

Freshwater crustaceans of Bykovsky Peninsula and neighboring territory (Northern Yakutia, Russia)

Пресноводные ракообразные Быковского полуострова и прилегающих территорий (Северная Якутия, Россия)

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KEY WORDS: Crustacea, Cladocera, Copepoda, fauna, biodiversity.

КЛЮЧЕВЫЕ СЛОВА: Crustacea, Cladocera, Copepoda, фауна, биоразнообразие.

ABSTRACT. Numerous water bodies in the northern portion of Eastern Siberia are poorly studied both in their species composition and community structure. The aim of this study is to provide an inventory of the freshwater microcrustaceans of Bykovsky Peninsula and neighboring territory (North Yakutia, Russia) and to analyse the community structure in the studied water bodies with the aim of revealing separate environmental factors affecting it. *In toto*, we identified 19 copepod species (belonging to 14 genera) and 16 branchiopod species (12 genera). Seven species were first records from this area of NE Siberia, namely calanoid copepods *Acanthodiaptomus denticornis*, *Arctodiaptomus wierzejskii* cyclopoid copepods *Acanthocyclops venustus*, *Diacyclops crassicaudis*, *D. languidoides*; cladocerans *Eurycerus* cf. *glacialis*, *Pleuroxus* cf. *trigonellus*. The fauna of Bykovsky Peninsula and neighbouring territory is very poor and mainly represented by eurybiotic taxa with wide Palearctic or Holarctic ranges. Differences in community structure of different water bodies could be explained mainly by abiotic preferences (i.e. in conductivity/salinity and temperature) of dominant species.

How to cite this article: Novichkova A.A., Kotov A.A., Chertoprud E.S. 2020. Freshwater crustaceans of Bykovsky Peninsula and neighboring territory (Northern Yakutia, Russia) // Arthropoda Selecta. Vol.29. No.1. P.1–12. doi: 10.15298/arthsel. 29.1.01

РЕЗЮМЕ. Многочисленные водоемы северной части Восточной Сибири плохо изучены как в части их фауны, так и структуры сообществ. Целью данной работы было провести инвентаризацию видового состава микроскопических ракообразных Быковского полуострова и его окрестностей (Северная Якутия, Российская Федерация) и проана-

лизировать структуру сообществ с целью выявить основные факторы среды, определяющие последнюю. Всего было идентифицировано 19 видов Copepoda (14 родов) и 16 видов Branchiopoda (12 родов). Среди них, семь видов были впервые найдены в этом регионе северной части Восточной Сибири, а именно два вида каляноид (*Acanthodiaptomus denticornis*, *Arctodiaptomus wierzejskii*), три вида циклопид (*Acanthocyclops venustus*, *Diacyclops crassicaudis*, *D. languidoides*) и два вида кладоцер (*Eurycerus* cf. *glacialis*, *Pleuroxus* cf. *trigonellus*). Фауна района очень бедна и в основном представлена эврибионтными видами с широкими палеарктическими или голарктическими ареалами. Различия в структуре сообществ в различных водоемах могут быть объяснены различными абиотическими предпочтениями (в т.ч., в части удельной электропроводности/солености и температуры) доминантных видов.

Introduction

Numerous water bodies of Eastern Siberia, especially in its northern portion, are poorly studied in terms of species composition and community structure. Few papers were published on the microscopic crustaceans of this vast part of Russia [Sars, 1898; Rylov, 1928; Behning, 1942; Urban, 1949; Vekhov, 1989]. During the last decade several detailed publications on zooplankton from a few regions of northern Yakutia have appeared, i.e. Yana River basin [Sobakina, 2013; Trofimova *et al.*, 2018], Indigirka River basin [Frolova *et al.*, 2016] and Anabar River basin [Sobakina *et al.*, 2009; Frolova *et al.*, 2013]. All such papers were based on data from a very limited number of water bodies. Moreover, author's identifications need a substantial

re-evaluation keeping in mind recent progress in the taxonomy of different microcrustaceans [Korovchinsky *et al.*, 2012; Kotov, 2015].

The best explored region is the Lena River Delta, one of the largest deltas in the world [Are, Reimbitz, 2000]. Its total area is almost 30.000 km² and there are more than 29.000 lakes within this area [Bolshiyarov *et al.*, 2013]. Although zooplankton investigations in the Lena River Delta date back to a Russian Polar expeditions at the beginning of the 20th century (1901–1903), the information on the structure and functioning of zooplankton communities within this large region is limited, although first data on the zooplankton were published already by Rylov [1928] and Behning [1942]. The general list of fauna, based on their data, included about 50 species and forms.

Further analysis of the material collected throughout the Lena River from Yakutsk prior to the beginning of the delta, and also in Olenekskaya and Tumatskaya channels of the delta, the bay of Tiksi, the Oleneksky Gulf and Neyelov's Gulf, expanded this list to 75 taxa [Pirozhnikov, Shulga, 1957]. The studies of the zooplankton in the Lena River Delta, first of all, covered the

largest river channels — Oleneksky, Bykovsky, Tumatskaya and Trofimovskaya [Behning, 1942; Urban, 1949; Pirozhnikov, Shulga 1957; Serkina, 1969; Abramova, 1996; Nikanorov *et al.*, 2011; Nigamatzyanova *et al.*, 2014; 2016] or brackish estuarine areas around the delta [Virketis, 1932; Lutsik *et al.*, 1981; Sorokin, Sorokin, 1996; Abramova, Tuschling, 2005]. It was noted that the structure of zooplankton of the Lena River is characterized by absence of some representatives of Copepoda and Cladocera, widespread in plankton of other large rivers of Siberia (for example, Yenisei and Ob) [Nigamatzyanova *et al.*, 2014]. It was shown that rotifers are most numerous in the zooplankton of the channels. In general, the planktonic community of channels is characterized by low species richness and abundance [Nigamatzyanova *et al.* 2014]. The structure of the domination is unstable and varies considerably both on a time span of several years, and within one season [Nikanorov *et al.* 2011].

