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Cladocera and Copepoda of Shokalsky Island: new data from northwest Siberia

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ABSTRACT

Information on the freshwater fauna of the remote Arctic territories is very patchy, and most of the isolated islands of the Arctic Ocean remain absolutely unexplored. The pioneer data on the species composition of microcrustaceans of Shokalsky Island (northwest Siberia, Russia) is reported here. The initial three-year research revealed a total of 31 new for the area species of Cladocera and Copepoda, including new records for the whole of northwestern Siberia. Comparing the interannual differences in faunal composition, we suggested the hypothesis of the existence of a cryptic pool of species' resting stages, which can invade the community in the event of favourable environmental conditions in the Arctic freshwaters. We also compiled all the available data from different parts of northern Siberia and compared them with the fauna of Shokalsky Island to analyse the connection between the diversity and distributional patterns of copepods and cladoceran species and the climate conditions of different territories.

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Microcrustacean; Yamal region; Arctic; climate effect

Introduction

Shokalsky Island is a small island lying in the southern part of the Kara Sea in the Yamalia (Yamalo-Nenets Autonomous Okrug of Russia), forming the northwestern top end of the Gydan peninsula and separated from it by a narrow strait. The island is included in the Gydan Nature Reserve, one of the most remote and difficult-to-access areas in the Arctic tundra and the northernmost reserve in western Siberia (Nikiforov 1997). The history of scientifical researches on the territory is rather young, and there is no data of any hydrobiological surveys on the island in the available literature. Thus, the current work provides the results of the pioneer study of microcrustacean fauna of Shokalsky Island.

The freshwater invertebrate fauna of the whole Yamalia region, which includes the Taz, Gydan and Yamal peninsulas, the lower Ob River and some neighbouring territories, is studied very unevenly. The investigations of the zooplankton fauna began here with a hydrobiological survey in 1908 (Voronkov 1911; Werestschagin 1913) in the southern and middle parts of the Yamal peninsula. During the last century, the research process has expanded very fragmentarily, with different efforts in different regions. Information

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on the zooplankton of the northen Yamal is still very scarce, while the species inhabiting the water bodies of the Tazovsky and Gydan peninsulas are known only from rare publications focused on separate lakes and rivers. Nevertheless, according to works led in the whole district, a high level of diversity is characteristic for the species composition of the zooplankton fauna of the Yamalia, with the highest number of species occurring in the lower Ob River and its bay.

The goal of this study was the investigation of the cladocerans and copepods from the shallow freshwater bodies of Shokalsky Island and the comparative analysis of faunas of these taxonomical groups with other areas of Yamalia and the whole of northern Siberia.

Materials and methods

Study area

Shokalsky Island is a part of flat plain covered by tundra, with the highest point only 10 m above sea level. The total area of the island is 496 km^2. Its southwestern coast is bounded by the waters of the Ob Bay, the southeastern by the waters of the Taz estuary. There are several quite large rivers running through the central elevated part, and a great number of small lakes and ponds on the island. The rivers' mouths on the west coast form wide deltas of several kilometres, providing a great inflow of marine water into the streams with the tides, while the estuaries on the north and east coasts are rather narow.

Sampling

The samples of microcrustaceans were collected by the members of the complex expedition of CYBZ (Club of the Young Biologists of the Zoo) in August 2014, 2015 and 2016. During the first two years zooplankton samples were collected from various freshwater habitats of Shokalsky Island, while in 2016 some additional brackish estuaries were investigated for the meiobenthos fauna (Figure 1).

Most of the freshwater habitats were small thermokarst ponds with depths of 0.2–1.5 m. The sampling was performed from the shore using a qualitative plankton net (type 'Apstein', mesh size 50 μm). Meiobenthos samples were taken from the bottom sediments using a 1.5 cm diameter corer (surface area 1.77 cm^2). Three replicate sediment samples were taken from each station. Altogether, 45 samples from 33 water bodies were taken. Upon collection, all samples were preserved in ethanol (96%). Species identification and enumeration was carried out primarily in Bogorov counting chambers; the total numbers of Cladocera and Copepoda were recorded.

