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Salinity Tolerance of Macrozoobenthic Taxa in Small Rivers of the Lake Elton Basin

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Abstract—The results of studies on the distribution of macrozoobenthic taxa along the water mineralization gradient in the small salt rivers of the Lake Elton basin are presented. The optimum and tolerance intervals for dominant species have been determined. Species with the highest tolerance to the high-salinity aquatic environment have been identified.

Keywords: high-salinity rivers, mineralization gradient, macrozoobenthos, salinity tolerance, optimum, tolerance interval

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Along with factors such as current speed, biotope type, and water temperature, the composition and distribution of zoobenthos in river ecosystems is largely dependent on water salinity (Piscart et al., 2005; Zinchenko et al., 2014). The effect of temperature and river hydraulics has been studied sufficiently (*Zhizn' presnykh vod...*, 1950; Vannote et al., 1980; Townsend, 1989; Bogatov, 1994), while data on the role of water salinity are relatively scarce (Piscart et al., 2005; Kefford et al., 2003).

Recent climate change and intensification of economic activities during the past few decades primarily affect arid and subarid ecosystems, both characterized by a high ecological vulnerability (Williams, 1987). The negative consequences of the above processes include increasing salinization of inland waters, which is regarded as a major environmental hazard in all continents (Kefford et al., 2005; Velasco et al., 2006). Water salinization is a natural phenomenon in inland regions where rivers and springs flow into drainless lakes (Hart et al., 1991). Studies on the biotic component of such basins provide the possibility to obtain information on natural communities in the aquatic ecosystems of this type and to evaluate the effect of high water salinity on the fauna (Gallardo-Mayenco, 1994).

Macrozoobenthos is a major component of the biota in saline lotic systems, where the effect of water salinity on benthic communities depends primarily on the tolerance of particular species and individuals (Williams and Williams, 1998). Tolerance (sustaining power) and resistance (hardiness) to a certain factor, most often abiotic, are critically important characteristics of an individual (Khlebovich, 2012).

The aim of this work was to assess the salinity tolerance of different macrozoobenthic taxa along a wide water salinity gradient in rivers of the Lake Elton basin in comparison with rivers in other arid regions of the world.

MATERIAL AND METHODS

The study was based on the collections of benthic invertebrates from the small high-salinity rivers of the Lake Elton basin (Volgograd oblast; 49°13′ N, 46°40′ E): the Khara, Lantsug, Chernavka, Solyanka, Bol'shaya Smorogda, Malaya Smorogda, and Karantinka (April–November 2006–2013). Samples were taken at permanent stations distributed along the rivers, from the headwaters to the mouth, using an Ekman–Birge bottom sampler (sampling area 25 cm^2, 8 replicates from each station) and a hydrobiological scraper (sampling area 1000 cm^2). The material was fixed with 4% formaldehyde and processed in the laboratory by standard hydrobiological methods (Zhadin, 1960; *Metodika izucheniya...,* 1975). To analyze the salinity tolerance of species, we used 95 samples of zoobenthos from the points where water salinity was measured.

The salinity tolerance of hydrobionts was determined from the range of water salinity levels at which they occurred in the rivers (Zinchenko and Golovatyuk, 2013). To calculate the optimum and tolerance intervals, we used the Gaussian response curve (GAUS) showing the distribution of dominant macrozoobenthic species along the gradient (Gauch et al., 1974; Shitikov et al., 2012). This is a symmetric bell-shaped curve that reflects the dependence of the pop-

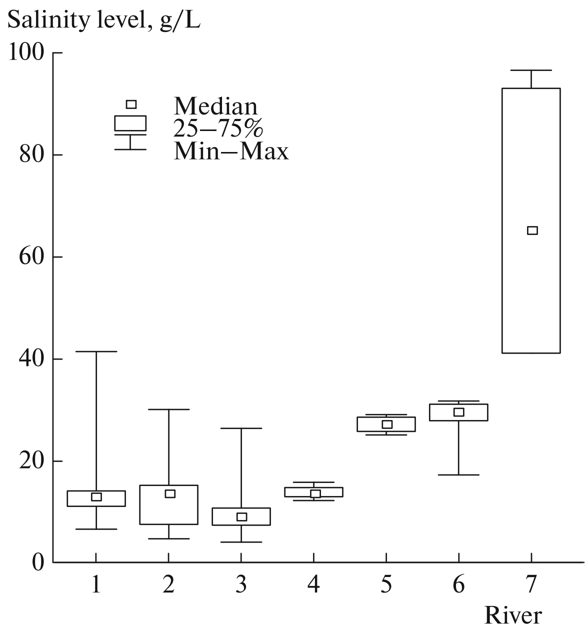

Fig. 1. Water salinity levels in the rivers (1) Khara, 2) Lantsug, (3) Bol'shaya Smorogda, (4) Karantinka, (5) Solyanka, (6) Chernavka, and (7) Malaya Smorogda (April–November 2006–2013).

ulation density of species y on factor x and has three interpretable parameters: $y = he^{-(x-\mu)^2/2\sigma^2}$, where μ is the estimated mean indicating the ecological optimum of a species on axis x that corresponds to the maximum species abundance h, and σ is the standard deviation from this optimum on the gradient scale. The value $\pm 2\sigma$ corresponds to the ecological niche width, i.e., to the tolerance range in our case. This pattern of change in the response is traditionally used as part of gradient analysis, being theoretically based on the concept of limiting resource and the Shelford tolerance law (Guisan and Thuillier, 2005).