Compared to other arctic territories of Russia, information on the pelagic fauna of lakes, ponds and wetlands in the Lena River Delta is rather detailed (*e.g.* Rylov, 1928; Kerer, 1968; Abramova, 1996, 2003;

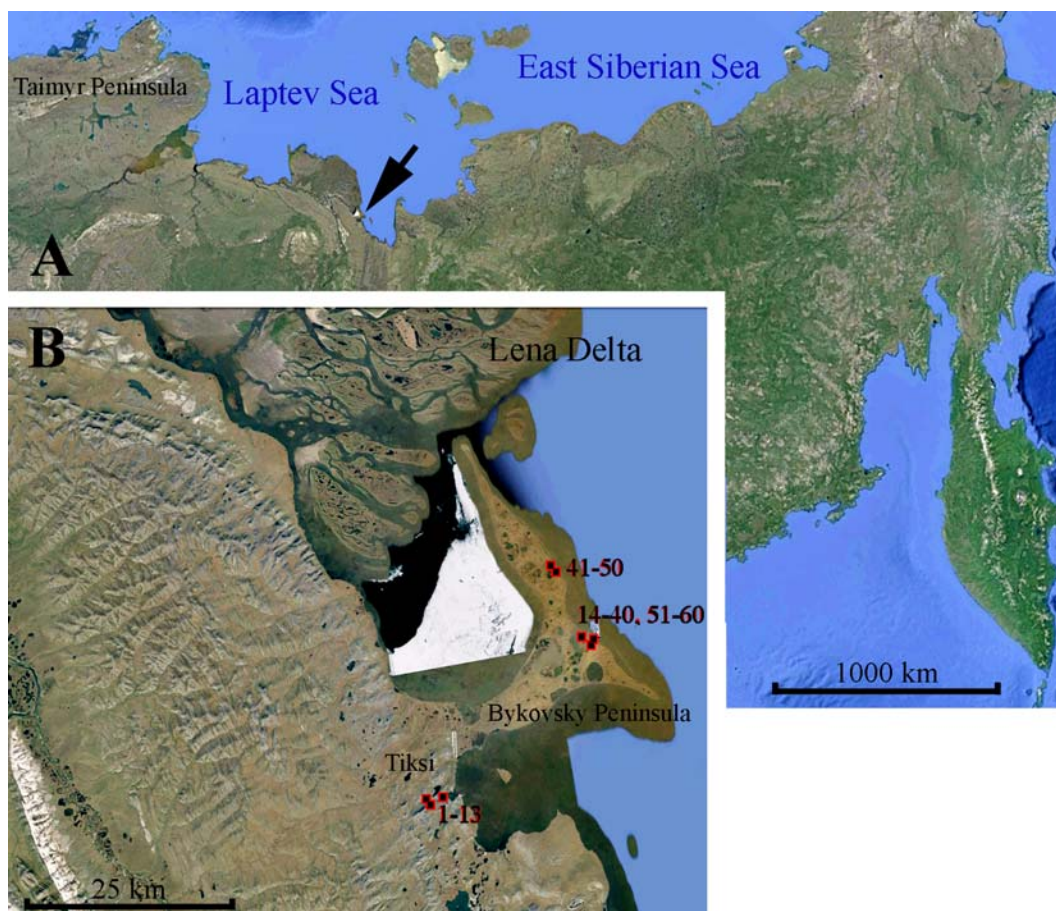


Fig. 1. Map of Eastern Siberia with position of the Lena Delta (A, arrow) and three areas of sampled stations (1–60) in the vicinities of Tiksi and on Bykovsky Peninsula (B). Initial maps are from Google Earth (<https://www.google.ru/intl/ru/earth/>).

Рис. 1. Карта Восточной Сибири с отмеченным положением дельты Лены (А, стрелка), а также три района отбора проб (1–60) в окрестностях Тикси и на Быковском полуострове (В). Исходная карта взята с портала Google Earth (<https://www.google.ru/intl/ru/earth/>).

Abramova, Sokolova, 1999; Abramova *et al.*, 2009; 2017; Vishnyakova, Abramova, 2009; Nigamatzyanova *et al.*, 2014; 2016, etc.). The fauna of such water bodies is found to be much richer than that of the Lena River Delta [Kerer, 1968]. It was also shown that the fauna of standing waters of a seaside part of the delta is slightly poorer than that in central and southern portions [Serikina, 1969]. Our knowledge on the water communities of the Lena River delta has been slowly but steadily growing during the last decades. The most recent and comprehensive study of the zooplankton of the Lena River Delta has resulted in the list of 125 zooplankton taxa belonging to Rotifera (67) and Arthropoda (58) [Abramova *et al.*, 2017].

