissus (Berlese, 1892)	C	Pz	–	–	–	–	–	160	–
A. weberi Evans, 1955	H	ABM	–	–	–	–	560	–	80
Ologamasidae									
Acugamasus montanus (Willmann, 1936)	P	Pz	–	–	–	–	–	160	6960
Melicharidae									
Melichares parvanalis (Thor, 1930)	H	AM	–	–	–	–	–	+	–
Phytoseiidae									
Neoseiulus cf. *tobon* (Chant & Hansell, 1971)	H	A	–	–	–	–	–	+	320
ACARIFORMES									
PROSTIGMATA									
Bdellidae									
Bdella muscorum Ewing, 1909	C	Pz	20	–	–	–	–	–	160
Cyta latirostris (Hermann, 1804)	C	Pz	–	–	–	–	320	+	80
Neomolgus sp.	n.d.		–	–	+	–	+	+	+
Eupodidae									
Claveupodes delicatus Strandtmann & Prasse, 1977	P	Pz	–	–	–	–	–	80	–
Claveupodes sp.	n.d.		–	–	–	–	–	–	2400
Cocceupodes breweri Strandtmann, 1971	H	Pz	–	–	3000	1200	1680	+	80
C. cf. *mollicellus* (C.L. Koch, 1838)	H	Pz	–	160; 160	400	1920	3600	–	80
Eupodes cf. *voxencollinus* Thor, 1934	H	Pz	–	–	–	–	–	+	–
Neoprotereunetes cf. *boerneri* (Thor, 1934)	H	A	80	–	4800	2800	3360	720	1520
Neoprotereunetes sp. 1	n.d.		20	–	–	–	400	–	–
Neoprotereunetes sp. 2	n.d.		–	–	–	–	–	–	–
Penthaleidae									
Penthaleus cf. *major* (Dugès, 1834)	C	Pz	–	–	+	+	–	–	–
Penthaleus sp.	n.d.		–	80; –	–	–	–	+	–
Penthalodidae									
Penthalodes ovalis (Dugès, 1834)	H	Pz	–	–	+	80	–	+	–
Rhagidiidae									
Coccorhagidia pittardi Strandtmann, 1971	H	AM	–	–	–	–	240	–	400
Evadorhagidia cf. *quinqueseta* Zacharda, 1980	H	A	–	–	100	80	–	–	–
Poecilophysis cf. *saxonica* (Willmann, 1934)	H	AM	–	–	–	–	560	–	80
Tydeidae									
Lorrya aff. *obstinata* (Livshitz, 1973)	n.d.		–	–	–	–	2640	27600	2400
Tydeus sp.	n.d.		–	–; 160	–	80	–	960	8560
Ereynetidae									
Ereynetes sp.	n.d.		–	–	–	–	560	–	–
Iolinidae									
Coccotydeolus sp.	n.d.		–	–	–	–	–	400	5120
Paratriophtydeus sp.	n.d.		+	–	–	240	–	29040	102880
Tydaeolus sp.	n.d.		–	–	–	–	–	–	2800
Eriophyidae									
Aceria sp.	n.d.		–	–	50	–	–	–	–
Aculodes sp.	n.d.		540	–	850	–	–	–	–
Eriophyidae gen. sp.	n.d.		–	1600; –	–	–	–	–	–

Table 2 Continued.