Crustacean identification followed both standard taxonomic treatises and recent taxonomic revisions: Lieder (1996), Kotov et al. (2009), Sinev (2002), Smirnov (1971), Alekseev and Tsalolikhin (2010), Brtek and Mura (2000), Borutsky (1952, 1966), Borutsky et al. (1991), Dahms et al. (2006), Rylov (1948).

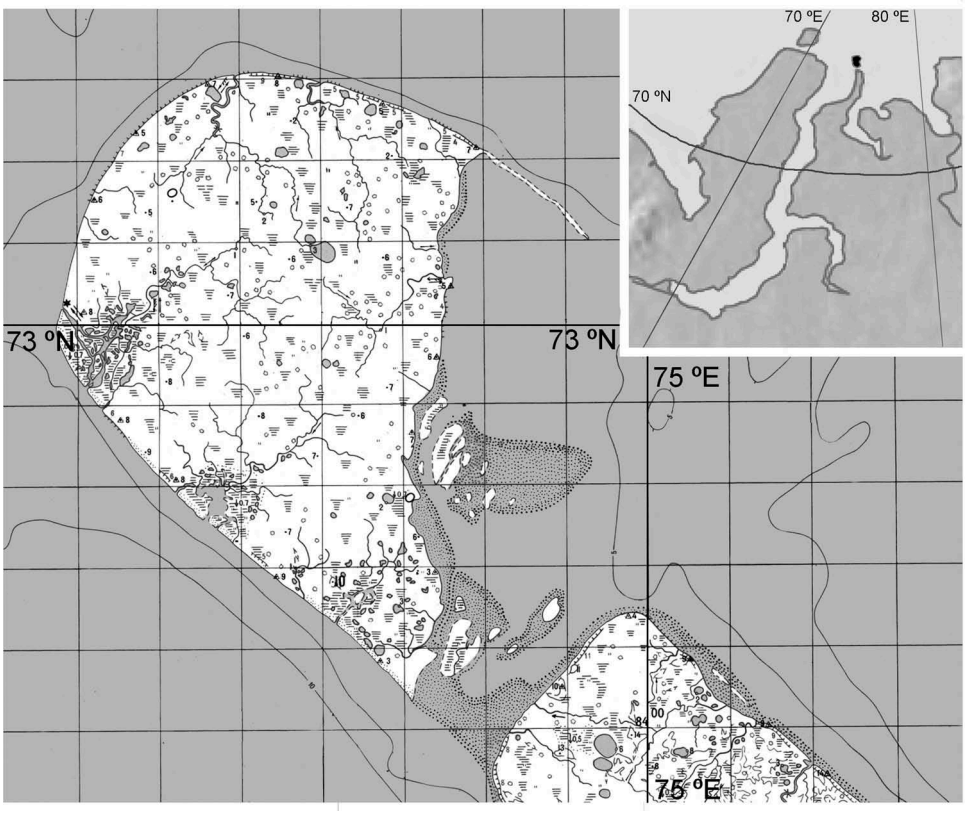

Figure 1. Location of the sampled stations in inner water bodies on the map of Shokalsky Island.

Statistical analysis and literature review

To determine the degree of overlap in faunal composition between different areas of Yamalia and northern Siberia (western Siberia: between the Ural Mountains and the Yenisei River; eastern Siberia: from the lower reach of the Khatanga River to the Lena River delta; northeast of European Russia: Malozemelskaya and Bolshezemelskaya tundra), we compiled species lists using data from the current study and the existing database on microcrustaceans (Novchkova and Azovsky 2017). For the Yamalia region, we obtained a small database on the microcrustaceans of its different geographical parts: the Yamal, Gydan and Taz peninsulas and also the lower Ob River and the Ob Bay. The existing literature, which mostly consists of short articles by local collectors as well as the accounts of some ecological investigations and engineering surveys, were evaluated and compiled into species lists (Yukhneva 1970; Kubyshkin and Yukhneva 1971; Venglinskii 1971; Krokhalevskaya et al. 1981; Krokhalevskaya and Aleksyuk 1983; Bogdanova 1985, 1990, 1995, 2000, 2006a, 2006b, 2007, 2008, 2009a, 2009b, 2010, 2013; Sinitsyna 1996; Aleksyuk et al. 2001; Sharapova and Abdullina 2004; Aleksyuk 2008; Abdullina and Aleksyuk 2009; Semyonova and Aleksyuk 2009, Sharapova 2009; Semyonova