The aim of this study is to provide an inventory of the freshwater microcrustacean fauna of Bykovsky Peninsula and neighboring territory, closely located to the Lena Delta (Fig. 1A). We believe that our study of this remote and uninvestigated area will improve the knowledge of the diversity of microcrustacean species in the

water bodies across the northeastern part of Siberia. We also aimed to analyse the community structure in the studied water bodies and to evaluate the main environmental factors affecting it.

Material and methods

The samples were collected in August 2015 in 60 shallow water bodies in the northern part of Yakutia (Sakha Republic, Russia): near the Settlement of Tiksi (Table 1, Fig. 1B: 1–13) and on Bykovsky Peninsula (14–60). Water bodies near Tiksi are tundra ponds and puddles with a moderate anthropogenic influence. Domestic and construction waste is present in littoral zone, the water in some cases is moderately polluted with fuel products. The anthropogenic influence in such water bodies was not estimated quantitatively, but its absence or presence was noted. Bykovsky Peninsula is a permafrost territory with typical water bodies of the “polygonal tundra” [Washburn, 1979; Veremeeva, Gubin, 2009]: ponds or mires in the centers of the polygons; ditches above the ice wedges; few large, shallow thermokarst

Table 1. List of water bodies and their main characteristics.
Таблица 1. Список исследованных водоемов и их основные характеристики.

No	AREA	N	E	DEPTH	TEMP	PH	SALT	ORP	COND	TDS
01	TIK	71.63756	128.84471	0.15						
02	TIK	71.63936	128.84564	0.5						
03	TIK	71.63968	128.8419							
04	TIK	71.64091	128.84087							
05	TIK	71.64151	128.8438	0.2						
06	TIK	71.63639	128.84198							
07	TIK	71.64159	128.84276							
08	TIK	71.63631	128.84201							
09	TIK	71.63524	128.84177							
10	TIK	71.63501	128.84239							
11	TIK	71.63412	128.84486							
12	TIK	71.63678	128.86964							
13	TIK	71.63659	128.84352	0.2						
14	MB	71.78642	129.40312	0.7	10.6	6.56	0	362	34	21
15	MB	71.7863	129.40292	0.7	9.5	6.55	0	322	0	0
16	MB	71.78641	129.40265	0.2	9.3	7.07	0	327	0	0
17	MB	71.78639	129.40186	0.3	9.6	6.74	0	0	0	0
18	MB	71.7866	129.40101	0.2	10.7	6.26	11	148	27	16
19	MB	71.78674	129.40062	0.5	10.0	5.95	20	149	41	28
20	MB	71.78687	129.40035	0.7	11.8	6.23	12	120	33	22
21	MB	71.78702	129.40028		9.5	5.76	15	140	31	20
22	MB	71.78702	129.39961		9.9	5.98	11	156	21	20
23	MB	71.78703	129.39934		8.3	5.73	33	106	66	44
24	MB	71.78718	129.39926	0.2	8.3	5.80	0	100	0	0

Table 1 (continued).
Таблица 1 (продолжение).

No	AREA	N	E	DEPTH	TEMP	PH	SALT	ORP	COND	TDS
25	MB	71.78712	129.39755		8.5	5.90	104	88	214	110
26	MB	71.78721	129.39703		9.5	5.66	27	70	46	34
27	MB	71.79087	129.38036	0.1	11.5	5.26	8	202	31	15
28	MB	71.79111	129.38016	0.2	10.3	4.82	0	186	0	0
29	MB	71.79108	129.38022		8.3	2.77	0	190	0	0
30	MB	71.79111	129.37953	0.5	9.6	5.10	16	164	27	21
31	MB	71.78645	129.39719	0.7	9.5	7.52	34	205	67	44
32	MB	71.78407	129.40381							
33	MB	71.78252	129.40111	0.3						
34	MB	71.78204	129.39914		8.1	4.22	32	180	66	44
35	MB	71.78423	129.39674		8.0	4.08	17	175	33	23
36	MB	71.78511	129.39992							
37	MB	71.78551	129.39653	0.3						
38	MB	71.78472	129.39511	0.4	8.3	5.21	0	181	0	0
39	MB	71.78382	129.39682	0.2	7.8	4.22	11	219	22	14
40	MB	71.78329	129.39862		7.9	5.06	16	181	30	19
41	UM	71.85961	129.34065		8.7	5.22	177	100	344	228
42	UM	71.85938	129.33861		9.1		164	126	338	228
43	UM	71.85928	129.33788		9.1		205	127	415	269
44	UM	71.85928	129.33707		8.7		170	116	346	229
45	UM	71.85979	129.33681		9.3		223	56	461	307
46	UM	71.85979	129.33482		8.2		284	-30	556	376
47	UM	71.85995	129.33488							
48	UM	71.86027	129.3349							
49	UM	71.86027	129.33514							
50	UM	71.86101	129.33803		9.0		344	111	688	457
51	MB									
52	MB	71.77942	129.41396		12.8		34		66	39
53	MB	71.77934	129.41415		13.3		25		82	40
54	MB	71.78687	129.38808		14.2		9		0	17
55	MB	71.7868	129.38608	0.2	14.8		0		14	0
56	MB	71.78629	129.38483	0.2	14.8		10		21	12
57	MB	71.78607	129.38023	0.2	13.0		20		22	22
58	MB	71.78567	129.37704	0.2	14.2		0		0	0
59	MB	71.78523	129.37421		14.2		9		23	14
60	MB	71.78568	129.37233		12.5		0		0	0

Abbreviations for regions: TIK — vicinities of settlement of Tiksi; MB — Mamontoviy Basagasa Alas, Bykovsky Peninsula; UM — Usun-Mas Alas, Bykovsky Peninsula.

