



Macrozoobenthic communities of the saline Bolshaya Samoroda River (Lower Volga region, Russia): species composition, density, biomass and production

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Abstract We investigated species composition, density, biomass and estimated production of macrozoobenthos communities in the middle and mouth reaches of the saline Bolshaya Samoroda River (Volgograd region, Russia) from May 2013 to April 2014. A total of 30 euryhaline and halophilic taxa were found during the study period. There were significant differences in the species composition between both study sites that could be explained by differences in ecological conditions. The production of

macrozoobenthos in the middle reach was 22.54 g dry wt m⁻² yr⁻¹, and in the mouth reach the production was 117 g dry wt m⁻² yr⁻¹. In all seasons of the year at both sites, the greatest contribution to benthic production was made by the same taxonomic groups. Diptera dominated at both sites. Amphipods were abundant only in the middle reach. In the middle reach, the greatest contributions to production were made by *Gammarus lacustris*, *Sphaeromias pictus* and *Glyptotendipes salinus*, and in the mouth reach, *Microchironomus deribae*, *Tanytarsus kharaensis* and *Chironomus salinarius* contributed to benthic production the most.

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Introduction

The importance of stream productivity for surrounding terrestrial habitats has been shown in many studies (Nakano et al. 1999; Nazarova et al. 2004; Baxter et al. 2005; Ballinger and Lake 2006; Moore et al. 2007; Benke and Huryn 2010; Zinchenko et al. 2014; Benke and Huryn 2017; Golovatyuk et al. 2018). These works have demonstrated that rivers can supply the surrounding terrestrial ecosystems with nutrients and energy via the emergence of aquatic insects. However,

all these studies were conducted on freshwater lotic systems. In contrast to freshwater streams, practically no studies examining energy and matter fluxes from saline rivers to the surrounding landscape have been performed until now (Zinchenko et al. 2014), although saline rivers are widespread in arid zones of the world and play a large role in maintaining the biodiversity of these ecologically sensitive regions (Moreno et al. 2001; Piscart et al. 2005; Palmer and Bennett 2006). Among the various groups of aquatic organisms living in saline rivers, macrozoobenthic organisms play an important role in the flow of matter and energy from aquatic to terrestrial ecosystems, as they serve as a food source for a number of species of fish, waterfowl, reptiles and mammals (Ballinger and Lake 2006; Kasatkina and Shubin 2012; Sukharev 2015). Benthic invertebrates in saline rivers have a physiological tolerance to salinity gradients and are adapted to habitats that undergo constant changes in abiotic factors (Velasco et al. 2006; Golovatyuk and Shitikov 2016).

The arid region around the hyperhaline Lake Elton (Caspian lowland, southeastern European Russia) includes seven saline rivers that run into the lake. These rivers are used as feeding places not only by indigenous birds but also by migratory waterfowl on their transcontinental and inland migration routes. During the migration stops, many species of sandpipers, such as the common *Charadrius hiaticula*, *Ch. dubius*, *Ch. alexandrinus* and *Phalaropus lobatus*, have high abundances here (Kasatkina and Shubin 2012; Sukharev 2015). Surveys have shown that macrozoobenthic organisms play a main role in the diet of many species of migratory waders (Andrei et al. 2009; Kasatkina and Shubin 2012). In the rivers of the catchment area of the lake, Elton chironomids accounted for up to 48–95% of the diet of different species of birds, and Ephydriidae accounted for up to 18–96% (Sukharev 2015).

Currently, the reduction in the populations of some species of wader fauna is associated with a deterioration in the feeding conditions that occur at their migratory stop locations (Brown et al. 2001; Fellows et al. 2001; International Wader Study Group 2003), which makes an evaluation of the macrozoobenthic production of saline rivers that are used by migratory birds, such as rivers in the catchment of the hyperhaline Lake Elton, especially important.

The main goal of our work was to study the species composition, seasonal dynamics of density and biomass of the main groups of macrozoobenthos in the middle reaches and at the mouth of the saline Bolshaya Samoroda River that belongs to the catchment of the hyperhaline Lake Elton and to estimate their production in relation to the salinity gradient and to other ecological conditions.

Materials and methods

Study site

The Bolshaya Samoroda (B. Samoroda) River (49°07', 46°47') is a saline river in the catchment of the hyperhaline Lake Elton, located in the Volgograd region of the Russian Federation (Fig. 1). This is an arid area with an annual precipitation below 280 mm y^{-1} . The climate is continental with an air temperature minimum in January of -36.1 °C and a maximum in August of 41.1 °C (Vodno-bolotny... 2005). The B. Samoroda River is 24.3 km long, with a catchment area of 130 km². The B. Samoroda River has a permanent flow in the middle and lower reaches, whereas the flow is intermittent at the upper reaches, especially during dry years.

Two sampling stations with different levels of salinity were selected for the present study: Site 1 in the middle reach and Site 2 in the mouth of the river. The main characteristics and hydrochemical parameters of the B. Samoroda River at Sites 1 and 2 are given in Table 1.

Sampling and laboratory analysis

Two integrated samples for quantitative of macrozoobenthos analysis were taken monthly from May 2013 to April 2014 using Ekman-type grab sampler (surface area 25 cm²) (Zinchenko et al. 2014). Each integrated sample consisted of eight samples taken from one sampling station at one date. In total, we sampled and analyzed 48 integrated samples. Average monthly density and biomass of macrozoobenthos at each sampling site were estimates from the integrated monthly samples.

Samples were washed in the field using a mesh screen with 300–310- μ m mesh size and preserved in 4% formaldehyde. Benthic organisms were