Taxon	Distribution pattern		Coastal marsh			Cotton-grass bog	Sedge-mossy hummocky tundra	Polar fox den	Dryad tundra
	Ln	Lt	Low marsh	Geese molting place (soil; goose excrements)	High marsh				
Johnstonianidae									
Charadracarus hurdi Newell, 1960[1]	n.d.		–	–	7350	240	–	–	–
Stigmaeidae									
Cheylostigmaeus longisetosus Willmann, 1951	P	AB	820	1120; 160	4700	8480	+	–	–
Eustigmaeus cf. *tjumeniensis* Khaustov & Tolstikov, 2014	P	AB	380	10720; 800	3200	–	–	–	–
Stigmaeus parmatus Summers, 1962	H	A	–	–	1600	880	–	–	–
Tetranychidae									
Bryobia praetiosa C.L. Koch, 1836	C	Pz	–	–	+	–	80	560	+
Neopygmephoridae									
Bakerdania cf. *arctobia* Khaustov & Makarova, 2005	P	A	–	–	–	–	–	80	–
Kerdabania sp.	n.d.		–	–	–	–	+	28560	+
Scutacaridae									
Scutacarus montanus (Paoli, 1911)	P	Pz	20	–	–	–	–	–	–
S. offaliensis Momen & Curry, 1987	P	Pz	1260	800; 80	–	–	–	–	–
Tarsonemidae									
Steneotarsonemus arcticus Lindquist, 1986	H	A	2060	–	22550	18000	3120	81440	–
Steneotarsonemus sp.	n.d.		–	–	–	–	–	–	80
Tarsonemus aff. *figuratus* Kaliszewski, 1993	n.d.		–	–	–	–	–	–	4880
Tarsonemus sp.	n.d.		–	–	–	80	–	–	–
ENDEOSTIGMATA									
Nanorchestidae									
Nanorchestes cf. *gilli* Strandtmann, 1982	H	A	–	–; 80	550	400	45280	400	28400
Terpnacaridae									
Terpnacarus bouvieri Grandjean, 1939	H	Pz	–	–	–	–	–	–	720
Alicorhagiidae									
Alicorhagia clavipilus (Thor, 1931)	H	AB	–	–	–	–	1200	–	–
A. fragilis Berlese, 1910	H	Pz	–	–	–	–	–	2640	28240
Alicorhagia sp.	H	A	–	–	–	–	400	–	80
ORIBATIDA									
Brachychthoniidae									
Liochthonius brevis (Michael, 1888)	H	Pz	–	–	–	–	400	–	2160
L. sellnicki (Thor, 1930)	H, Or	PZ	20	3600; –	61750	1200	7440	480	–
Liochthonius sp.	n.d.		–	–	–	–	–	80	800
Cosmochthoniidae									
Cosmochthonius lanatus (Michael, 1885)	C	Pz	40	–	–	–	–	–	–
Crotoniidae									
Camisia dictyna Colloff, 1993	H	AM	+	–; 80	–	–	80	–	320
Hermanniidae									
Hermannia scabra (L. Koch, 1879)	H	A	+	80; –	–	240	4000	160	31680
Peloppiidae									
Ceratoppia bipilis (Hermann, 1804)	H	Pz	–	–	–	80	6160	–	–
C. sphaerica (L. Koch, 1879)	sC	AB	–	–	–	–	3040	+	80
Pyroppia arctica Krivolutsky, 1974	EP	AB	–	–	–	160	160	–	–
Oppiidae									
Moritzoppia clavigera (Hammer, 1952)	H	AB	–	–	–	–	–	–	19920
M. neerlandica (Oudemans, 1900)	H	Pz	–	–	–	3760	–	–	–
M. similis (Gordeeva & Grishina, 1991)	H	AB	–	–	–	–	80	–	19520
Suctobelbidae									
Suctobelbella sp.	n.d.		+	80; –	–	–	–	–	–
Ameronothridae									
Ameronothrus nigrofemoratus (L. Koch, 1879)	H	AB	9460	4480; 4320	150	–	–	–	–
Ceratozetidae									
Ceratozetes spitsbergensis Thor, 1934	H	AM	–	–	–	–	960	560	19760
Diapterobates notatus (Thorell, 1871)	H	AB	–	–; 80	–	+	800	21360	1920
Melanozetes interruptus Willmann, 1953	H	AM	–	–	–	–	–	–	5440
Svalbardia lucens (L. Koch, 1879)	H	AM	2060	2160; 4240	28050	15440	–	400	+
ASTIGMATA									
Acaridae									
Schwiebea cf. *danielopoli* Fain, 1982	n.d.		–	–	–	–	–	400	+
Schwiebea sp.	n.d.		–	–	50	–	–	–	–
Histiostomatidae									
Histiostoma sp.	n.d.		20	–	–	–	–	–	–
Total density, ind./m²			17560	26960; 10160	142450	60480	94080	213280	299440
Number of all mite individuals found in habitat			347	380;127	2849	756	1176	2666	3743