Аббревиатуры для районов: ТИК — окрестности поселка Тикси; MB — Алас Мамонтовий Басагаса, Быковский полуостров; UM — Алас Усун-Мас, Быковский полуостров.

Table 2. List of Cladocera and Copepoda species recorded in the vicinities of Tiksi and on Bykovsky Peninsula in August 2015, and number of water bodies in which each species was found.

Таблица 2. Список видов Cladocera и Copepoda, найденных в окрестностях поселка Тикси и на Быковском полуострове в августе 2015 г., а также число водоемов, в которых они были найдены.

Taxa		Frequency (No of water bodies)
COPEPODA		
Cyclopoida	<i>Acanthocyclops venustus</i> (Norman et Scott, 1906)	12
	<i>Cyclops abyssorum</i> (Sars, 1863)	7
	<i>Cyclops</i> cf. <i>strenuus</i> Fischer, 1851	12
	<i>Cyclops kolensis</i> Lilljeborg, 1901	2
	<i>Diacyclops crassicaudis</i> (Sars, 1863)	2
	<i>Diacyclops languidoides</i> (Lilljeborg, 1901)	11
	<i>Eucyclops</i> sp.	1
	<i>Megacyclops gigas</i> (Claus 1857)	16
	<i>Megacyclops viridis</i> (Jurine, 1820)	11
	<i>Mesocyclops leuckartii</i> (Claus, 1857)	1
	<i>Paracyclops</i> sp.	1
Calanoida	<i>Acanthodiaptomus denticornis</i> (Wierzejski, 1887)	3
	<i>Arctodiaptomus bacillifer</i> (Koelbel, 1885)	1
	<i>Arctodiaptomus wierzejskii</i> (Richard, 1888)	9
	<i>Eurytemora lacustris</i> (Poppe, 1887)	3
	<i>Heterocope borealis</i> (Fischer, 1851)	20
	<i>Leptodiaptomus angustilobus</i> (Sars, 1898)	1
	<i>Mixodiaptomus theeli</i> (Lilljeborg in Guerne et Richard, 1889)	10
Harpacticoida	<i>Canthocamptus glacialis</i> Lilljeborg, 1902	14
CLADOCERA		
Daphnidae	<i>Daphnia middendorffiana</i> Fischer, 1851	13
	<i>Daphnia</i> cf. <i>pulex</i> Leydig, 1860	26
Bosminidae	<i>Bosmina</i> cf. <i>longispina</i> Leydig, 1860	4
Eurycercidae	<i>Eurycercus</i> cf. <i>glacialis</i> Lilljeborg, 1887	3
	<i>Eurycercus lamellatus</i> (O.F. Müller, 1776)	4
Chydoridae	<i>Acroperus harpae</i> (Baird, 1834)	1
	<i>Alona</i> cf. <i>affinis</i> (Leydig, 1860)	2
	<i>Alona guttata</i> Sars, 1862	5
	<i>Alonella exigua</i> (Lilljeborg, 1853)	6
	<i>Chydorus</i> cf. <i>sphaericus</i> (O.F. Müller, 1776)	26
	<i>Pleuroxus</i> cf. <i>trigonellus</i> (O.F. Müller, 1776)	1
Polyphemidae	<i>Polyphemus</i> cf. <i>pediculus</i> (Linnaeus, 1761)	6

stagnant lakes and those originated as creek impoundments. Such water bodies could not be subdivided into discrete types (i.e. in their size).

At each site, zooplankton samples were collected qualitatively by hauling a plankton net (diameter 0.2 m, 50 µm mesh) through the water column, engaging the upper layer of the bottom with the detached sediment filtered through

the net up to the surface. The samples were preserved with 96% ethanol. All the samples were taken from the shore. Environmental variables such as water temperature, pH, salinity, conductivity, TDS (total dissolved solids) and ORP (oxidation reduction potential) were measured by AMT03R meter (Amtast USA Inc.) only from the water bodies of Bykovsky Peninsula, but not from Tiksi region (Table 1).