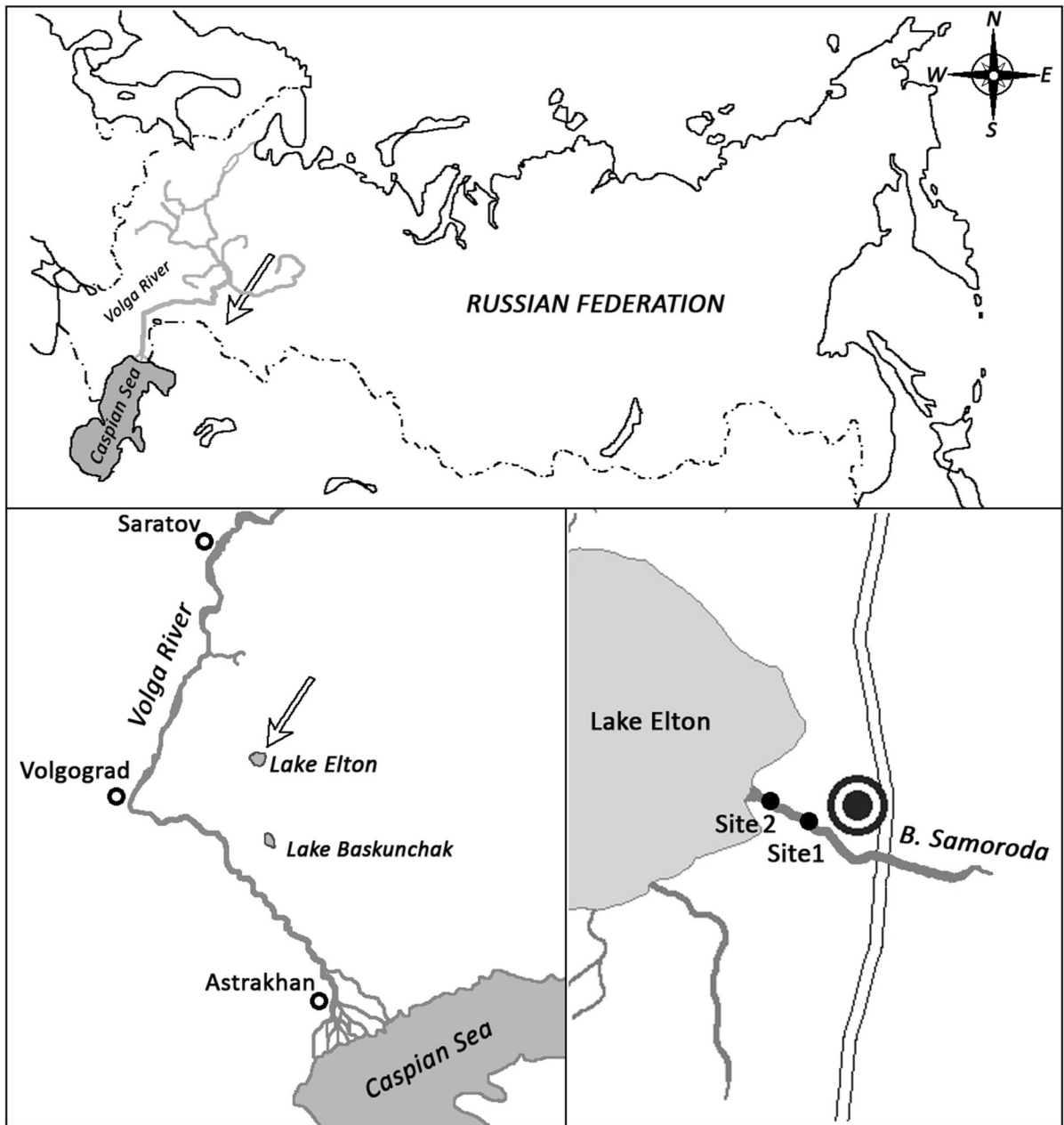


Fig. 1 Map of the study area

handpicked in laboratory under a stereomicroscope, identified, counted and weighed using electronic scales (Pioneer TM) with a resolution of 0.01 g. Ecological information on the macrozoobenthos species was taken from Zinchenko et al. (2014), Golovatyuk and Shitikov (2016), Szadziewski et al. (2016), and Zinchenko et al. (2017).

Concentration of chlorophyll-*a* was measured in May, August and September 2013 by spectrophotometry, using extraction in acetone (Nomokonova et al. 2013). Concentration of chlorophyll-*a* was measured to assess the relationship between primary production and the production of macrozoobenthos.

The number of generations of *Gammarus lacustris* during a year of investigation (May 2013–April 2014)

Table 1 Characteristics and hydrochemical parameters (min–max) of the sampling sites of the B. Samoroda River from May 2013 to April 2014

Parameter	Site 1	Site 2
Depth (m)	0.2–1.0	0.05–0.80
Width (m)	3.5–8.0	5.0–35.0
Temperature (°C)	4.0–25.6	4.0–27.6
Current velocity (m s ⁻¹)	0.2–0.24	0.02–0.03
Vegetation (%)	30–70	10–30
pH	7.4–8.2	7.8–8.7
Dissolved O ₂ (mg l ⁻¹)	6.2–31	6.9–25.3
Salinity (g l ⁻¹)	5.2–8.5	5.8–26.3
Chlorophyll-a (mg m ⁻³)	7.3–19.4	4.9–18.8
Na ⁺ +K ⁺ (g l ⁻¹)	1.44–2.09	1.86–5.5
Ca ²⁺ (g l ⁻¹)	0.28–0.36	0.3–0.6
Mg ²⁺ (g l ⁻¹)	0.22–0.41	0.3–2.6
Cl ⁻ (g l ⁻¹)	3.22–3.91	3.36–15.9
SO ₄ ²⁻ (g l ⁻¹)	0.41–1.44	0.51–1.28
HCO ₃ ⁻ (g l ⁻¹)	0.48–0.59	0.43–0.62
Total P (mg l ⁻¹)	1.06–2.0	1.1–1.43
NH ₄ ⁺ -N (mg l ⁻¹)	1.06–2.33	0.18–1.8
NO ₃ ⁻ -N (mg l ⁻¹)	0.06–1.06	0.09–1.03

was estimated by the method described by Bazikalova (1945).

At each sites of B. Samoroda River, we used field analytical instruments for measuring pH (HANNA pH Tester HI 98127), oxygen content (HANNA Oximeter HI 9146) and water velocity (ISP-1). Hydrochemical analysis (Table 1) was performed in the Hydrochemical Laboratory “Center for Monitoring of Water and Geological environment” in Samara, Russian Federation. Water temperature was measured at each sampling site and date at 15-min intervals during 24 h (WTW, MultiLine, Germany). For our study, we used an average monthly temperature. Overgrowth or macrophytes density at the sampling sites was estimated as a ratio of the area occupied by macrophytes at the 5-m-long river section to the entire area of this section, expressed in %.

Calculation of macrozoobenthos production

Daily production P (g m⁻² day⁻¹) of macrozoobenthos was estimated as

$$P = GB \quad (1)$$

where G (day⁻¹) is the daily instantaneous growth rate and B (g m⁻²) is the biomass and dry weight (Benke 1998). The growth rate for family Ceratopogonidae, subfamilies Orthoclaadiinae and Chironominae, other Diptera, Coleoptera and Heteroptera was calculated by equations developed by Golubkov (2000):

$$\text{Orthoclaadiinae} : G = 0.0126e^{0.121T} \quad (2)$$

$$\text{Chironominae} : G = 0.0084e^{0.149T} \quad (3)$$

$$\text{Ceratopogonidae} : G = 0.0041e^{0.116T} \quad (4)$$

$$\text{Diptera(others)} : G = 0.0075e^{0.143T} \quad (5)$$

$$\text{Coleoptera} : G = 0.0049e^{0.092T} \quad (6)$$

$$\text{Heteroptera} : G = 0.007e^{0.095T} \quad (7)$$

where T (°C) is temperature.

These equations can be used to express calculations of production of aquatic insects (Golubkov 2000) when the data on growth rates are available not for all species of aquatic organisms from the studied macrozoobenthos community.

The production of Oligochaeta was calculated using a growth rate of 0.03 (Zaika 1972). A growth rate of 0.03 was used to calculate the production of *G. lacustris* based on studies from the brackish Lake Shira (Yemelyanova et al. 2000).

Monthly production was calculated by multiplying the average daily production for all sampling dates by 31 days (January, March, May, July, August, October and December), 30 days (April, June, September and November) or 28 days (February) (Zinchenko et al. 2014).

Numerical methods

Detrended correspondence analysis (DCA) with detrending by segments was performed on the macrozoobenthos data (rare taxa downweighted) to explore the main pattern of taxonomic variation among sites and to determine the lengths of the sampled environmental gradients, from which we decided whether unimodal or linear statistical techniques would be the most appropriate for the data analysis (Birks 1995; Palagushkina et al. 2012, 2017; Frolova et al. 2013).

The gradient length of species scores was relatively long. DCA axes 1 and 2 were 4.265 and 2.525 standard deviation units, respectively, indicating that numerical methods based on a unimodal response model were the most appropriate to assess the variation in the structure of zoobenthos assemblages (ter Braak 1995).