et al. 2000; Bogdanov et al. 2012, 2015; Stogov and Movchan 2014; Stogov et al. 2015).

Faunal similarity between regions was estimated using the Kulczynski index (K) for qualitative (presence/absence) data (Clarke and Gorley 2001):

$$K\ (x, y) = (a/(a + b) + a/(a + c))/2, \quad (1)$$

where a is the number of species common to faunal lists x and y; and b and c are the numbers of species restricted to one of the groups.

The resemblance matrix was visualized using hierarchical agglomerative clustering with a complete linkage mode. The clustering was performed using PRIMER (http://www.primer-e.com).

Results

Species occurring on Shokalsky Island

A total of 31 species of Crustacea were found on Shokalsky Island, with 13 species and 12 genera of Cladocera and 18 species and 16 genera of Copepoda, including both freshwater and brackish representatives (Table 1). All of the taxa have not been previously documented on the island.

Characteristics of fauna of the observed water bodies

The diversity of microcrustaceans of the observed water bodies of Shokalsky Island is quite low. The number of species at each station varied from one to ten. The most common and abundant species, occurring in almost half of all water bodies, were *Daphnia pulex*, *Chydorus sphaericus* and *Polyphemus pediculus* among Cladocera and *Leptodiaptomus angustilobus* among Copepoda. Other species of Crustacea were not recorded frequently.

In brackish waters, only Harpacticoida species were present. The most abundant were *Nannopus procerus*, *Microarthridion littorale* and *Tachidius discipes*. Other brackish copepods were found only as single specimens.

Concerning only freshwater habitats, Cladocera and Copepoda are equally represented in number of species on the island – 13 and 12 respectively. It is notable that the first year of research showed an entirely different result (Novichkova 2016): cladoceran species outnumbered copepods by four times, which is quite unusual for Arctic insular territories (Novichkova and Azovsky 2017). The second year broadened the variety of the investigated water bodies and enlarged the number of Copepoda species significantly. Additionally, the third year of research added six new brackish species of Harpacticoida found in brackish lagoons and river estuaries.

Comparison with the faunas of neighbouring regions

Based on our original data and available literature sources, we analysed the variety of crustacean species inside the Yamalia region, the whole of northwestern Siberia and neighbouring areas (Table 2). First, we compared faunas inside the Yamalia. Due to very

Table 1. List of species Cladocera and Copepoda recordered on Shokalsky Island and their occurrence in different regions of Yamalia.