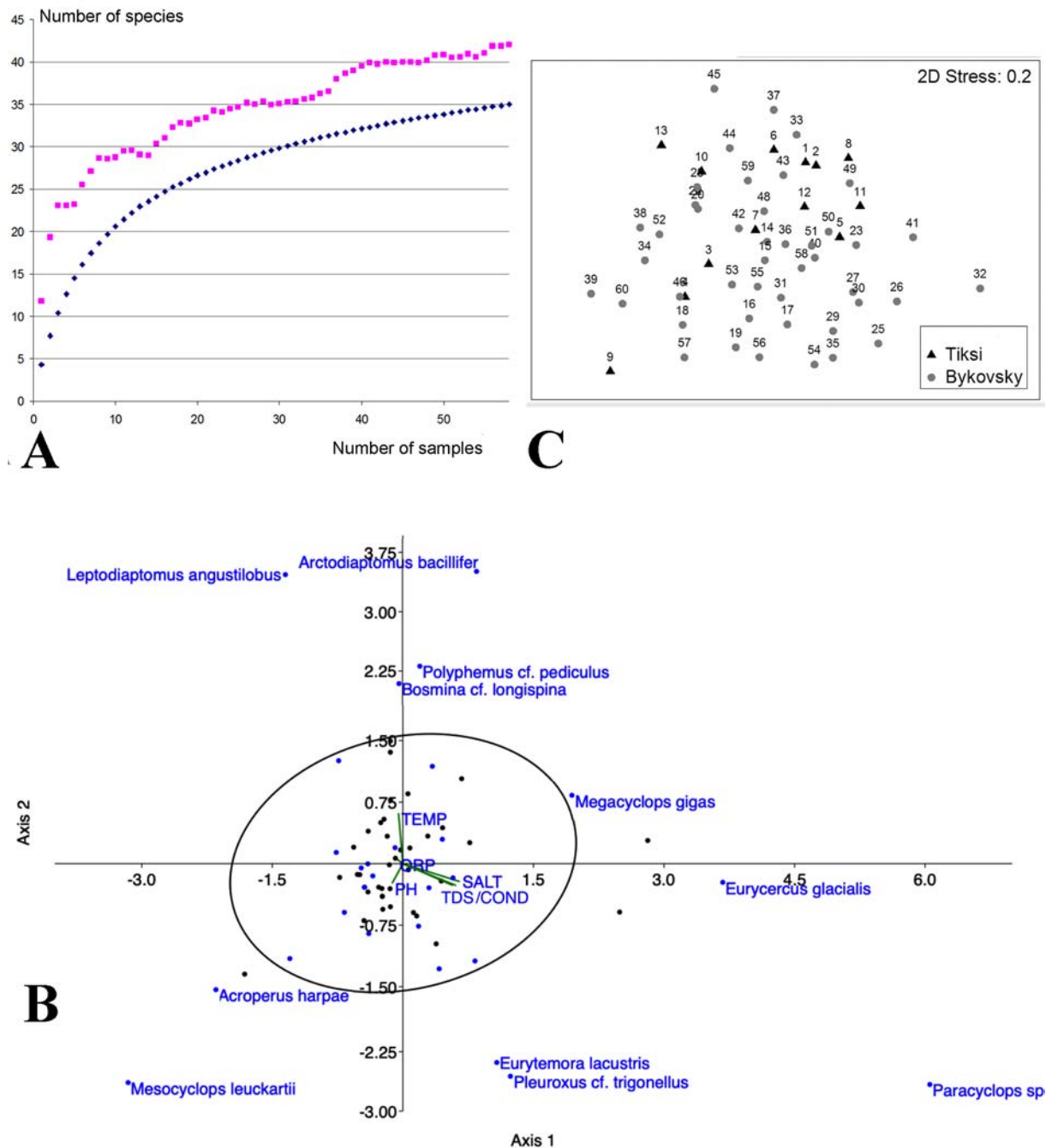


Fig. 2. Analysis of the microcrustacean fauna and communities in the water bodies in the vicinities of Tiksi and on Bykovsky Peninsula. A — species (Cladocera and Copepoda) accumulation curves depending on the number of analyzed samples from Bykovsky Peninsula and its vicinities: empiric (lower blue dots) and estimated (upper red dots) curves; B — results of CCA of the microcrustacean communities in the studied water bodies on Bykovsky Peninsula (species indicated only outside the 95% confidence ellipse area); C — MDS ordination of waterbodies from different localities (Tiksi and Bykovsky) according the species composition.

Рис. 2. Анализ фауны и структуры сообществ микроскопических ракообразных водоемов окрестностей Тикси и Быковского полуострова. А — кумулятивная кривая накопления видов (Cladocera и Соперода) в зависимости от числа проб с Быковского полуострова и прилегающих районов: эмпирическая (синие точки, нижняя) и модельная (красные точки, верхняя) кривые; В — результат анализа канонических соответствий (ССА) сообществ микроскопических ракообразных в исследованных водоемах Быковского полуострова (названия указаны только для видов не входящих в 95% доверительную область); С — MDS-шкалирование водоемов из разных участков исследованной территории (Тикси и Быковский) по видовому составу.

Preliminary species identification and counting was carried out in Bogorov counting chambers; the total numbers of Cladocera and Copepoda were recorded. The qualitative data was used to reveal dominant and rare species and the ratio of species in the community. Statistical analyses performed for qualitative data, *i.e.* considered only presence or absence of species. High power microscope Olympus CX-41 was used for accurate crustacean identification followed both standard taxonomic treatises [Rylov, 1948; Borutsky, 1952; Dahms *et al.*, 2006; Alekseev, Tsalolikhin, 2010] and recent taxonomic revisions [Sinev, 2002, 2009; Kotov, Bekker, 2016; Garibian *et al.*, 2018].

For estimation of the contribution of the identified species to the potential species pool of the studied area, the accumulation curves of the number of species were plotted depending on the number of samples analyzed. We used the computer package EstimateS [Colwell, 2013] to estimate species richness of the cladocerans and copepods in the region.

A canonical correspondence analysis (CCA) was used to reveal the impact of environmental variables on the invertebrate community. The analysis was performed using PAST software [Hammer *et al.*, 2001] for qualitative data on the water bodies of Bykovsky Peninsula (sites 14–60). The whole species list, including both rare and dominant species was applied.