Relationships between macrozoobenthos distribution and environmental variables were assessed using a set of canonical correspondence analyses (CCA) with each environmental variable as the sole constraining variable (Nazarova et al. 2015). The percentage of the variance explained by each variable was calculated. Manual forward selection was used to identify a subset of environmental variables that explained significant variations in the macrozoobenthos data (Nazarova et al. 2017). The statistical significance of each forward-selected variable was tested by a Monte Carlo permutation test (999 unrestricted permutation, $p \leq 0.05$) (ter Braak 1990). With the selection of each variable in forward selection, the relative importance of the remaining variables is re-evaluated. Relationships between the significant environmental variables and the individual CCA axes were examined through correlation coefficients and t values. Both DCA and CCA were performed using CANOCO 4.5 (ter Braak and Šmilauer 2002b).

Results

Species composition

In total, 30 taxa of benthic invertebrates were found during the entire study period. Diptera and Oligochaeta were the richest taxonomic groups, with 18 and 5 species, respectively. Four species of Coleoptera, two species of Heteroptera and one species of Amphipoda were also recorded.

In the middle reaches (Site 1), 18 taxa were found, and 21 taxa were found at the mouth site (Site 2). There was a significant faunistic difference between the two sampling sites: 9 species were found only at Site 1 and 13 species only at Site 2. At Site 1, *G. lacustris*, *Limnodrilus profundicola* and *Sphaeromias pictus* had the highest frequencies (> 50%), while at Site 2, *Cricotopus* gr. *sylvestris*, *Chironomus salinaris*, *Tanytarsus kharaensis*, *Cricotopus salinophilus*

and *Microchironomus deribae* had the highest frequencies (Tables 2, 3).

Ordination of the data

CCA with all seven environmental variables (water temperature, water velocity, total phosphorus, overgrowth—macrophyte density, water depth, pH and salinity) resulted in a CCA axis 1 of 0.713 and a CCA axis 2 of 0.267, explaining 31.5% and 43.4% of the variance in the data, respectively (Table 4). Juggins (2013) suggests that a ratio of eigenvalues of CCA axes 1 and 2 (λ_1/λ_2) below 1 indicates that potential factors affecting assemblages besides the explored variables have not been assessed. In our study, this ratio is 2.67 ($\lambda_1/\lambda_2 = 0.713/0.267$), which indicates that the most important explanatory variables are most likely included in the analysis.

The forward selection reveals that four of seven explanatory variables were statistically significant ($p \leq 0.05$): vegetation, water velocity, pH and salinity (Table 5).

The CCA eigenvalues for axes 1 (0.679) and 2 (0.241) constrained by the four significant environmental variables (Table 4) are only slightly lower than those obtained for axes 1 and 2 from CCA for all seven environmental variables, suggesting that the four selected variables explain the major gradients in the macrozoobenthic community data.

Axis 1 of the CCA most strongly correlates with vegetation (Table 6). The canonical coefficient is the highest in absolute value, and the t value is greater than 2.1, the critical value for a t test at the 5% significance level (ter Braak and Šmilauer 2002a). Axis 2 correlates with vegetation, water velocity, pH and salinity. Axis 3 correlates with pH and water velocity, and axis 4 correlates with salinity.

A CCA biplot of the sample scores shows that both sampling sites are plotted separately, confirming their taxonomic differences: All samples taken from Site 1 (S1) are grouped in the right part of the biplot, and all samples taken from Site 2 (S2) are grouped in the left part of the diagram. Additionally, the distribution of the samples taken at different dates reflects a seasonal shift in the taxonomic composition of the benthic communities: Samples taken in the early vegetation season are plotted in the lower part of the biplot when the water velocity was higher and the salinity lower, and the samples from the late season are grouped in the

Table 2 List of benthic macroinvertebrates, their frequency (F , % of samples), average density (D , ind. m^{-2}), average biomass (B , g dry wt m^{-2}), summary production (P , g dry wt $m^{-2} yr^{-1}$) and P/B values at Site 1 in the B. Samoroda River from May 2013 to April 2014; salinity ranges

at which these taxa were found at the Site 1 of the B. Samoroda River from May 2013 to April 2014 (S_B , g l^{-1} , min–max) and salinity ranges (S , g l^{-1} , min–max)) at which these taxa were found in the rivers of the Elton Lake basin during our earlier studies (Golovatuk and Shitikov 2016)

Taxa	F	D	B	P	P/B	S_B	S
Oligochaeta							
<i>Limnodrilus hoffmeisteri</i> Claparede, 1862	13	60	0.002	0.014	7	7.1–7.3	7–13
<i>Limnodrilus profundicola</i> (Verril, 1871)	53	400	0.118	0.984	8	5.2–8.5	5–14
<i>Limnodrilus udekemianus</i> Claparède, 1862	7	10	0.008	0.07	9	5.2–5.6	4–7
<i>Nais elinguis</i> Müller, 1773	13	217	0.029	0.246	8	5.6–7.3	4–26
<i>Paranais simplex</i> Hrabe, 1936	40	1183	0.032	0.269	8	5.6–7.8	4–26
Malacostraca							
<i>Gammarus lacustris</i> Sars, 1863	67	1570	1.86	15.34	8	5.2–8.5	5–16
Insecta							
Heteroptera							
<i>Paracorixa concinna</i> (Fieber, 1848)	27	13	0.012	0.18	15	7.3–7.6	6–13
Coleoptera							
<i>Hydrobius fuscipes</i> Leach, 1815	7	3	0.002	0.03	15	7.3–7.6	7–16
Diptera							
Psychodidae							
<i>Psychoda</i> sp.	7	57	0.003	0.22	73	7.3–7.6	7–26
Ceratopogonidae							
<i>Culicoides riethi</i> Kieffer, 1914	20	87	0.001	0.016	16	7.3–7.8	4–32
<i>Dasyhelea</i> sp.	7	3	0.002	0.005	3	7.3–7.6	7–17
<i>Sphaeromias pictus</i> (Kieffer, 1919)	53	473	0.119	1.93	16	5.6–8.5	5–12
Chironomidae							
<i>Cricotopus ornatus</i> (Meigen, 1818)	20	107	0.015	1.02	68	7.1–7.8	7–16
<i>Cricotopus salinophilus</i> Zinchenko. Makarchenko et Makarchenko, 2009	13	17	0.002	0.14	70	7.3–7.8	4–32
<i>Cricotopus</i> sp.	13	20	0.0017	0.118	69	7.3–7.8	4–14
<i>Glyptotendipes salinus</i> Michailova, 1987	27	33	0.027	1.31	49	5.6–7.8	4–29
<i>Chironomus</i> gr. <i>plumosus</i>	7	3	0.013	0.551	42	7.3–7.6	4–10
<i>Microchironomus deribae</i> (Freeman, 1957)	20	17	0.001	0.076	76	6.6–7.8	5–29
<i>Tanytarsus kharaensis</i> Zorina et Zinchenko, 2009	7	7	0.0002	0.019	95	7.6–7.8	5–26
All taxa		4280	2.25	22.54			

upper part of the diagram when the conditions became less turbulent and salinity and pH increased (Fig. 2).

The distribution of benthic taxa along the CCA axes reflects their ecological spectra (Fig. 3). In the bottom right part are typical phytophilic taxa that can tolerate higher water velocity but are less tolerant to high salinity and pH: *G. lacustris*, *Cricotopus ornatus*, *Cricotopus* sp., *Culicoides riethi*, *Limnodrilus hoffmeisteri*, *Hydrobius fuscipes*, *Dasyhelea* sp. and *Paracorixa concinna*.