	ShI	TP	GP	YP	LO
CLADOCERA	+	+	+	+	+
Order ANOMOPODA Sars					
Family **BOSMINIDAE** Baird					
Bosmina (Bosmina) longirostris (O. F. Müller)					
Family **CHYDORIDAE** Dana	+	+	+	+	+
Acroperus harpae (Baird)					
Alona affinis (Leydig)	+	+	+	+	+
A. quadrangularis (O. F. Müller)	+	+	+	+	+
Chydorus sphaericus (O. F. Müller)	+	+	+	+	+
Graptoleberis testudinaria (Fischer)	+				+
Family **DAPHNIDAE** Straus	+	+	+	+	+
Daphnia (Daphnia) pulex Leydig					
Scapholeberis mucronata (O. F. Müller)	+	+	+	+	+
Simocephalus vetulus (O. F. Müller)	+	+		+	+
Family **EURYCERCIDAE** Kurz sensu Dumont and Silva-Briano	+	+		+	+
Eurycercus (Teretifrons) glacialis Lilljeborg					
Family **MACROTHRICIDAE** Norman et Brady	+	+		+	+
Macrothrix hirsuticornis Norman et Brady					
Order CTENOPODA Sars	+				
Family **SIDIDAE** Baird					
Latona setifera (O. F. Müller)					
Order ONYCHOPODA Sars	+	+	+	+	+
Family POLYPHEMIDAE Baird					
Polyphemus pediculus (Linnaeus)					
COPEPODA	+				
Order CALANOIDA Sars					
Family **DIAPTOMIDAE** Baird					
Diaptomus (Diaptomus) cf. *castor* (Jurine)					
Eudiaptomus vulgaris (Schmeil)	+				+
Leptodiaptomus angustilobus (G.O. Sars)	+	+		+	
Family **TEMORIDAE** Giesbrecht	+	+	+	+	+
Eurytemora lacustris (Poppe)					
Order CYCLOPOIDA Burmeister	+	+	+	+	
Family **CYCLOPIDAE** Rafinesque					
Cyclops kolensis Lilljeborg					
C. strenuus Fischer	+	+	+	+	+
C. vicinus Uljanin	+	+		+	+
Diacyclops crassicaudis (Sars G.O.)	+			+	+
Megacyclops gigas (Claus)	+	+		+	+
Mesocyclops leuckarti (Claus)	+	+			+
Order HARPACTICOIDA Sars	+				
Family **CANTHOCAMPTIDAE** Brady					
Attheyella (Neomrazekiella) nordenskioldii (Lilljeborg)					
Canthocamptus staphylinus (Jurine)	+				
Family **ECTINOSOMATIDAE** Sars	+				
Halectinosoma curticorne Boeck					
Family **MIRACIIDAE** Dana	+			+	
Delavalia arctica Scott					
Family **NANNOPODIDAE** Brady	+			+	
Nannopus procerus Fiers et Kotwicki					
Family **PSEUDOTACHIDIIDAE** Lang	+				+
Archisenia sibirica (Sars)					
Family **TACHIDIIDAE** Sars	+			+	
Microarthridion littorale (Poppe)					
Tachidius discipes Giesbrecht	+			+	

ShI – Shokalsky Island, TP – Taz peninsula, GP – Gydan peninsula, YP – Yamal peninsula, LO – Lower Ob and Ob Bay.

limited data, we eliminated the Harpacticoida species from the analysis and compared Cladocera and Copepoda (Cyclopoida, Calanoida) faunas. The degree of overlap in faunal composition was estimated using the Kulczynski index and illustrated as a dendrogram for

Table 2. Number of species of Cladocera and Copepoda in different parts of the Yamalia region and other bordering territories.

	Total number of species	Cladocera	Copepoda (incl. Harpacticoida)
Shokalsky Island	31	13	18 (8)
Taz peninsula	81	42	39 (4)
Gydan peninsula	38	23	15 (0)
Yamal peninsula	90	40	50 (9)
Lower Ob River + Ob Bay	132	66	67 (1)
Yamalia	160	75	85 (16)
Western Siberia	174	95	79 (10)
Eastern Siberia	83	27	56 (7)
NEER	152	70	82 (27)