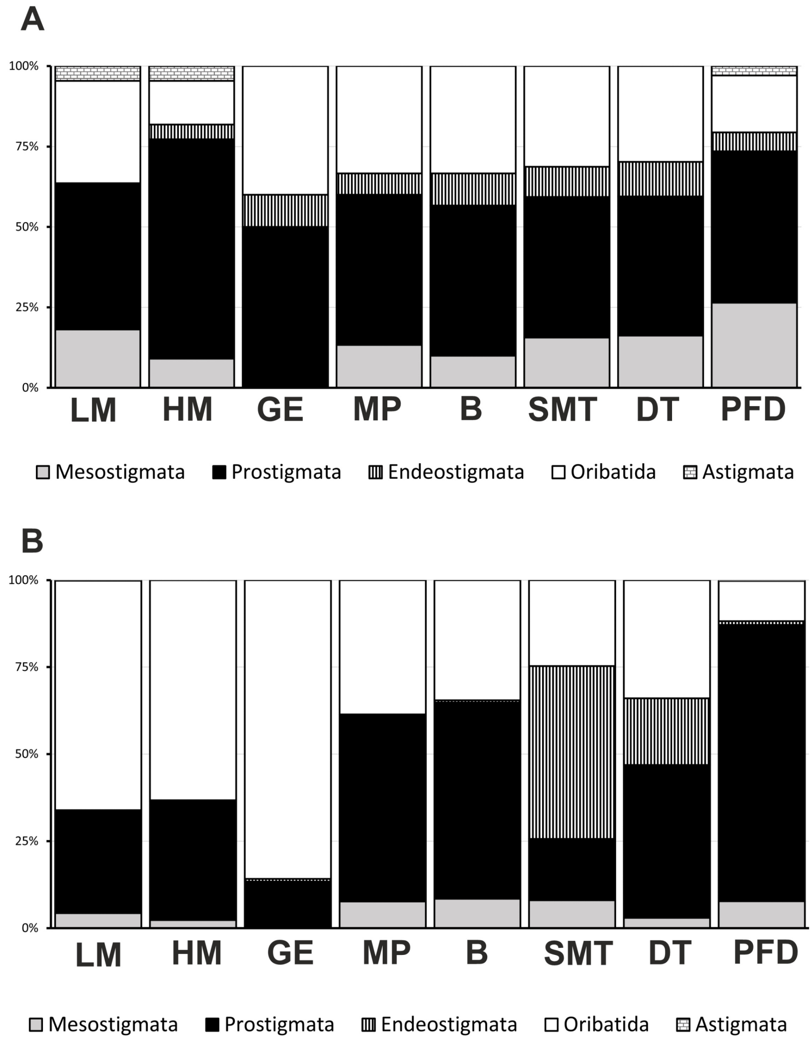

Figure 3 Proportions of main groups of free-living mites in studied habitats; A – percentage of species; B – percentage of individuals (Shokalsky Island, Kara Sea; August 2016). Acronyms as in Table 1.

arctic-montane). The proportion of these cryobiontic species varied between suborders from 30% (Prostigmata) to 58% (Mesostigmata).

The species, *Liochthonius sellnicki* (Thor, 1930), *Hermannia scabra* (L. Koch, 1879), *Nanorchestes* cf. *gilli* Strandtmann, 1982, *Svalbardia lucens* (L. Koch, 1879), as well as *Cocceupodes* cf. *mollicellus* (C.L. Koch, 1838), *Eupodes* cf. *boerneri* (Thor, 1934), *Cheilostigmaeus longisetosus* Willmann, 1951 occurred in six of the eight studied habitats (Table 2). Two other species, *Steneotarsonemus arcticus* Lindquist, 1986 and *Paratriophtydeus* sp., were recorded in five and four habitats, respectively. At the same time, 28 species were found only in one biotope.

The NMDS plot showed that samples generally grouped into clusters in accordance with habitat attribution (Figure 4). Each separate habitat series of samples supported 10–37 species (mean = 24.1, Table 3), while the individual samples yielded 3–22 species (mean = 11.4) in different habitats. The cumulative curve (Figure 5A) grows regularly, where sets of samples from the coastal plain found their places, and shows a steeper trajectory in the right half, where data from the sedge-mossy tundra, the dryad tundra and the meadow of the polar fox den were

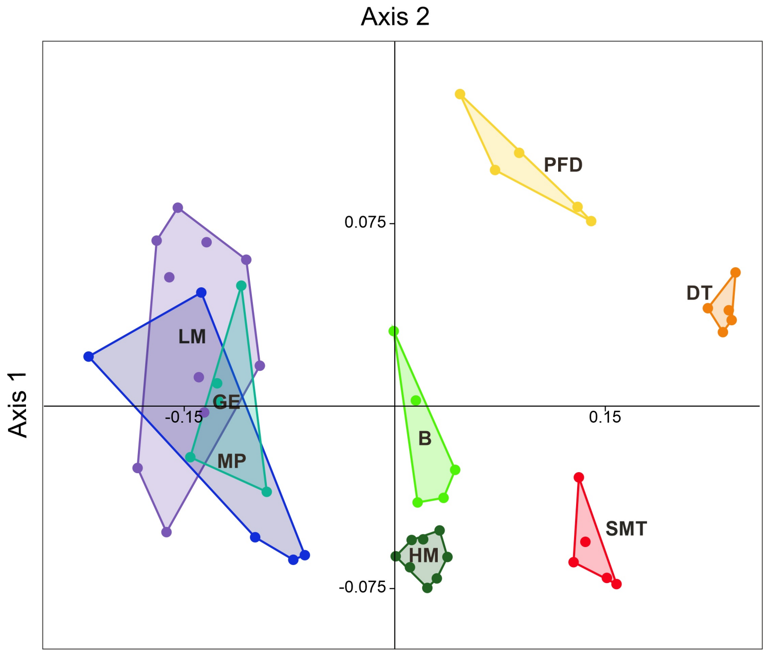

Figure 4 NMDS ordination (Bray-Curtis index) of the mite assemblages of studied habitats (Shokalsky Island, Kara Sea; August 2016). Acronyms as in Table 1.

accumulated. The overall sampling rarefaction curve failed to approach an asymptote (Figure 5B).

The total mite density of individual habitats varied significantly (χ^2 = 41.6; df = 7; p-value = 0.000), increasing along the hydrological gradient from low marsh and cotton-grass bog (10160–60480 ind./m²) to dryad tundra and polar fox den, reaching 213280–299440 ind./m² (Table 2).

In the material examined (including specimens collected by pitfalls and hand sorting), the most abundant species were found to be *Steneotarsonemus arcticus* (13% all individuals), *Paratriophtydeus* sp. (12%), *Liochthonius sellnicki* (10%), *Nanorchestes* cf. *gilli* (7%), *Svalbardia lucens* (7%), and *Hermannia scabra* (4%). Members of Prostigmata were dominant in a half of habitats (Table 2, Figure 3B). Only on salt marshes they were replaced by Oribatida.