Along the positive scores of CCA axis 1 in the right part of the diagram are the phytophilic taxa that are indifferent to salinity fluctuation within the frames of the investigated ecological conditions: *L. profundicola*, *Paranais simplex* and *S. pictus*. In the bottom left part of the biplot, the taxa that are indifferent to the presence of vegetation prefer lower salinity and can survive higher water velocities that are grouped: *Chironomus aprilinus*, *Mallochohelea* sp., *Psychoda* sp., *Hygrotus enneagrammus*, *Berosus fulvus*, etc.

Table 3 List of benthic macroinvertebrates, their frequency (F , % of samples), average density (D , ind. m^{-2}), average biomass (B , g dry wt m^{-2}), summary production (P , g dry wt $m^{-2} yr^{-1}$) and P/B values at Site 2 in the B. Samoroda River from May 2013 to April 2014, the basin of Lake Elton, Russian Federation. Salinity ranges (S_B , $g l^{-1}$,

min–max) in water of the Site 2 where benthic species were found in the B. Samoroda River from May 2013 to April 2014 and salinity ranges (S , $g l^{-1}$, min–max) in water areas where benthic species were found in rivers of the Lake Elton basin (Golovatyuk and Shitikov 2016)

Taxa	F	D	B	P	P/B	S_B	S
Oligochaeta							
<i>Nais elinguis</i> Müller, 1773	27	17	0.0003	0.002	7	8–26.3	4–26
<i>Paranais simplex</i> Hrabe, 1936	20	80	0.0004	0.004	10	6.1–26.3	4–26
Insecta							
Heteroptera							
<i>Paracorixa concinna</i> (Fieber, 1848)	7	3	0.011	0.05	5	5.8–6.1	6–13
<i>Sigara lateralis</i> (Leach, 1817)	33	33	0.049	0.61	12	8–26.3	8–29
Coleoptera							
<i>Berosus fulvus</i> Kuwert, 1888	7	40	0.025	0.37	15	10.3–10.8	7–32
<i>Berosus</i> sp.	13	30	0.022	0.35	16	8.3–10.3	8–32
<i>Hygrotus enneagrammus</i> (Ahrens, 1833)	33	17	0.007	0.1	14	7.2–14.2	7–29
Diptera							
Psychodidae							
<i>Psychoda</i> sp.	13	13	0.002	0.17	85	7.2–8.3	7–26
Ceratopogonidae							
<i>Culicoides riethi</i> Kieffer, 1914	20	23	0.0039	0.012	3	6.1–13.5	4–32
<i>Mallochohelea</i> sp.	7	10	0.0006	0.015	25	6.1–7.2	7–16
<i>Palpomyia schmidtii</i> Goetghebuer, 1934	27	37	0.001	0.024	24	5.8–14.2	8–32
<i>Sphaeromias pictus</i> (Kieffer, 1919)	7	20	0.006	0.024	4	7.2–8.1	5–12
Chironomidae							
<i>Cricotopus salinophilus</i> Zinchenko, Makarchenko et Makarchenko, 2009	67	85	0.102	5.34	52	5.8–14.2	4–32
<i>Cricotopus</i> gr. <i>sylvestris</i>	80	233	0.032	1.41	44	5.8–26.3	4–30
<i>Glyptotendipes salinus</i> Michailova, 1987	20	30	0.103	0.38	4	9.2–26.3	4–29
<i>Chironomus aprilinus</i> Meigen, 1838	7	3	0.0009	0.024	27	10.3–10.8	4–17
<i>Chironomus salinarius</i> Kieffer, 1915	73	1997	0.707	36.4	51	5.8–26.3	7–41
<i>Microchironomus deribae</i> (Freeman, 1957)	60	8850	0.781	49.2	63	5.8–26.3	5–29
<i>Tanytarsus kharaensis</i> Zorina et Zinchenko, 2009	67	5283	0.441	15.47	35	5.8–26.3	5–26
Dolichopodidae							
<i>Ephydra</i> sp.	40	110	0.079	6.78	86	7.2–14.2	7–90
All taxa		16,924	2.38	117			

In the upper left part of the biplot, the taxa that are able to withstand high salinity prefer standing or slow-moving waters and are not dependent on the presence of vegetation that are grouped: *M. deribae*, *T. kharaensis*, *Ch. salinarius*, *C. gr. sylvestris*, *Sigara lateralis* and *Nais elinguis*.

Density and biomass

The average densities of macrozoobenthos in the river mouth significantly exceeded those in the middle reach in all months except for June (Fig. 4). In the middle reach, the highest density of 14,548 ind. m^{-2}

Table 4 Eigenvalues, cumulative % variance and significance of the CCA axes

Full data set	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.713	0.267	0.166	0.090
Cumulative % variance of species data	31.5	43.4	50.7	54.7
Cumulative percentage variance of species–environment relation	53.0	72.8	85.2	91.9
Sum of all unconstrained eigenvalues	2.259			
<i>CCA with four significant variables</i>				
Eigenvalues	0.679	0.241	0.162	0.047
Cumulative % variance of species data	29.3	39.7	46.7	48.7
Cumulative percentage variance of species–environment relation	60.1	81.5	95.9	100.0
Sum of all unconstrained eigenvalues	2.318			

Table 5 Significant variables as identified by manual forward selection in CCA and the variance they explain

Variable	Added with selection	<i>p</i> Value estimates	<i>F</i> value
Vegetation	0.675	0.002	6.573
Water velocity	0.333	0.002	2.096
pH	0.383	0.004	1.77
Salinity	0.163	0.03	0.991
Total variance explained	1.554		
Total variance	2.318		

Table 6 Environmental variables, canonical coefficients and *t* values of significant environmental variables used in the CCA

	Canonical coefficients				<i>t</i> values			
	Axis 1	Axis 2	Axis 3	Axis 4	Axis 1	Axis 2	Axis 3	Axis 4
Water velocity	− 0.027	− 0.908	0.642	0.5682	− 0.339	− 3.758	3.873	0.904
pH	0.024	0.764	1.029	− 0.461	0.275	2.899	5.690	− 0.673
Salinity	0.087	0.478	0.244	0.988	1.213	2.184	1.632	1.743
Vegetation	1.062	1.129	0.419	− 0.277	10.280	3.583	1.939	− 0.338

occurred in June, and in the river mouth, the highest density of 53,752 ind. m^{−2} occurred in September. During the year, the average density of all taxa in the middle reach was 4280 ind. m^{−2}, and in the river mouth reaches the average was 16,924 ind. m^{−2} (Tables 2, 3).

The average biomass of benthos was the highest at both stations in the summer when the water temperature ranged from 20.8 to 27.6 °C (Fig. 4). The highest biomass was observed in August at both sites: 6.23 g dry wt m^{−2} in the middle reaches and 5.84 g dry wt m^{−2} at the river mouth. The average

biomass of all taxa at Site 1 was 2.25 g dry wt m^{−2}, and at Site 2, it was 2.38 g dry wt m^{−2}.

In the middle reaches, *G. lacustris*, *P. simplex* and *S. pictus* constituted up to 75.4% (3391 ind. m^{−2}) of the average benthos density and *G. lacustris*, *S. pictus* and *L. profundicola* constituted up to 89.3% (2.01 g dry wt m^{−2}) of the average biomass of all taxa. At the mouth reaches, three chironomid taxa, *M. deribae*, *T. kharaensis* and *Ch. salinarius*, constituted up to 95.3% (16,130 ind. m^{−2}) of the average density and up to 81.1% (1.93 g dry wt m²) of the average biomass of macrozoobenthos.