NEER: northeast of European Russia

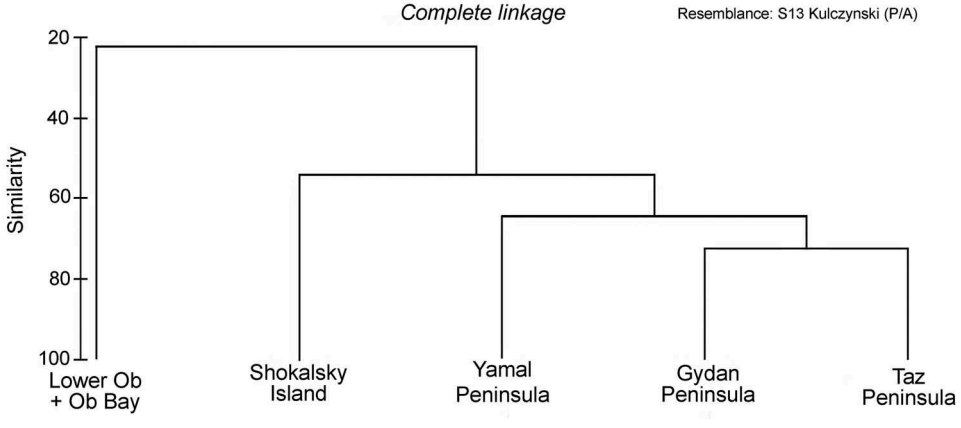

Figure 2. Dendrogram for hierarchical clustering (complete linkage) of faunas of different areas of the Yamalia region.

hierarchical clustering (Figure 2). The Gydan and Taz peninsulas were the most similar in faunal composition, and, together with Yamal peninsula and Shokalsky Island, form a cluster separated from the most diverse lower Ob and the Ob Bay.

The comparison of the Yamalia fauna with other neighbouring regions showed the significant similarity (>80%) between the Yamalia itself and the whole of western Siberia, and a rather high similarity (>70%) with the NEER (northeast of European Russia), while the fauna of eastern Siberia differs from the others in a greater degree.

Discussion

New findings for the region

The distributional ranges of all the species found are rather wide, and none of them are restricted to the Arctic area or a more limited region. But among the findings, several are worth mentioning as a separate point, such as *Latona setifera*, *Diaptomus* cf. *castor*, *Graptoleberis testudinaria* and *Eudiaptomus vulgaris*. The first two species have never been found on the territory of Yamalia, and the others were only known of in the waters of the lower Ob River and Ob Bay (Borutsky et al. 1991; Semyonova et al. 2000). All of them occurred rarely in separate water bodies.

All the Harpacticoida species found on the island are also records of high importance for the whole Siberian region due to the very low exploration degree of this taxonomical group. There is no specific data on the species of freshwater harpacticoids of any parts of the Yamalia region in the existing literature. The distributional ranges of many brackish species inhabiting the Arctic Ocean margin is likely to also include the Yamalia region; however, there is no confirmation of this fact because of the insufficient research level of this group (Borutsky 1952). Only some occasional scarce data exist on brackish species of some estuaries of the Taz River Bay and the Sharapov Shar Gulf on the western coast of the Yamal peninsula (Chertoprud, unpublished data).

Cladocera. For the species *L. setifera*, this record is the northernmost finding ever. It has also never been recorded for the neighbouring territories – neither eastern Siberia nor NEER. There is another species of this genus, *L. glacialis*, which is mostly distributed through the northern territories, while *L. setifera* is distributed in temperate Holarctic latitudes up to 63–65°N, reaching Ireland, Scotland and the Shetland Islands, but it is absent in Iceland (Korovchinsky 2004).

Graptoleberis testudinaria (Sars 1862) is cosmopolitan, with several subspecies indicated by Smirnov (1971), but an updated revision is lacking (Van Damme et al. 2010). It occurs everywhere from the tropics to high latitudes (e.g. Greenland), including some areas of western Siberia and NEER, but is usually more common in more southern regions. Within the Yamalia, this species has been previously found only in the lower Ob.

Copepoda. *Eudiaptomus vulgaris* has been only recorded in the Ob Bay (Borutsky et al. 1991), Bolshezemelskaya tundra (Izjurova 1966) and some more southern territories of the Komi Republic (Fefilova 2015). Besides that, this species is widely distributed in Europe, Asia and northern Africa (Borutsky et al. 1991; Fefilova 2015). *E. vulgaris* usually inhabits shallow ponds and temperate water bodies (Fefilova 2015).

The species designated as *Diaptomus* cf. *castor* was quite rare in the samples, leading to uncertainty of its exact taxonomical status. This species may be new to the region. It is mostly distributed in Europe, penetrating rather far north – to northern Norway and Greenland – but absent in northern Siberia (Reid and Williamson 2010). This finding has significantly expanded the distributional range of this species in the eastern Palaearctic.