The Shannon index of the assemblages varied from 0.7 (low marsh) to 2.2 (dryad tundra), the mean value being 1.3 (Table 3). The differences between all habitats were statistically significant (χ^2 = 38.0; df = 7; p-value = 0.000003). On the studied landscape profile, the index changed in accordance with species number (both increased with elevation).

The dominance structure estimated based on the Berger–Parker index (used as 1/D) changed

Table 3 Diversity and abundance parameters of free-living mite communities in the studied habitats (Shokalsky Island, Kara Sea; August 2016). The variables that did not differ significantly within a row are marked by the same letters.

Parameter	Low marsh	Geese molting place (soil)	Geese molting place (excrements)	High marsh	Cotton-grass bog	Sedge-mossy hummocky tundra	Polar fox den	Dryad tundra
Total number of species found	22	22	10	13	23	32	34	37
Mean number of species per sample	3.7±0.4^{a}	6.4±1$^{a, c}$	4.4±0.8$^{a, c}$	11.9±0.6$^{b, c}$	11.4±1$^{b, c}$	18.0±1^{b}	13.0±2.3$^{b, c}$	22.0±1.5^{b}
Mean number of individuals per sample	43.9±11.3^{a}	67.4±20.9$^{a, b, c}$	25.4±8.7^{a}	356.1±54.8$^{b, c}$	151.2±36.3^{b}	235.2±32.3^{b}	533.2±188.2$^{b, c}$	748.6±79.8^{b}
Shannon index	0.7±0.1^{a}	1.3±0.1$^{a, b}$	0.9±0.2^{a}	1.6±0.05^{b}	1.7±0.1^{b}	1.9±0.1$^{b, c, d}$	1.3±0.3$^{b, c}$	2.2±0.1$^{b, d}$
Berger-Parker index	1.8±0.1^{a}	2.2±0.5$^{a, b}$	1.6±0.2^{a}	2.3±0.2$^{a, b}$	2.3±0.2$^{a, b}$	2.3±0.4$^{a, b}$	2.8±0.9$^{a, b}$	3.1±0.4^{b}

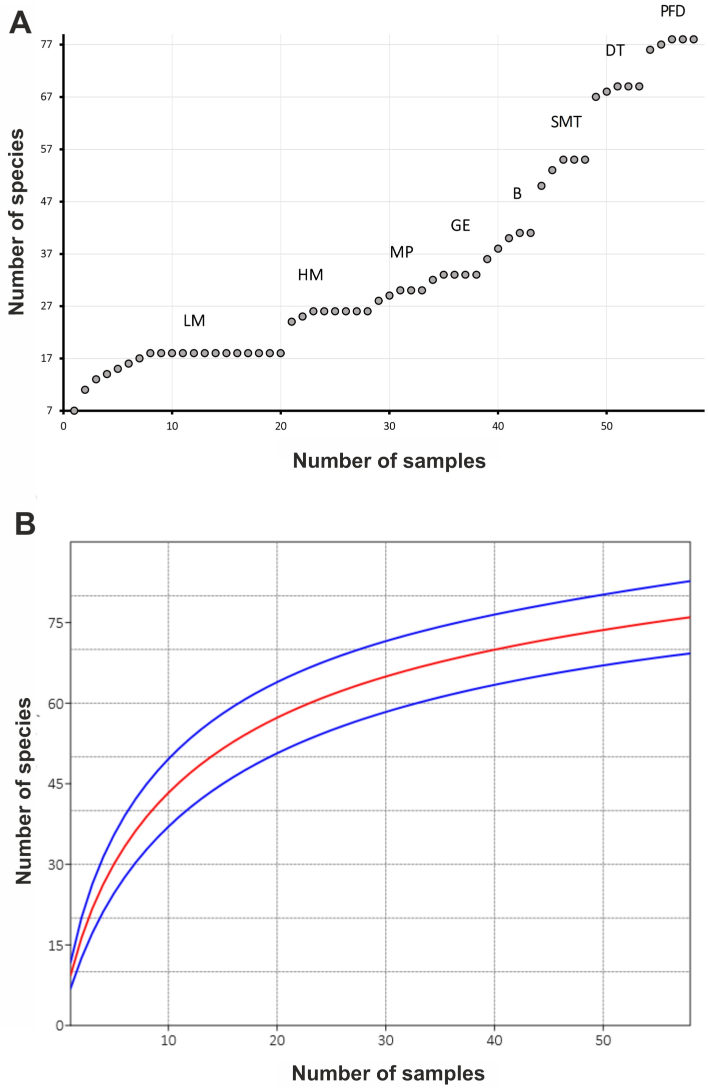

Figure 5 Cumulative curve (A) and general sample-based rarefaction curve (B), Shokalsky Island, Kara Sea; August 2016. Acronyms as in Table 1.

irregularly along the profile (Table 3). The highest values belonged to polar fox den (2.8) and dryad tundra (3.1), the lowest to low marsh (1.8) and geese molting place (for samples of excrements, 1.6). As a whole, the values of that index for all habitats were barely differed from one another (χ^2 = 14.4; df = 7; p-value = 0.04).