To represent the faunistic relationships among water bodies from different localities in low-dimensional space, a non-metric multidimensional scaling (nMDS) ordination was performed using PRIMER software [Clarke, Gorley, 2001]. The faunal similarity was estimated using the Kulczynski index (K) for the qualitative data: $K = (M/N1 + M/N2)/2$, where N1 and N2 are the total numbers of taxa present in the compared lists and M is the number of common taxa. This index is independent of joint absence and is moderately sensitive to differences in the total length of the compared lists, making it preferential for potentially incomplete data [Clarke, Warwick, 2001].

Results

We identified 35 crustacean species and taxa: 19 copepod species (belonging to 14 genera) and 16 branchiopod species (12 genera) (Table 2). Seven of these crustaceans have not previously been recorded from the neighboring territories of NE Siberia, although they are quite widespread through the northern Palaearctic: two calanoids (*Acanthodiptomus denticornis*, *A. wierzejskii*), three cyclopoids (*Acanthocyclops venustus*, *Diacyclops crassicaudis*, *D. languidoides*) and two cladocerans (*Eurycercus cf. glacialis*, *Pleuroxus cf. trigonellus*).

Microcrustacean diversity in the studied water bodies was low, and averaged 4.7 species (ranging from 0 to 10). The most common and abundant species in the planktonic samples were the cladocerans *Daphnia pulex* and *Chydorus cf. sphaericus* and copepod *Heterocope borealis*. They occurred in more than 20 localities each (34–45%). *D. middendorffiana*, *Canthocamptus glacialis*, *Megacyclops gigas*, *M. viridis*, *D. languidoides*, *Cyclops cf. strenuus* and *A. venustus* were also quite frequent in the samples and occupied in 19–24% of the

investigated water bodies. Almost half of the species (9 copepods and 6 cladocerans) were rare and occurred only in one to four water bodies. Our analysis reveals that neither sample-based rarefaction curve nor the best species richness estimator (Chao 1) curve reaches a plateau (Fig. 2A). Therefore, the cladoceran and copepod biodiversity of the region is still incompletely studied, but only few additional taxa could be found here, and a preliminary analysis on the biodiversity could be made in such a situation.

Majority of observed species (>80%) has wide Palearctic and Holarctic distribution areas (Table 3). Only five of the species (*Heterocope borealis*, *Leptodiptomus angustilobus*, *Canthocamptus glacialis*, *Daphnia middendorffiana*, *Eurycercus cf. glacialis*) are limited to the Arctic area and are specific only for high latitudes of the northern hemisphere.

The investigated lake analysis revealed that the zooplankton communities of most lakes and ponds are relatively similar both in community structure and species composition. Most of the lakes are characterized by a combination of high abundances of small and large crustaceans. Thus, large copepods like *Heterocope borealis* and large cladocerans *Daphnia pulex* and *D. middendorffiana* coexist with small cyclopoid copepods and small chydorids. The same trend was observed for the thermokarst lakes of the Lena River Delta region [Abramova *et al.*, 2017]. The species composition of big foodplain lakes in the Lena River Delta region differs from the small ones. Several rather big lakes of Bykovsky Peninsula with rare species stay a little bit separately too (Fig. 2C).

CCA indicated complex relationships between assemblage composition and habitat variables measured in this study (Fig. 2B, Table 4). Vectors superimposed on the CCA ordination plot graphically represented the correlations between environmental variables and assemblage structures. First two canonical axes explained together 56% of the response table's inertia. The first axis accounted for 36% of the total variation in zooplankton assemblage and mainly correlated with water salinity, conductivity; this axis discriminates sharply the two localities with the maximal values of salinity, and with the noticeable role of *Eurycercus cf. glacialis* and *Megacyclops gigas*. The salinity varied in the range from 0 to 344 ppm; the conductivity ranged from 0 to 688 μ S. The second axis (20% of the total variation) was mainly related to water temperature (varied from 7.8 to 14.8°C). Along this axis, the stations were arranged gradually from cold-water bodies preferred by *Eurytemora lacustris*, *Pleuroxus trigonellus*, *Mesocyclops leuckartii* and *Acroperus harpae*, to the warm waters, where *Arctodiptomus bacillifer*, *Leptodiptomus angustilobus*, *Polyphemus cf. pediculus* and *Bosmina cf. longispina* were the characteristic species.

The comparison of the samples by the nMDS (Fig. 2C) method does not show a significant separation of the crustacean assemblages in the water bodies of Tiksi vicinities, subjected to a moderate anthropogenic im-

Table 3. Crustacean species from Bykovsky Peninsula belonging to different groups and biogeographical regions.
Таблица 3. Принадлежность видов ракообразных, выявленных на Быковском полуострове, к систематическим группам и биогеографическим регионам.

Cladocera		Copepoda		
Anomopoda	Onycopoda	Calanoida	Cyclopoida	Harpacticoida
36%	3%	22%	36%	3%
11 species	1 species	7 species	11 species	1 species
Whole Holarctic		Whole Palaearctic		Arctic (north of Holarctic / Palaearctic)
41%		41%		18%
12 species		12 species		5 species

Table 4. Results of the CCA of the taxonomical composition of the microcrustacean communities in the water bodies of Bykovsky Peninsula.

Таблица 4. Результаты ССА таксономического состава микроскопических ракообразных водоемов Быковского полуострова.