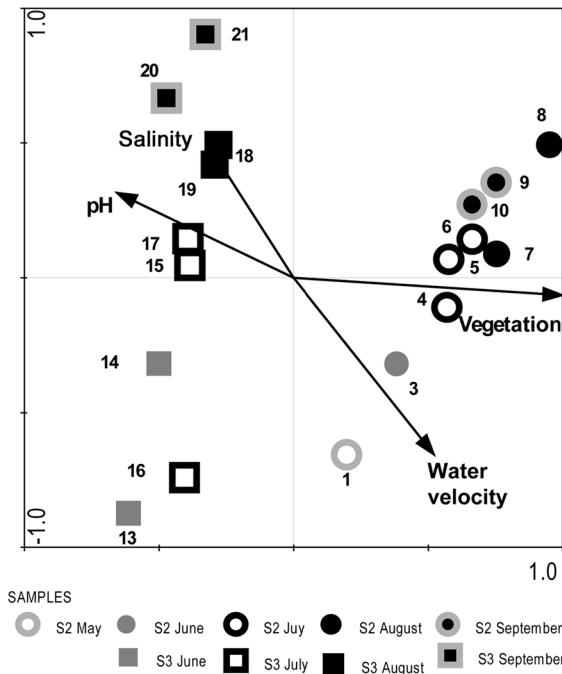


Fig. 2 CCA biplot of the relationship between the four significant environmental variables and the taxonomic composition of macrozoobenthos in the middle (S1) and the mouth section (S2) of the B. Samoroda River during the different months of the vegetation season

Growth rates, production and production/biomass ratio (P/B)

Daily growth rates estimated by the temperature-dependent growth equations were very high for Chironomidae taxa. Growth rates for this group were usually at least 0.03 d⁻¹ and sometimes (in June, Site 2) exceeded 0.5 day⁻¹ (Table 7). For other insects, the growth rate was lower, varying from 0.012 to 0.378 day⁻¹.

In both habitats, the production for the whole study period ranged between 0.67 g dry wt m⁻² month⁻¹ (at Site 1 in January) and 44 g dry wt m⁻² month⁻¹ (at Site 2 in July) (Fig. 5). The production was the lowest in both sites in winter and early spring when the water temperature was ≤ 8.5 °C. The highest production peak of 6.13 g dry wt m⁻² month⁻¹ was at Site 1 in June at 25.6 °C, and at Site 2, it was 44 g dry wt m⁻² month⁻¹ in July at 26 °C.

The average production of all taxa for the year was much higher at Site 2 and reached 117 g

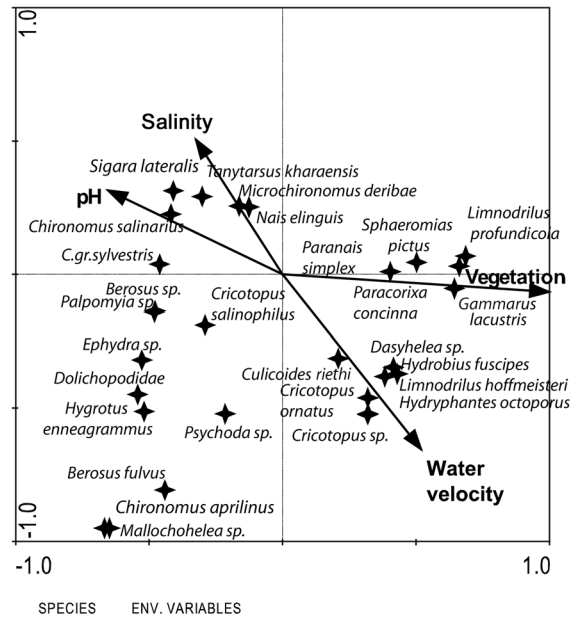


Fig. 3 CCA biplot of the relationship between the four significant environmental variables and the species of macrozoobenthos of the B. Samoroda River

dry wt m⁻² yr⁻¹, while at Site 1, it reached only 22.54 g dry wt m⁻² yr⁻¹ (Tables 2, 3).

In all seasons of the year at both sites, the same taxonomic groups of macrozoobenthos contributed the most to benthic production. Diptera dominated in both places, while the Amphipoda dominated only at Site 1. In the middle reaches, three taxa, *G. lacustris*, *S. pictus* and *G. salinus*, constituted 82.5% (18.58 g dry wt m⁻² yr⁻¹) of the average production of all taxa. At the river mouth, *M. deribae*, *T. kharraensis* and *Ch. salinaris* constituted up to 86.4% of the average production of all taxa (101.1 g dry wt m⁻² yr⁻¹).

The highest values for the production/biomass (*P/B*) ratio during the year were recorded for Diptera species: 95 for *T. kharraensis*, 86 for *Ephydra* sp., 85 for *Psychoda* sp., 76 for *M. deribae*, 70 for *C. salinophilus*, 68 for *C. ornatus* and 51 for *Ch. salinaris* (Tables 2, 3). For other groups of macrozoobenthos, *P/B* varied from 3 to 16.

The concentration of chlorophyll-*a* in the middle reach of the B. Samoroda River reached 19.4 mg m⁻³, and at the river mouth, it reached 18.8 mg m⁻³, reflecting high biomass and phytoplankton production in both sections of the river (Table 1).