In general, mite diversity was higher in well-drained habitats (tundra sites, polar fox den). Species compositions clearly form three groups (Figure 6) encompassing the coastal, wet mossy, and well-drained habitats.

Discussion

Even though the above information on the mite communities of Shokalsky Island is based on relatively limited material collected in small areas, it is interesting to compare it to the polar desert acarocenoses of the Bolshevik Island (Severnaya Zemlya), and Franz Josef Land, the closest Arctic archipelagos where soil mites have been studied in detail (Makarova 1999, 2002a, b, 2023).

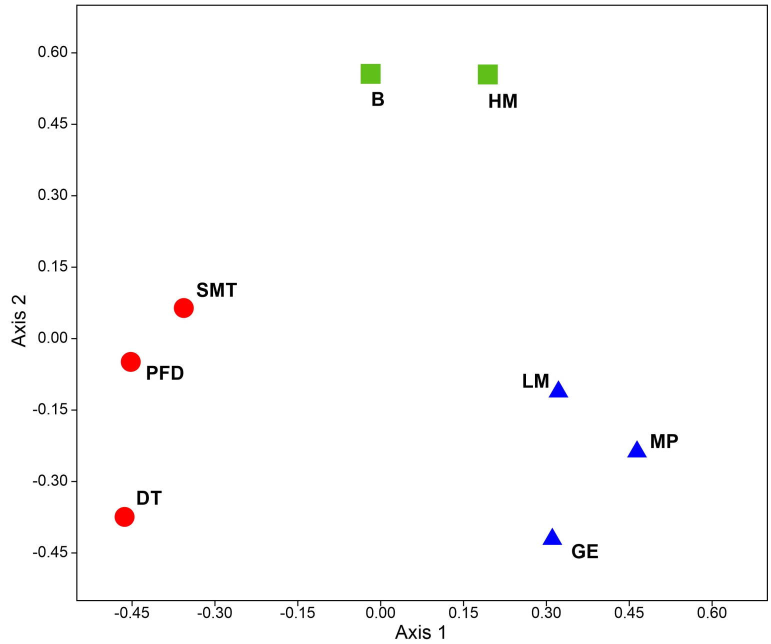

Figure 6 PCoA ordination (Jaccard index) of mite compositions (qualitative data) of habitats studied (Shokalsky Island, Kara Sea; August 2016). Acronyms as in Table 1. Groups of coastal, wet mossy, and well-drained habitats are shown with different symbols and colors.

The acarocenoses of polar deserts show some peculiarities making them distinguishable from those in the tundra zone (Makarova, 2002a, b, 2023): **(1)** first, they support a relatively high taxonomic diversity of mites (and arachnids in general) compared to the insects. **(2)** Species of the suborder Prostigmata (usually members of Eupodoidea) in terms of both diversity and abundance prevail in most habitats, while the representation of the suborder Oribatida is considerably lesser. **(3)** Most acarine genera are represented by a single species only, while the diversity of *Arctoseius* remains as high as in the subarctic regions. **(4)** Mites appear to be unevenly distributed within individual habitats (due vegetation heterogeneity), as well as across a landscape: many species prefer the warmest substrates, often of zoogenic origin.

Species diversity and taxonomic structure of the fauna

The number of mite species revealed on the Shokalsky Island (81 species; Table 2) makes up about 13% of all mite diversity across the Arctic (Hodkinson *et al.* 2013) and about 20–25% of the species richness known from such large arctic regions as Taymyr, Greenland, the Canadian Arctic, or the Bolshezemelskaya Tundra (Behan 1978; Makarova 2015a; Rozhnov *et al.* 2019; Makarova *et al.* 2022). This number of species (81) represents less than half of the mite species diversity of the mountainous Svalbard Archipelago located nearly at about the same latitude and where acarofauna had been studied for over a century (Seniczak *et al.* 2020b). However, in comparison with polar desert districts hosting 15–61 species, the acarofauna of Shokalsky Island is noticeably enriched (cf. McAlpine 1965; Makarova 2002a, 2023). As can be easily seen (Figure 7), the numbers of species revealed in relatively well studied local faunas differ in high-arctic and low-arctic regions. Thus, the widely adopted division of polar area into High and Low Arctic demarcated by the mean July isotherm of 5–6 °C (Alexandrova 1980; Böcher *et al.* 2015) appears to be supported by acarological evidence as well.

In comparison to vascular plants, mosses, and lichens, soil mites appeared to maintain similarly high levels of diversity (Table 4). Among the animal taxa studied in the island (Table