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.26296	0.16155	0.1456	0.10749
%	35.96	22.09	19.91	14.7
Permutation	0.244	0.62	0.232	0.21
Intraset correlations of environmental variables with axes				
	Axis 1	Axis 2	Axis 3	Axis 4
TEMP	-0.0464	0.6161*	0.0327	0.0936
PH	-0.1249	-0.2199	-0.2746	-0.1311
SALT	0.6529*	-0.2217	-0.0044	0.1837
ORP	-0.0654	0.0503	-0.0820	-0.3322
COND	0.6094*	-0.2866	0.1481	0.0243
TDS	0.5711*	-0.2851	0.1718	0.1831

* verifiable correlations

pact, and in undisturbed water bodies of the Bykovsky Peninsula. The analyzed samples compose a single group, that indicates the high similarity of the Cladocera and Copepoda species complexes in the compared lakes and ponds.

Discussion

Following recent phylogeographic studies [Crease *et al.*, 2012; Kotov *et al.*, 2016] and conventional taxonomic revisions based mainly on the male characters [Kotov, Bekker, 2016; Garbian *et al.*, 2018], we know that a significant portion of the cladoceran taxa revealed here belong in reality to cryptic species complexes. Therefore, in some cases we cannot make an accurate conclusion on the biogeographic traits of the taxa. But, surprisingly, only *D. middendorffiana* and *Eurycercus* cf. *glacialis* are truly Arctic species, while other Arctic taxa (for example, *D. longiremis* or *D. umbra*) are absent on Bykovsky Peninsula and neighbouring territory. The species diversity of the area

investigated is significantly lower as compared to the total microcrustacean diversity of northeastern Siberia (from the lower reach of the Khatanga River to the Lena River Delta), where 98 species (34 Cladocera and 64 Copepoda) are reported [Pirozhnikov, Shulga, 1957; Colbourne *et al.*, 1998; Abramova, 2003; Abramova *et al.*, 2009, 2017; Sobakina *et al.*, 2009; Vishnyakova, Abramova, 2009; Alekseev, Defaye, 2011; Abramova, Vishnyakova, 2012; Korovchinsky *et al.*, 2012; Frolova *et al.*, 2013, 2016; Nigamatzayanova *et al.*, 2014; Abramova, Zhulay, 2016]. However, several species have not been previously documented from the neighboring regions: *Acanthodiptomus denticornis*, *Arctodiptomus wierzejskii*, cyclopoid copepods *Acanthocyclops venustus*, *Diacyclops crassicaudis*, *D. languidoides*, *Eurycercus* cf. *glacialis*, *Pleuroxus* cf. *trigonellus*.

Among the copepods, calanoids *A. denticornis* and *A. wierzejskii*, recorded for the first time for the NE Siberia, are eurybiotic species [Borutsky *et al.*, 1991; Alekseev, Tsalolikhin, 2010]. Both species are eurythermic and euryhaline, living in freshwater and brackish

water bodies of various hydrological types and size. *A. denticornis* is also characteristic for mountain lakes at altitudes from 500 to 2500 m [Borutsky *et al.*, 1991]. *A. wierzejskii* is distributed in the Palaearctic in a large latitudinal range from the Bolshezemelsky Tundra to Central Asia, and *A. denticornis* has a Holarctic circumpolar range [Borutsky *et al.*, 1991; Fefilova, 2015]. *A. venustus* and *D. languidoides*, as well as *D. crassicaudis*, are typical for the shallow-water swampy water bodies of the northern regions; to the south these species are found in springs or highland water bodies [Alekseev, Tsalolikhin, 2010; Rylov, 1948]. The first two species are Palearctic, and the third has Holarctic circumpolar range [Alekseev, Tsalolikhin, 2010; Fefilova, 2015].

In general, most taxa recorded in this study are Palearctic or Holarctic with wide latitudinal ranges (Table 3); the latter are confirmed by genetic studies for several members of cryptic species complexes [Crease *et al.*, 2012; Kotov *et al.*, 2016]. Most taxa revealed in the region of this study have wide temperature ranges [Rylov, 1948; Borutsky *et al.*, 1991; Alekseev, Tsalolikhin, 2010; Fefilova, 2015]. The exception is *Acanthocyclops venustus*, which, although widespread in the Palearctic, is exceptionally cold-water, and is noted only in springs and wells south of the Polar Circle [Alekseev, Tsalolikhin, 2010]. Similar trend in the composition of species areas has been previously noted for plankton crustaceans of other high-altitude regions: Svalbard [Dimante-Deimantovica *et al.*, 2018], Iceland [Novichkova *et al.*, 2014], Shokalsky island [Novichkova, Chertoprud, 2017] and Bering Island [Novichkova, Chertoprud, 2016].

Although the observed crustacean communities are relatively similar to those from the thermokarst lakes of the Lena River Delta, we found some exceptions from this rule. It was previously shown that the small cladocerans *Bosmina longirostris* and *Chydorus sphaericus* are typical inhabitants of the large thermokarst lakes on Samoylov Island, together with the larger *Daphnia pulex* and two Anostraca species, *Polyarthemia forcipata* and *Branchinecta paludosa*. Among calanoid copepods, *Eudiaptomus graciloides*, *L. angustilobus* and *H. borealis* are the dominant copepods in the thermokarst lakes in August [Abramova *et al.*, 2017]. Most of these species are also typical for the observed water bodies of the neighbourhood of Tiksi and Bykovsky Peninsula. Cyclopoid copepods occur in the samples regularly but are much less numerous.