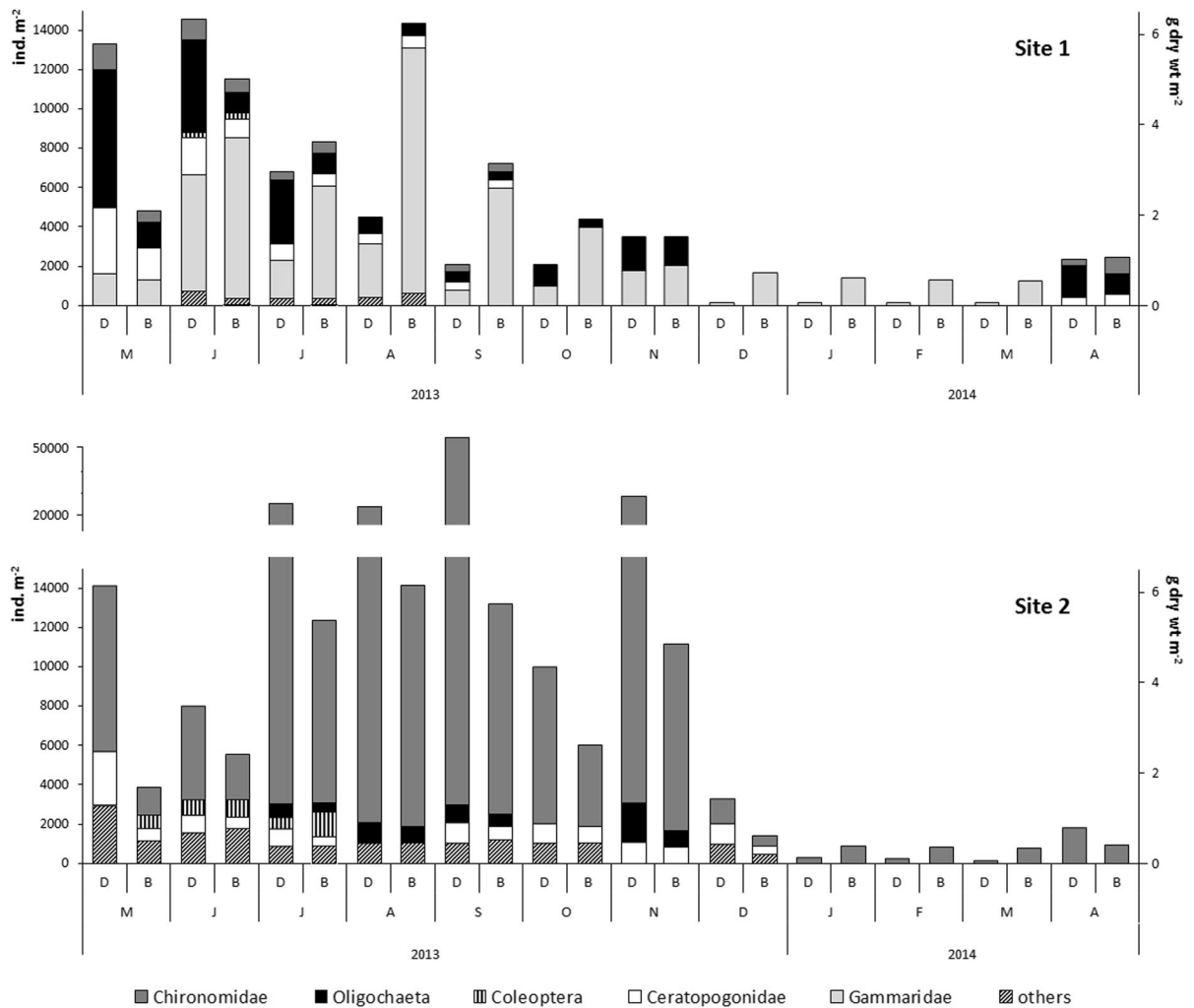


Fig. 4 Dynamic of density (*D*) and biomass (*B*) of the main groups of macrozoobenthos at the two sampling sites in the B. Samoroda River from May 2013 to April 2014

Number of *Gammarus lacustris* generations

Large, mature females of *G. lacustris* that represented the generation of the previous year and have eggs in brood chambers were found in May 2013 at a water temperature of 22 °C. Young individuals that emerged from these eggs developed during the year and reached sexual maturity by May 2014. At this time, large females with eggs in the brood chambers were found again in the population of *Gammarus lacustris*. In other months of the year, sexually mature females were not found. Thus, we suppose that the population of *G. lacustris* in the saline river B. Samoroda produces only one generation per year.

Discussion

Studies of ecosystem function in saline rivers are rare despite the high ecological importance of these rivers for the surrounding terrestrial ecosystems. Such investigations in arid regions are especially important in view of modern climate change and aridification of the climate in many regions on Earth (IPCC 2017). In our study, for the first time, we estimated the production of macrozoobenthos communities in saline rivers of the Lake Elton basin (Lower Volga Region), which is an important resting place for migratory birds.

Table 7 Growth rate (G , day^{-1} , min–max) of main groups of insects in B. Samoroda River at Sites 1 and 2 from May 2013 to April 2014 as estimated by the temperature-dependent growth equations

Taxa	Site 1		Site 2	
	Min	Max	Min	Max
Orthocladinae	0.177	0.273	0.039	0.347
Chironominae	0.03	0.371	0.033	0.501
Ceratopogonidae	0.011	0.078	0.012	0.099
Diptera (others)	0.285	0.285	0.202	0.378
Coleoptera	0.051	0.051	0.041	0.061
Heteroptera	0.05	0.078	0.017	0.081

Fauna

In the investigated B. Samoroda River, Diptera showed the highest diversity in comparison with other groups of invertebrates. The same was found in other saline rivers of arid regions (Bunn and Davies 1992; Gallardo-Mayenco 1994; Velasco et al. 2006; Zerguine 2014). In contrast, Plecoptera, Ephemeroptera, Trichoptera and Hirudinea, which are usually widespread in fresh waters, were not found in the B. Samoroda River at all. Apparently, this is due to the low-salinity tolerance of these taxonomic groups (Lukin 1976; Lepneva 1964; Hart et al. 1991). However, it was found in the rivers of Australia, Canada, Spain, France and Germany that some species of these groups could survive at salinities of up to 4–8 g l^{-1} (leeches), 2–9 g l^{-1} (stoneflies) and

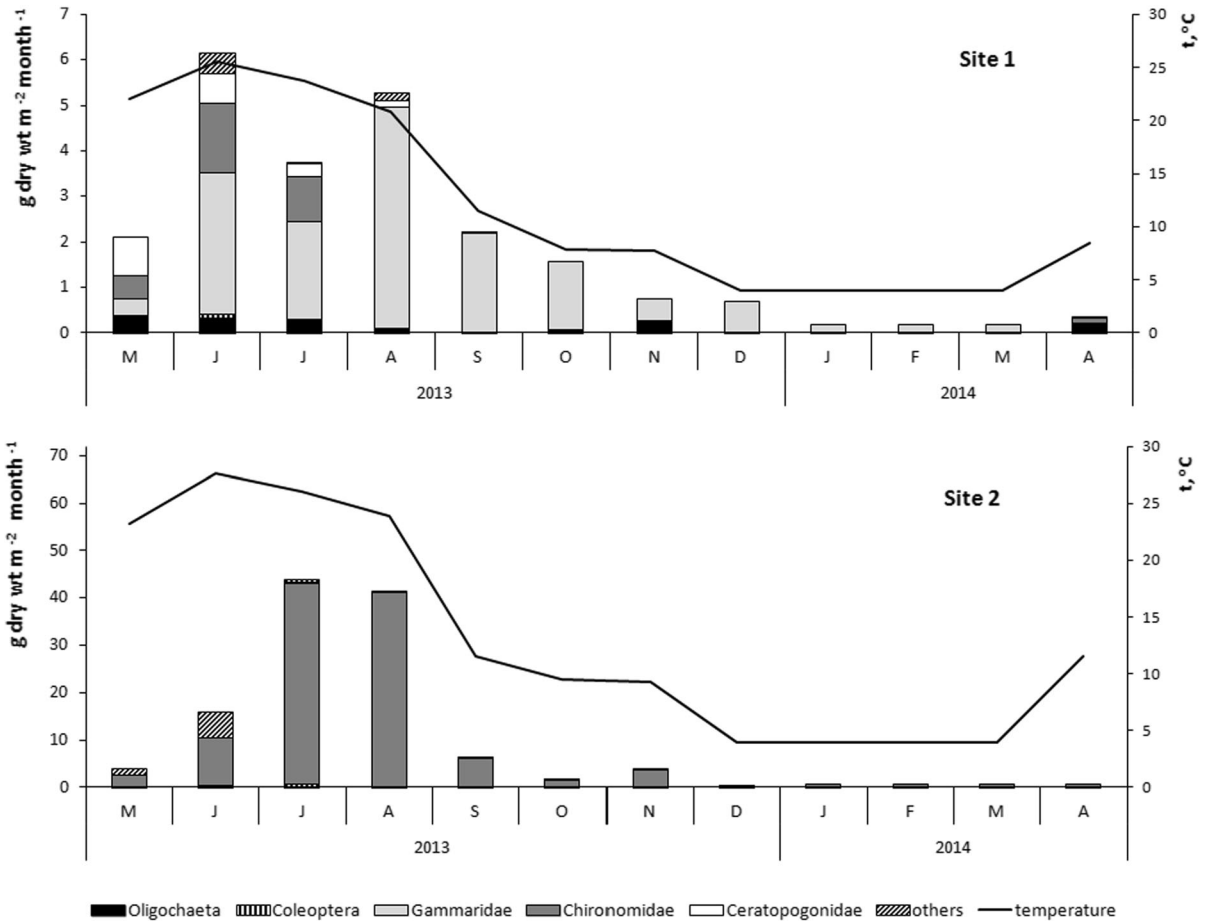


Fig. 5 Dynamics of production of the main groups of macrozoobenthos at two sampling sites of the B. Samoroda River from May 2013 to April 2014

9.2–75 g l⁻¹ (mayflies) (Short et al. 1991; Gallardo-Mayenco 1994; Ubero-Pascal et al. 1998; Kay et al. 2001; Rutherford and Kefford 2005; Velasco et al. 2006).