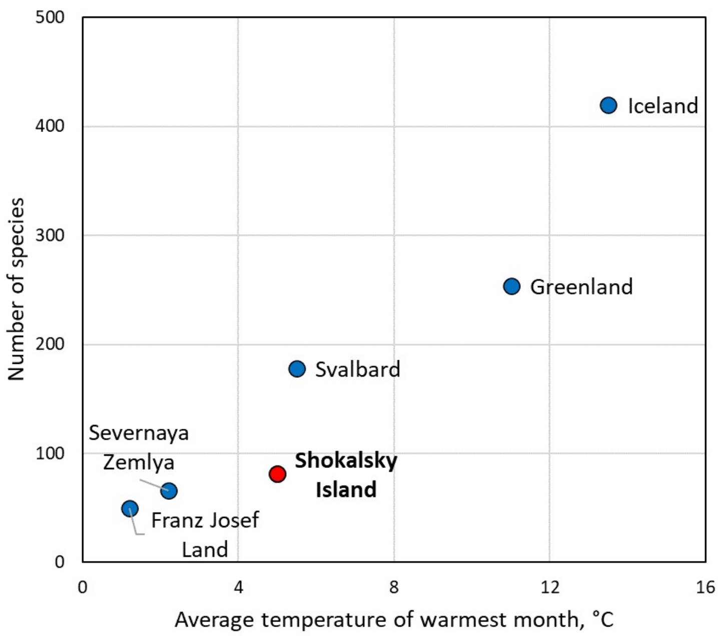

Figure 7 Free-living mite species diversity of some arctic islands and archipelagos.

4), only springtails were represented by a similar number of species (68 species; A.B. Babenko, personal communication, March 15, 2023).

The macrotaxonomic structure of the acarofauna (the proportion of the number of species in different orders and suborders) was closer to that known for the arctic polar desert areas (McAlpine 1965; Makarova 2002a, 2023) than for ones of the tundra zone. So, more than half of the species found were members of Prostigmata (Table 2; Figure 3A). Comparably to tundrian study areas of Yamal, Taymyr, and the Vaygach Island, all located south of Shokalsky Island, the diversity of Oribatida (18 species) was about twice as low, and the diversity of Mesostigmata (17 species) appeared to be 2–4 times lower (Grishina 1985; Davydova and Nikolsky 1986; Grishina *et al.* 1998; Marchenko 2012; Makarova 2013; Melekhina *et al.* 2019). At the same time, the species richness of Oribatida and Mesostigmata in the Shokalsky Island was similar to that revealed in the mountainous tundras of the northern Palaearctic

Table 4 Taxonomical diversity of the main groups of organisms on the Shokalsky Island, Kara Sea.

Taxon	Number of			Source
	species	genera	families	
Lichens	76	32	21	Andreev *et al.* 1987; Beldiman *et al.* 2020
Mosses	79	43	25	Beldiman *et al.* 2020
Vascular plants	99	48	20	Rebristaya 2002
Crustaceans	32	29	16	https://gdanskiynp.ru/?page_id=2983; Novichkova 2016; Novichkova and Chertoprud 2017
Springtails	68	30	9	A.B. Babenko, pers. comm., 2018
Free-living mites	81	55	36	New data
Spiders	15	10	2	Nekhaeva 2018
Beetles	13	11	6	Makarov *et al.* 2018
Birds	50	36	13	Evseeva and Shiryaev 2015; Dubrovsky *et al.* 2016
Mammals	8	7	6	Gorchakovsky 2004; Dubrovsky 2016; https://gdanskiynp.ru/?page_id=2983

(Sidorchuk 2009; Marchenko 2010, 2011; Melekhina and Zinovyeva 2012; Makarova 2019; Leonov 2020; Leonov and Rakhleeva 2020). Despite the similarity of the macrotaxonomic structure of the tundrian Shokalsky Island's acarofauna to that in the true polar desert regions, a clear diagnostic feature of these natural zones appeared to be the diversity of Oribatida (Makarova 2002a). On the Shokalsky Island, this suborder contained twice as many species as on the Severnaya Zemlya Archipelago or Franz Josef Land (Makarova 2002a, 2023). The shorter mesostigmatic mite list (17 species *vs* 20 on Severnaya Zemlya) was obviously due to our undersampling of the mites from zoogenic substrates (from seabird and lemming colonies) that are usually inhabited by specialized species.

The most genera (76%) comprising the Shokalsky Island's acarofauna were represented by one species only (Table 2), thus showing a strongly "fragmented" taxonomic structure. This also held true for other animal taxa studied on the island (Table 4). The fragmented biota is typical of polar deserts (Korotkevich 1972; Chernov and Matveeva 1979; Makarova 2002a, 2023; Babenko 2018). On the Shokalsky Island, this reflects its position at the northernmost margin of the tundra zone.

At the same time the genus *Arctoseius* Thor, 1930 is unprecedentedly diverse in the entire Arctic (more than 30 species, up to 12–15 species per local fauna) (Lindquist 1961; Makarova 1999, 2000b, 2013, 2015a, 2023). The number of its species is believed to reflect the age of the fauna to some extent (Makarova *et al.* 2022). At least 9 species dwell on the Shokalsky Island (up to 5 species per habitat and up to 3 species per individual sample), this being a moderate value close to that of both Svalbard (Seniczak *et al.* 2020b), Greenland (Makarova 2015a) and Franz Josef Land (Makarova 2023).