The species *Attheyella nordenskioldii* and *Canthocamptus staphylinus* found on Shokalsky Island are typical for the Arctic water bodies. The distributional range of *A. nordenskioldii* includes Arctic regions of Europe and Asia from Fennoscandia up to the Bering Strait (Fefilova 2015). The species is typical of shallow tundra ponds (Borutsky 1952). The species *C. staphylinus* has a wide distributional range through the whole Palaearctic and inhabits different water bodies from lakes to silted estuaries. It is a cold-water species which has previously been found on the territory of Bolshezemelskaya tundra (Borutsky 1966) and Novaya Zemlya Archipelago (Vekhov 2000).

Three brackish species, *Nannopus procerus*, *Microarthridion littorale* and *Tachidius discipes*, are typical of estuaries and lagoons and widely distributed in the Arctic, so that their occurrence on Shokalsky Island is predictable. A rather recently described species, *N. procerus* has been found in the estuaries of the White, Barents and North seas (Fiers and Kotwicki 2013), while the other two are cosmopolite. Their areas comprise both Arctic areas (the White, Barents, Laptev and the East Siberian seas) and tropics and subtropics (the Mediterranean, Yellow and South China seas and the Bay of Bengal) (Borutsky 1952; Chertoprud et al. 2014).

Species *Halectinosoma curticorne*, *Delavalia arctica* and *Archisenia sibirica* inhabit marine waters, but can also be found in some brackish waters. Two of them, *H. curticorne* and *A. sibirica*, haven't been registered for the Kara Sea previously. *D. arctica* is typical for the seas of the Arctic Ocean (Lang 1948), *A. sibirica* is noted for Arctic seas and also for the Okhotsk Sea and the North Atlantic (Chertoprud et al. 2015), *H. curticorne* has a wide cosmopolite distributional range, including Arctic water areas, as well as the Mediterranean, the Bay of Bengal and central part of the Pacific coast of the USA (Chertoprud et al. 2010).

Taxonomic commentary

The taxonomic status of the species of family Tachidiidae *Microarthridion littorale* and *Tachidius discipes* found on Shokalsky Island is not obvious. The populations of these species inhabit isolated brackish water bodies within the bounds of a very wide distributional range, prompting suggestions of the existence of considerable genetic differences between them. Earlier, on the territory of Svalbard, there were two new species of *Tachidius* described (Olofsson 1918). However, the validity of these species was not confirmed, and was later reduced to one species, *T. discipes*, despite the morphological differences (Lang 1948).

The analysis of the genetic structure of the isolated *M. littorale* population, inhabiting the estuaries of the Atlantic coast of the USA, revealed that this species is actually a group of cryptic taxa (Schizas et al. 1999, 2002). For the Arctic water areas, such surveys of the interpopulation genetic variability of *M. littorale* haven't yet been conducted. Presumably, the detailed molecular genetic analysis of this species from different parts of the Arctic may clarify this situation.

Interannual dynamics of fauna

During the first year of research (2014), the crustacean fauna of Shokalsky Island showed predominance in the number of cladoceran species over copepods by four times, which is highly unusual for Arctic water bodies. Usually, in the high latitudes under the pressure of the severe cold climate, the species richness of Copepoda is greater than or equal to that of Cladocera (Novichkova and Azovsky 2017). It is noteworthy that in 2014 we found several taxa typical of more southern regions (*Latona setifera*, *Graptoleberis testudinaria* and *Eudiaptomus vulgaris*). The second year of research (2015) enlarged the number of Copepoda species significantly, so that the faunistical structure becomes more typical for the Arctic.

Such a strong difference in the structure of crustacean fauna between different years could be caused by climatic factors. The year preceding the research (2013) was characterized by a very warm summer season with low wind weather (Weather Underground web portal 2017). This fact, together with low wind during summer 2014 compared to 2015, led to a more even heating of the waters. As a comparison, the summarized Growing Degree Days Index (GDD), a measure of heat accumulation used to predict plant and animal development rates, in 2013 totalled 67, whereas in 2015 it scored only 28 (Weather Underground web portal 2017).