The results of CCA indicated that assemblage structure was correlated mainly with conductivity/salinity and temperature. The correlation between the species composition of the zooplankton community and temperature and mineralization of water for small water bodies of high latitudes is noted in many previous publications [Novichkova, Chertoprud, 2017; Walseng *et al.*, 2018; Jensen *et al.*, 2019]. At the same time, the variability of mineralization of the water body usually correlates with the distance from the sea and/or nesting

places of geese on the banks of the water body [Walseng *et al.*, 2018; Jensen *et al.*, 2019, etc.]. In turn, the temperature factor is usually related to the altitude and distance to the focuses of glaciation [Walseng *et al.*, 2018]. It is known that inter-annual temperature fluctuations causing alternation of warm and cold summer seasons in high latitudes can significantly influence the composition of the fauna of Arctic water bodies [Novichkova, Chertoprud, 2017; Dimante-Deimantovica *et al.*, 2018]. Due to the accumulation of the resting stages of microcrustaceans in bottom sediments of water bodies, species of more southern regions may temporarily appear in communities in case of favorable temperature conditions [Novichkova, Chertoprud, 2017].

According to our data, *Eurycercus cf. glacialis* and *Megacyclops gigas* are characteristic of water bodies with relatively high mineralization and conductivity (not more than 344 ppm and 688 iS, responsibly). Both these species are able to inhabit a wide range of water bodies and have been previously documented for such lakes [Rylov, 1948; Bekker, Kotov, 2012]. The latter species occurs even in brackish-water lakes [Rylov, 1948]. However, variations in the hydrochemical parameters of the comparing lakes of the Bykovsky Peninsula are not significant, all the puddles and lakes considered are freshwater. The range of differences in temperature is also relatively small — only 7 °C. It is necessary to take into account that the temperature of water in Arctic water bodies can vary significantly during the day, which is connected both with their rapid warming due to small depth and mainly dark color of the bottom, and severe weather variability [Grigoriev, 1956]. Relatively warm waters are inhabited by *Arctodiaptomus bacillifer*, *Leptodiaptomus angustilobus*, *Polyphemus pediculus* and *Bosmina cf. longispina*. Apart from *L. angustilobus* all these species prefer quite warm water. Thus, the optimum temperature for the development of *P. pediculus* is 17–21 °C [Butorina, 1971]. Following recent climatic changes *B. cf. longispina* has propagated from temperate latitudes to Arctic water bodies [Walseng *et al.*, 2018]. *A. bacillifer* is distributed in the wide temperature ranges and inhabits water bodies of both, steppe and tundra zones [Borutsky *et al.*, 1991; Sergeeva, Yevdokimov, 2016]. The only typical coldwater species in this group is *L. angustilobus* inhabiting tundra water bodies [Borutsky *et al.*, 1991]. For cold water bodies, *Eurytemora lacustris*, *Pleuroxus trigonellus*, *Mesocyclops leuckartii* and *Acroperus harpae* are typical. However, only *E. lacustris* is a real cold-water taxon. This species is considered a ‘classical’ glacial relict species in central Europe [Maier *et al.*, 2011]. *E. lacustris* requires cold (around 10 °C) and well-oxygenated (>1 mg O₂ L⁻¹) waters [Patalas, Patalas 1966; Kasprzak *et al.*, 2005; Karpowicz, Kalinowska, 2018]. Oppositely, *M. leuckartii*, is relatively warm-water, it develops in 15–20 °C [Rylov, 1948], but has a wider distribution range — from tropics to Arctic [Fefilova, 2015]. Two cladoceran species (*P. trigonellus*, *A. har-*

pae) inhabit wide temperature range of water bodies, dwelling on the bottom and in the phytal zone [Aleksseev, Tsalolikhin, 2010]. Thus, the dominance of certain species in a particular water body in some cases may result from stochastic processes and be determined by the founder effect and subsequent water body monopolization [De Meeester *et al.*, 2002]. Probably, the local dominance of cold-water species in warmed water bodies could be explained by such reasons.

According to the non-metric multidimensional scaling, the species composition of Cladocera and Copepoda does not differ in the water bodies from Tiksi and from Bykovsky Peninsula. The domination structure in the microcrustacean species assemblages of two compared regions is almost similar, while the number of species differs significantly (11 in Tiksi and 29 in Bykovsky Peninsula). The overlap between the species lists of these areas is only 81%. Only two species, *Acanthocyclops denticornis* and *Diacyclops crassicaudis*, were found exclusively in the water bodies within the settlement. The reduced species richness and simplification of the species assemblages structure is characteristic for the water bodies exposed to pollution [Walseng *et al.*, 2018]. In general, zooplankton communities of high altitudes are very poor and driven, first of all, by the temperature factor and availability of food resources [Novichkova, Chertoprud, 2017; Walseng *et al.*, 2018; Jensen *et al.*, 2019]. Against this backdrop, a moderate anthropogenic impact has almost no effect on the distribution of dominant microcrustacean species, but leads to a significant reduction in taxonomic diversity due to the decrease of the number of rare species.

Acknowledgements. Many thanks to E.I. Izjumova, A.N. Maleeva, O.V. Levochkina, V.V. Skosar', V.E. Tumskoy, A.A. Zharov for their assistance during the works at Bykovsky Peninsula, R.J. Shiel for linguistic corrections in earlier draft. The study of Cladocera is supported by the Russian Science Foundation (grant 18-14-00325).

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Responsible editor V.A. Spiridonov