Among Diptera, the permanent inhabitants of the B. Samoroda River were Chironomidae, Ceratopogonidae, Ephydriidae and Psychodidae. Species of these families are widespread in saline waters of the world (Armitage et al. 1994; Velasco et al. 2006; Przhiboro 2014; Shadrin et al. 2017). Chironomid larvae were found in rivers with salinity up to 115 g l⁻¹ (Rutherford and Kefford 2005), Ceratopogonid larvae can tolerate salinity up to 108 g l⁻¹ (Rutherford and Kefford 2005) and Ephydriidae larvae up to 100 g l⁻¹ (Velasco et al. 2006).

The most abundant species in the B. Samoroda River, *M. deribae*, is a typical brackish water species. Larvae of this species were found in waters with a salinity of up to 42 g l⁻¹ (Laville and Toureno 1967). *Ch. salinarius*, which has a very high abundance in the river mouth, is known to be a halophilous organism inhabiting saline and brackish waters (Cartier et al. 2010; Estrella and Masero 2010). This species was also found in Europe, America and Asia (Fuentes et al. 2005; Ree and Yum 2006). *Ch. salinarius* and *M. deribae* usually inhabit coastal marine lagoons (Krebs 1979; Ceretti et al. 1987; Drake and Arias 1995). In contrast, *T. kharaensis* was first described by us in the rivers of the Lake Elton basin (Zorina and Zinchenko 2009) and is probably subendemic.

Among the other dipterans in the middle reaches of the B. Samoroda River, the Ceratopogonide *S. pictus* develops dense populations. This is a common arboreal species widely distributed in the Palaearctic (Szadziewski et al. 2007). Larvae are common in fresh waters and in highly mineralized lakes and ponds (Moller Pillot 2013).

Oligochaeta in the B. Samoroda River were represented by the families Naididae and Tubificidae, which were also found in Australian rivers with salinity of up to 39.6 g l⁻¹ (Tubificidae) and of up to 22.6 g l⁻¹ (Naididae) (Rutherford and Kefford 2005). Oligochaetes *L. profundicola* and *N. elinguis* reached very high abundances in the B. Samoroda River. Euryhaline *L. profundicola* is known from the profundal of Lake Baikal (Timm 2012), in lakes and rivers of Kamchatka and in the southern areas of the Russian Far East (Semernoi and Sidorov 1913),

Western Europe (Atanackovic et al. 2013), North America (Popchenko 1988) and Japan (Ohtaka 2014).

Nais elinguis is widely distributed in fresh and brackish waters. It has been found in cold-water rivers and streams, tidal littoral zones of lakes, in littoral areas of the White Sea and in lakes of the tundra (Popchenko 1988), as well as in warm ponds and channels of Central Asia (Chekanovskaya 1962). *Nais elinguis* also inhabits reservoirs of Western Europe, North and South America (Christoffersen 2007) and China (Wang and Cui 2007).

Beetle larvae are rare in the B. Samoroda River. Species of the genus *Berosus* have the highest density in the river mouth. Species of this genus are common in saline rivers (Velasco et al. 2006), in retention tanks, in ponds and in temporary reservoirs exposed to salinization (Prokin 2008). Species of the Hydrophilidae and Dytiscidae families (Coleoptera) that were found in the B. Samoroda River are common in the saline rivers of Spain and southeastern Australia, where they inhabit waters with salinities up to 81–135 g l⁻¹ (Bunn and Davies 1992; Gallardo-Mayenco 1994; Kay et al. 2001; Rutherford and Kefford 2005; Velasco et al. 2006).

Among the Heteroptera, only Corixidae were found. They are known for inhabiting waters with salinities of up to 2.60–100 g l⁻¹ in rivers of other arid regions of the world (Gallardo-Mayenco 1994; Kay et al. 2001; Piscart et al. 2005; Rutherford and Kefford 2005; Barahona et al. 2005).

Crustaceans were represented only by *G. lacustris*, a species that is widely distributed in fresh and saline waters (Väinölä et al. 2007).

Thus, at the level of families and some species, the fauna of the saline B. Samoroda River demonstrated similarities with the fauna of saline water bodies from other arid regions across the world. This indicates specialization of the found taxa to salty environments.

Biomass and production of macrozoobenthos

The average total biomass of macrozoobenthos at both sites was similar; however, there was a great difference in the production of benthic communities. It was influenced by differences in abiotic factors, especially the presence of macrophytes, flow water velocity, salinity and pH, which played a decisive role in defining the species composition and the dominance of individual species.

In the middle reach of the river under flowing water conditions, at lower salinity (up to 8.5 g l^{-1}), and in the presence of macrophytes, the amphipods *G. lacustris* developed mass populations. *G. lacustris* are frequently dominant or subdominant (Grabowskyi et al. 2007; Zadereev et al. 2010). Our study has shown that populations of this species have only one generation per year in the B. Samoroda River. This is consistent with the data obtained for the populations of *G. lacustris* living in rivers in Europe, where this species is also univoltine (Hynes and Harper 1992; Grabowskyi et al. 2007).

The calculated annual *P/B* coefficient for the univoltine amphipod *G. lacustris* was relatively low ($P/B = 8$), suggesting that the population of this species was characterized by a low reproduction rate, which resulted in lower macrozoobenthos production in the middle reach of the river in comparison with the river mouth.

In the mouth reaches, where salinity was higher (up to 26.3 g l^{-1}) and macrophytes had lower density, the chironomids *M. deribae*, *Ch. salinarius*, *T. kharaensis* and *C. salinophilus* had high biomass. These species, such as many other chironomid taxa, have a multi-voltine life cycle. Our earlier study, in which we reared *Ch. salinarius* and *C. salinophilus* from eggs to adults in laboratory conditions (Golovatyuk and Zinchenko 2015), showed that *C. salinophilus* can develop 7–8 generations per year, and *Ch. salinarius* can have 3–4 generations per year. Our results indicated that larvae of these species have higher biomass turnover and therefore higher production. Conceivably, high production of chironomid larvae may be a characteristic of many brackish and saline waters. For instance, in a brackish pond of a coastal lagoon system of the northern Adriatic Sea (Italy), annual production of *Ch. salinarius* was as high as $69.2 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Ponti et al. 2007).

The data on the production of bottom communities of saline rivers are available only for some groups of hydrobionts, such as Chironomidae, Ceratopogonidae and Corixidae (Barahona et al. 2005; Zinchenko et al. 2014; Golovatyuk et al. 2018). The annual production for the study period in the saline B. Samoroda River was much higher than the annual production of some freshwater rivers and lakes. For example, the annual production of macrozoobenthic fauna of the Lambourn River (Southern England) was $22.55 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Tod and Schmid-Araya 2009). In a

Canadian cold-water spring-brook system (Toronto, Ontario), the annual production of macrozoobenthos was $11.21 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ in the upstream area and $4.01 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ in the downstream area (Williams and Hogg 1988). In the Yangtze floodplain (China), the annual production of macrozoobenthos was $3.23 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Pan et al. 2011).