A rather mild summer climate in 2013 and 2014 promoted the development of boreal elements of fauna. Apparently, atypical Arctic faunistic elements had previously dispersed to the island and remained in resting stages, in particular cladocerans *Graptoleberis* (order Anomopoda) form ephippia (Smirnov 1996) and *Latona* (order Ctenododa) form resting eggs (Korovchinsky 2004), with thick shells to be able to survive harsh environmental conditions. Copepods *E. vulgaris* are also able to withstand freezing and drying of water bodies (Borutsky 1966).

The existence of resting stages with the ability to withstand unfavourable conditions determines the success of species' dispersal and their capacity to colonize the utmost regions of their distributional ranges. Thus, in the Arctic water bodies a constant cryptic pool of species exist. These species do not usually present in the communities, but they can appear and invade in the event of favourable environmental conditions.

Biogeographical features of fauna

The most similar location in faunal composition (about 65%) to Shokalsky Island was the Yamal peninsula, the most extensively studied of the nearest continental regions (Figure 2). In its turn, Cladocera and Copepoda fauna of the Yamal peninsula is rather similar to that of the neighbouring Taz and Gydan peninsulas. These territories have 33 species in common, which is not less than 40% of the total species richness of certain peninsulas. Fauna of the lower Ob River and the Ob Bay is significantly different from the mentioned territories; it includes many elements of more southern boreal fauna brought from the upstream and overflow lands (Borutsky et al. 1991; Semyonova et al. 2000), as well as some marine elements coming from the Kara Sea.

The structure of the fauna of the whole Yamalia region is close to those of neighbouring northwestern Siberia and the northeast of European Russia, but quite distinct from that of the northern part of eastern Siberia. These differences in faunal composition are connected to the climatic differences: this part of eastern Siberia lies further north than western Siberia and has a much more harsh climate. Thus, the mean annual air temperature of the Taymyr peninsula (northeastern Siberia) varies from −12° to 15°C, the Yamal peninsula from −8° to −12°C and the Kanin peninsula (northwestern Siberia) from 0° to −4°C (Weather Underground web portal 2017). The climate factor determines the number of crustacean species of different groups in the faunas of the compared regions. Cladocerans are more sensitive to low temperatures than copepods, so the Cladocera/Copepoda species ratio increases significantly with temperature (Novichkova and Azovsky 2017). Admittedly, the species richness of Cladocera is much lower in eastern Siberia (27 species) compared to that of the Yamalia (75 species), western Siberia (95 species) and NEER (70 species) (Table 1).

Thus, Shokalsky Island is one of the northernmost outposts of the spread of microcrustacean faunistical complexes, typical for western Siberia. Its fauna is derived from the neighbouring continental territories, especially the Yamal peninsula. The species composition of Cladocera and Copepoda of the whole Shokalsky Island was unknown up to the present research. This situation is typical for most of the insular territories of the Arctic Ocean, including large archipelagos, such as Severnaya Zemlya or the New Siberian Islands, which remain almost unexplored. Every research project in this area contributes valuable new data, which together with further explorations in the Arctic helps to find out the

specificity of Arctic insular biota and the functioning of freshwater ecosystems in the high latitudes, and provides background for assessing the effects of global climate changes.

Conclusions

(1) A total of 13 species of Cladocera and 18 species of Copepoda, including both freshwater and brackish representatives, were found on Shokalsky Island. All of the taxa have not been previously documented on the island.
(2) On the basis of interannual differences in the faunal composition of Shokalsky Island, the hypothesis of the existence of a constant cryptic pool of species of microcrustaceans in their resting stages, which can invade to the community in the event of favourable environmental conditions in the Arctic water bodies, is suggested.
(3) Shokalsky Island and the nearby mainland Yamal peninsula are quite similar in faunal composition of Cladocera and Copepoda due to the low isolation between territories and high accessibility for species' distribution.
(4) Microcrustacean fauna of the Yamalia region is quite similar to that of the northern part of western Siberia and the northeast of European Russia, but far different from the northern part of eastern Siberia on account of the differences in the climate conditions between regions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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