Distributions

In the north of Eastern Europe and West Siberia, representatives of the European (West Palaearctic) and Siberian faunogenetic complexes coexist (Eskov 1988; Babenko 2012; Babenko *et al.* 2017; Makarova *et al.* 2019). The proportion of these zoogeographic elements in the acarofauna of Shokalsky Island (totaling about 9%) was not as significant as that observed in the tundra areas lying more southerly in the same sector of the Arctic (27–36%; Marchenko 2012; Babenko *et al.* 2017; Makarova *et al.* 2019; Babenko and Antipova 2022). Only two species, *Zercon forsslundi* Sellnick, 1956 and *Halolaelaps* cf. *gerlachi* Hirschmann, 1966, are associated with the West Palaearctic (the latter species is also known from Greenland), while *Arctoseius productus* Makarova, 2000, *Zercon* aff. *bajkalensis* Blaszak, 1979, and *Pyroppia arctica* Krivolutsky, 1974 can be considered as "Siberian" species (see Ghilarov *et al.* 1975; Grishina 1985; Krivolutsky *et al.* 1995; Grishina *et al.* 1998; Marchenko 2012; Makarova 2013).

At the same time, 16 mite species found, which belong to different suborders, could be considered as true arctic elements (Table 2). In addition, nine species, namely *Zercon michaeli* Halašková, 1977; *Arctoseius idiodactylus* Lindquist, 1961; *Melichares parvanalis*; *Coccorhagidia pittardi* Strandtmann, 1971; *Poecilophysis* cf. *saxonica*; *Camisia dictyna* Colloff, 1993; *Ceratozetes spitsbergensis* Thor, 1934; *Melanozetes interruptus* Willmann, 1953; *Svalbardia lucens*, inhabit both Arctic and mountainous landscapes more to the south (Lindquist 1963; Ghilarov *et al.* 1975; Krivolutsky *et al.* 1995; Makarova 2000b, 2013; Kamali *et al.* 2001; Zacharda and Kučera 2006; Fischer *et al.* 2016; Behan-Pelletier and Lindo 2019). On the Shokalsky Island, the proportion of cryobiont species is the highest among Mesostigmata (58%), but much lower in both Oribatida (31%) and Prostigmata (30%). The high specialization of the arctic mesostigmatan fauna has repeatedly been discussed (Makarova and Böcher 2009; Hodkinson *et al.* 2013; Makarova 2015a, 2023; Makarova *et al.* 2019).

The pattern characterized, namely a reduced sectoral specificity and an increased proportion of Holarctic cryobiont species seem to be among the most distinctive features of high-arctic biota (Chernov 1978; Babenko 2005; Bayartogtokh *et al.* 2011).

Abundance and diversity indicators

The total mite density in the soil of the studied habitats ranged similar to other tundra regions across the Arctic (e.g., Bengtson *et al.* 1974; Douce and Crossley 1977; MacLean *et al.* 1978; Byzova *et al.* 1995) or tundra-like alpine heaths (e.g., Petrova and Grechanichenko 1987; Minor *et al.* 2016a). Similar values were revealed for the polar deserts of both Severnaya Zemlya (Makarova 2002a) and Franz Josef Land (Makarova 2023). Thus, as pointed out earlier (Makarova 2002a), the acarofaunas of the tundra zone and polar deserts cannot be distinguished based on this parameter alone.

The number of species in every habitat series on Shokalsky Island reached a plateau on the cumulative curve (Figure 5A) already following the 3rd to 7th sample, showing the sampling effort's sufficiency.

The main diversity indicators (number of species per sample and habitat, and the Shannon index; Table 3) increased along an environmental gradient from cold waterlogged sites of low marsh to the warmest and well-drained habitats (sedge-mossy tundra, dryad tundra and meadow of polar fox den). Such a pattern is considered to be quite typical of the soil mites of high-arctic landscapes (Ananjieva *et al.* 1979; Makarova 2002b).

Assemblage structure

Mite assemblages of all studied habitats showed a mono- or an oligodominant structure (one to four dominant species). Prostigmatans were most diverse and abundant virtually in all habitats (Figure 3B), being mainly represented by species of Eupodoidea. These are members of this superfamily that constitute the main body of acarocenoses everywhere in the polar regions (Strandtmann 1971; Usher and Booth 1984; Makarova 2002b, 2023) and in cold treeless nival heaths (Zacharda and Kučera 2006, 2010).

Ordination based on both abundance and diversity split all habitats in three separate groups, i.e. wet coastal habitats, wet mossy habitats, and drained habitats of the inner area (Figures 4, 6).

Wet coastal habitats

Both the geese molting place located in the river delta and the low marsh on the marine coast were regularly inundated by tides. The tidal regime supported the high density of such a characteristic littoral species as *Ameronothrus nigrofemoratus* (L. Koch, 1879), as well as some hygrophilous mites (*Eustigmaeus* cf. *tjumeniensis* Khaustov & Tolstikov, 2014, *Svalbardia lucens*, *Cheylostigmaeus longisetosus, Arctoseius ornatus* Lindquist, 1961 etc.). Remarkably, *A. nigrofemoratus* and *Halolaelaps* cf. *gerlachi*, another seashore-dweller [along with *Ameronothrus lineatus* (Thorell, 1871)], are probably the northernmost members of the specialized littoral species complex along the latitudinal transect (compare with Seniczak *et al.* 2020b). On Severnaya Zemlya, such species failed to occur at all (Makarova 2002a). The regular residence of *Ameronothrus* members on Franz Josef Land needs confirmation. Until now, this genus is known from the archipelago from a single deutonymph (Makarova 2023).