However, in a brackish coastal lagoon of the northern Adriatic Sea (Italy), the production of macrozoobenthos reached up to $152.6 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Ponti et al. 2007). Our study has shown that macrozoobenthos production in the less-saline middle reaches of the B. Samoroda River was comparable or 2–5 times higher than production in fresh water. Production in the more saline mouth reaches was 5–29 times higher than in fresh water and similar to the production of brackish waters.

Density, biomass, production and *P/B* of chironomid larvae populations

The larvae of Chironomidae comprise one of the most important components of the macroinvertebrate community in the mouth reaches of the B. Samoroda River, where waterfowl has high density. Here, chironomids have a high density and constitute 97% of the total density, 91% of the total biomass and 92% of the total production of zoobenthos.

The observed high density of chironomid larvae in the mouth reaches of the saline B. Samoroda River exceeds or is comparable to that of other important rest stops for migratory waders in Europe, for example, Kirov Bay on the southwest coast of the Caspian Sea (Kyzylgachsky nature reserve) (Shubin 1998), Sylvas Bay, the Sea of Asov (Chernichko and Kirikova 1999), Kalmykia (southwestern Russia; Shubin and Ivanov 2005), Hungary (Székely and Bamberger 1992) or Great Britain (Goss-Custard 1977). The annual production of chironomid larvae in different regions of the world varies considerably. In the cold-water Lambourn River (Southern England), chironomid production was $0.36 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Tod and Schmid-Araya 2009), and in the Canadian cold-water spring-brook system, it was 0.36 and $0.67 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ in the upstream and downstream areas, respectively (Williams and Hogg 1988). The annual production of chironomid larvae in Rocky Mountain streams did not exceed $0.81 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Carlisle and Clements 2003). In two polluted

midlatitude Polish rivers (the Widawka River and the Grabia River), the annual production of chironomids was approximately $25 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Grzybkowska 1989). In a subtropical stream in China, the annual production of chironomid larvae was approximately $35.6 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Yan and Li 2006), and in a coastal plain blackwater river, the annual production of chironomid larvae was twice as high as even the production in eutrophic and warm-water rivers and reached $82 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ (Benke et al. 1998).

Our earlier study has shown that average content of the essential long-chain fatty acids (HUFA) in *C. salinophilus* was 18.2 mg g^{-1} dry wt, and in *Ch. salinarius*+*Ch. aprilinus* it was 3.5 mg g^{-1} dry wt. The average content of EPA (Eicosapentaenoic) in the chironomid larvae was 10.8 mg g^{-1} dry wt (Zinchenko et al. 2014). Production of these species was $16.7 \text{ g dry wt m}^{-2} \text{ month}^{-1}$ in August 2006–2010 and the monthly flux of EPA from the studied rivers of Lake Elton basin to land due to chironomid potential emergence was $33 \text{ mg m}^{-2} \text{ month}^{-1}$, which is roughly comparable to the global average estimation of annual water-land HUFA export via emerging insects ($40 \text{ mg m}^{-2} \text{ month}^{-1}$; Gladyshev et al. 2009). Calculated annual production only three species *C. salinophilus*, *Ch. salinarius* and *Ch. aprilinus* in the B. Samoroda River was $41.9 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$ which significantly exceed the average estimate of annual water-land HUFA export and give evidence for a high importance of chironomid productivity from saline B. Samoroda River for surrounding terrestrial habitats.

Comparison of the production of chironomid larvae in the saline B. Samoroda River with that of rivers from other regions of the world has demonstrated that production of chironomid larvae in the mouth reaches of the B. Samoroda River was much higher than that of any of these rivers, accounting for $108.2 \text{ g dry wt m}^{-2} \text{ yr}^{-1}$, which can be considered extremely productive (hyper-eutrophic) (Tokeshi 1995).

The concentrations of chlorophyll-*a* indicate a high biomass of microalgae in the B. Samoroda River (Table 1). This, together with thick silt deposits that are characteristic of estuaries of saline rivers (Vodnolotnye 2005), constitutes a rich food source for bacterivorous organisms and contributes considerably to the high production of chironomid larvae in saline rivers (Zinchenko et al. 2014). Additionally, we

suggest that the high water temperatures ($8.5\text{--}27.6 \text{ }^\circ\text{C}$) observed during the growing season (from April to September) could play an important role in the high production of hydrobionts in the B. Samoroda River.

Max *P/B* values of chironomid populations in the mouth reaches of the B. Samoroda River are comparable to the highest average annual *P/B* ratio in freshwater rivers (Benke and Huryn 2017). For example, in the Satilla River (USA), the annual *P/B* ratio for the *Tanytarsini* group was 176–184, and the annual *P/B* ratio for the *Cricotopus* group was 99–118 (Benke et al. 1984). In Polish rivers, the annual *P/B* ratio for *Cladotanytarsus* sp. was 45–46, and for *Polypedilum* sp. it was 32–34 (Benke et al. 1984; Grzybkowska 1989).

Usually, benthic fauna of saline waters, like those investigated in our study of the B. Samoroda River, is characterized by a small number of highly specialized species (Velasco et al. 2006). They are adapted to extreme salinity and are able to develop populations of very high density and biomass (Bunn and Devis 1992; Velasco et al. 2006) due to low interspecies competition (Zinchenko et al. 2014; Golovatyuk et al. 2018). This, together with the high availability of food resources for chironomid larvae and other hydrobionts, leads to high production of macrozoobenthos, as seen in the saline B. Samoroda River.

However, our earlier study in the Elton Lake catchment showed that during periods of sharp increases in the salinity of rivers due to the influx of hypersaline water from Lake Elton, the abundance and biomass of major species of macrozoobenthos decrease significantly (Zinchenko et al. 2012). During these periods, the rise of water salinity up to $100\text{--}200 \text{ g l}^{-1}$ leads to death or massive upstream movement of such chironomid species as *T. kharaensis*, *M. deribae* and *Ch. salinarius* (Zinchenko et al. 2012). It is likely that surging phenomena and water exchange with water bodies of higher salinity are among the critical factors limiting the production of hydrobionts in the estuaries of saline rivers.

Conclusions

Macrozoobenthic fauna of the saline B. Samoroda River is represented by 30 euryhaline and halophilic taxa of benthic macroinvertebrates. The taxonomic

composition of macrozoobenthos in the middle reaches and at the mouth of the B. Samoroda River differed significantly, which was caused by differences in major abiotic factors affecting hydrobionts, such as the presence of vegetation, water flow velocity, pH of the water and salinity, at both sites.

In seasonal dynamics, a stable high density of macrozoobenthos was observed in the middle reach from May to August with the highest abundances in June and at the river mouth from May to November with the highest abundances in September. The lowest abundances were found in winter and early spring at both study sites (March and April).

The highest production in the benthic communities at the mouth of the saline B. Samoroda River is provided by multivoltine chironomid species *T. kharaensis*, *M. deribae* and *C. salinarius*, which have higher biomass turnover. The production of the benthos at the middle reach was lower than at the mouth reach due to the dominance of the univoltine population of crustaceans *G. lacustris* at the middle reach.

Our analysis showed that the calculated annual production of benthic invertebrates in the B. Samoroda River was comparable with the annual production in brackish waters of other regions of the world and was several times higher than the production of freshwater river benthic communities. The saline B. Samoroda River play an important role for surrounding terrestrial habitats due to high production of macrozoobenthos communities and especially of chironomid larvae that provide high annual water-land HUFAs export.

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