RESULTS AND DISCUSSION

The average salinity levels in the rivers are within the ranges of 4–16 g/L in the Khara, Lantsug, Bol'shaya Smorogda, and Karantinka; 25–31 g/L in the Chernavka and Solyanka; and 41–91 g/L in the Malaya Smorogda (Fig. 1). The highest values, significantly deviating from the average, are due to hypersaline water surges from the lake to the river mouths.

The bottom communities of the rivers comprise 91 zoobenthic species from 19 families (Fig. 2). Their fauna does not include certain taxa that are usually widespread in fresh waters, such as stone flies, mayflies, caddis worms, mollusks, and leeches. It has been repeatedly noted that they are poorly tolerant of high water salinity (Lukin, 1976; Lepneva, 1964; *Opredelitel' presnovodnykh*..., 1997; Hart et al., 1991). At the same time, some species of these groups in the rivers of Australia, Canada, Spain, France, and Germany can live at salinities of up to 4–8 g/L (leeches), 2–9 g/L (stone flies), 9.2–75 g/L (mayflies), or 2.7–32.1 g/L (mollusks) (Short et al., 1991; Gallardo-Mayenco, 1994; Ubero-Pascal et al., 1998; Kay et al., 2001; Rutherford and Kefford, 2005; Velasco et al., 2006).

Crustaceans in the bottom communities of the rivers are represented by *Gammarus* (*Rivulogammarus*) *lacustris* amphipods that reach high abundance (up to 6500 ind./m^2) in macrophyte beds at the banks of the Khara, Lantsug, and Bol'shaya Smorogda. Water salinity in these areas does not exceed 15.77 g/L. As calculated by GAUS, the optimum salinity level for this species is 7.33 g/L, and the tolerance interval varies is between 6.55 and 13.11 g/L (table, Fig. 3).

Oligochaetes of the families Naididae, Enchytraeidae, and Tubificidae are highly abundant in the salt rivers of the Lake Elton basin with a salinity level of 3.97–26.32 g/L (Fig. 2). The highest salinity tolerance is demonstrated by *Paranais simplex* and *Nais elinguis*: both survive at salt concentrations of up to 26.32 g/L. The optimum salinity levels calculated for different oligochaete species vary significantly: from 6.50 g/L for *Limnodrilus hoffmeisteri* to 15.12 g/L for *Uncinais uncinata* (Table 2, Fig. 3). The widest tolerance interval is characteristic of *Paranais simplex* (6.50–23.45 g/L), while *Limnodrilus profundicola* has a narrow interval of 6.55–8.79 g/L. *Limnodrilus hoffmeisteri*, *Nais communis*, *N. elinguis*, *Paranais simplex*, and *Uncinais uncinata* widely occurring in the salt rivers may be classified as euryhaline species, since they abundantly develop in rivers of the Middle and Lower Volga basin where water salinity does not exceed 1 g/L (Zinchenko et al., 2007; Golovatyuk, 2011). As noted in the special literature, oligochaetes have been found in the Australian rivers with a salinity of up to 82 g/L; high salinity tolerance is characteristic of species from the families Tubificidae (up to 39.6 g/L), Enchytraeidae (25.9 g/L), and Naididae (22.6 g/L) (Rutherford and Kefford, 2005). This agrees with our data for the rivers of the Lake Elton basin.

A few larvae of **dragonflies** such as *Sympetrum sanguineum*, *Ischnura elegans*, and *Aeschna* sp. from the families Coenagrionidae, Libellulidae, and Aeschnidae were collected in the Khara and Lantsug rivers from pondweed beds and silty grounds with an admixture of clay and plant remains (Fig. 2). *Aeschna* sp. larvae showed the highest salinity tolerance (21.17 g/L), while the upper salinity limit for *Ischnura elegans* was only 6.55 g/L. *Ischnura elegans* was previously found in rivers of the Lower Volga basin (the S"ezzhaya and Chapaevka) at a salinity level of up to 0.63 g/L (Zinchenko et al., 2007). According to published data (Gallardo-Mayenco, 1994; Rutherford and Kefford, 2005; Velasco et al., 2006), species of the families Coenagrionidae, Aeschnidae, Gomphidae, Libellulidae,