Wet mossy habitats

The vegetation cover of both the high marsh and cotton-grass bog is characterized by the presence of a thick moss cover incorporating sedge and graminoid tussocks. This type of vegetation was believed to ensure more stable environmental conditions and provided a variety of suitable microhabitats for mites showing different biotic preferences (Minor *et al.* 2016b; Seniczak *et al.* 2020a; Bizin *et al.* 2021). Most of the mass species in these habitats were hygrophilous or associated with grasses (*Steneotarsonemus arcticus*). On the Shokalsky Island, *S. arcticus* inhabited a wide range of biotopes like salt marshes and meadow of polar fox den where graminoids (*Alopecurus*, *Poa*, *Calamagrostis*, *Festuca*) prevailed, yet it was absent from both the dryad tundra where grasses were sparse, and bird-transformed sites with suppressed vegetation (Table 2).

The leading roles played by oribatid mites in waterlogged habitats (Figure 3B and Table 2) was a notable feature to distinguish the mite assemblages of the Shokalsky and Bolshevik islands. In areas where environmental conditions were intermediate between a tundra and polar deserts (like Shokalsky Island), some oribatid species, *S. lucens* and *A. nigrofemoratus* among them, showed their northernmost range limits (see Figure 2 in Ermilov *et al.* 2022; Artamonova *et al.* 2023) but they were virtually absent from polar deserts (Makarova 2002a, 2023).

Inner drained habitats

This cluster was formed by the warmest habitats characterized by the greatest taxonomic diversity and the highest densities (Tables 2 and 3). Only these habitats hosted relatively larger species (the idiosoma being more than 450 µm in length). Among them, were the arctic-boreal *Diapterobates notatus* (Thorell, 1871), *Acugamasus montanus* (Willmann, 1936), *Zercon* cf. *bajkalensis*, as well as the true arctic species *Hermannia scabra, Melanozetes interruptus,* and *Dinychus micropunctatus* Evans, 1955.

However, the dominant complex included only smaller species (the idiosoma not exceeding 300 µm in length). These were the prostigmatans *Steneotarsonemus arcticus*, *Lorrya* cf. *obstinata* (Livshitz, 1973), *Paratriophtydeus* sp., as well as *Kerdabania* sp. The genus *Paratriophtydeus* was only rarely to be recorded in polar regions of the Nearctic (Behan 1978; Makarova 2015). In the cosmopolitan genus *Kerdabania*, only one species, *K. arctica* (Thor, 1934), is presently known from the Arctic alone (Svalbard, as "*Pediculoides arcticus*"; Khaustov 2009).

The endeostigmatan, *Nanorchestes* cf. *gilli*, was the most abundant species both in the sedge-mossy and dryad tundra (Table 2). This species is very common in polar deserts of the Northern Hemisphere where it occupies a wide range of habitats (Makarova 2002a, 2023). Members of the algivorous genus *Nanorchestes* are the most common components of the acarofauna in Antarctic polar deserts as well (Rounsewell 1977). These mites usually prefer bare and/or pioneer sites (see references in Makarova 2002a; Usher and Booth 1984; Russell and Alberti 2010) where soil algae are also abundant.

The vegetation cover of the sedge-mossy and dryad tundras of Shokalsky Island was characterized by an increased share of lichens (Beldiman *et al.* 2020). That was probably why the lichenophagous *Ceratozetes spitsbergensis* (Makarova 2002b; Fischer *et al.* 2016) was found just in those habitats (Table 2).

The mite assemblage in the sandy grounds of polar fox den demonstrated the most complicated structure of dominance (Table 2). About a quarter of the species recorded (9; 26%) were found only in pitfall material including the characteristic arctic-montane species, *Melichares parvanalis*, which was absent from soil cores of all habitats.

Conclusion

Our study dealing with all groups of mites presents the first review of a local acarofauna of the West Siberian tundra. Compared to the data from polar deserts, the acarofauna of Shokalsky Island is more diverse and some of its features are transitional between the ones characteristic of the polar-desert and tundra zones. So, the Prostigmata is the most species-rich suborder in almost all habitats, just like this is observed in polar deserts. Nevertheless, the list of dominant mite species of the Shokalsky Island includes member of Endeostigmata and larger species of Oribatida (even in waterlogged habitats). The latter feature is typical only of the tundra zone. As in polar deserts, the proportion of genera represented by one species only is high (76%) while the genus *Arctoseius* is the most diverse (9 species). Besides this, our data confirm high specialization (Makarova and Böcher 2009; Makarova 2023) of the arctic mesotigmatan fauna (58% species showing arctic or arctic-montane distribution patterns) as opposed to the Oribatida fauna which mainly comprises arctic-boreal or polyzonal species (70% in total).

Along the other recent publications (Makarova 2002a, 2015a, b, 2023; Seniczak *et al.* 2020b), our research highlights the sharp need in identifying the arctic Prostigmata, especially the superfamily Eupodoidea, the leading taxon in high-arctic acarocenoses.

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