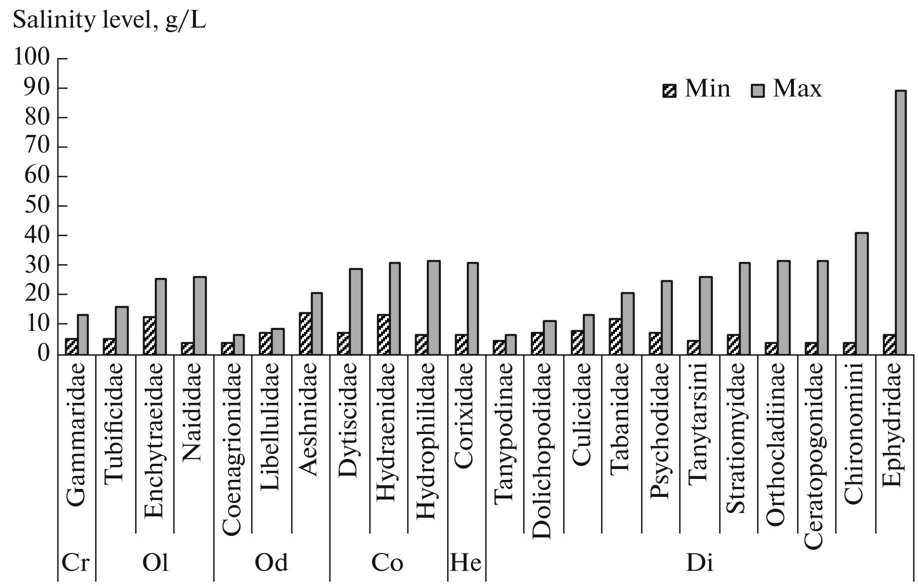

Fig. 2. Salinity ranges (min–max) in water areas where macrozoobenthic taxa were recorded in small rivers of the Lake Elton basin (Cr – Crustacea, Ol – Oligochaeta, Od – Odonata, Co – Coleoptera, He – Heteroptera, Di – Diptera).

Hemicorduliidae, and Lestidae live in the rivers of Australia and Spain with a salinity level of 3.50 to 40 g/L.

Larvae of **bugs (Hemiptera)** and imagoes and adult insects found in the study region belong to the genera *Callicorixa*, *Paracorixa*, and *Sigara* of the family Corixidae (Fig. 2). Their salinity tolerance differs significantly between species. For example, *Callicorixa gebleri* has not been found at salinity levels higher than 6.82 g/L, while *Sigara assimilis* abundantly develops in the Solyanka and Chernavka rivers with water salinity of up to 29.0–31.60 g/L. Accordingly, the optimum salinity is 6.80 g/L for *Callicorixa gebleri* vs. 30.12 g/L for *Sigara assimilis* (Fig. 3). These species are characterized by narrow tolerance intervals, while this interval for *Sigara lateralis* is within 10.55–23.10 g/L (table). The high tolerance of bugs from the families Corixidae, Veliidae, and Notonectidae inhabiting waters with salinities of up to 2.60–100 g/L is also known from other arid regions of the world (Gallardo-Mayenco, 1994: Kay et al., 2001; Piscart et al., 2005; Rutherford and Kefford, 2005).

Small rivers in the arid regions often serve as shelters for certain **beetles (Coleoptera)** of different ecological groups. Beetles recorded in the study region are from the families Hydrophilidae (nine species), Hydraenidae (two species), and Dytiscidae (one species) (Fig. 2). Species of the genera *Berosus*, *Ochthebius*, *Enochrus*, *Hygrotus*, *Paracymus*, *Helochares* etc. occur found at salinities of 6.82 to 31.60 g/L (table). Among halophilic beetles, attention should be paid to *Berosus bispina* and *Hygrotus enneagrammus*, whose ecological salinity optimum reaches 28.12 and 18.78 g/L, respectively (table, Fig. 3). The taxonomic diversity of beetles from the families Dytiscidae, Hydraenidae, and Hydrophilidae is also characteristic of the salt rivers of Spain and southwestern Australia, where they inhabit waters with the concentrations of salts reaching 81–135 g/L (Bunn and Davies, 1992; Gallardo-Mayenco, 1994; Kay et al., 2001; Rutherford and Kefford, 2005; Velasco et al., 2006).

Dipterans reach a high faunistic diversity in the salt rivers of the Lake Elton basin (Zinchenko and Golovatyuk, 2010). A total of 33 taxa from 8 families were recorded (Fig. 2), with most of them (25 species) belonging to the family Chironomidae. The highest salinity tolerance is characteristic of larvae and pupae from the family Ephydridae, which survive at salt concentrations of up to 89.5 g/L (table). In the family Chironomidae, highly tolerant are species from the subfamilies Chironominae (tribe Chironomini) (up to 41.06 g/L) and Orthocladiinae (up to 31.7 g/L), while representatives of Tanypodinae occur at salinities that do not exceed 6.8 g/L (Fig. 2). The calculated optimum salinity for species such as *Cricotopus* gr. *sylvestris*, *Glyptotendipes salinus*, *Chironomus* gr. *plumosus*, *Microchironomus deribae*, and *Sphaeromias pictus* varies between 6.5 and 10.6 g/L, and the upper limit of the tolerance interval is not higher than 21 g/L; i.e., they are poorly tolerant of high salinity. On the contrary, larvae and pupae of *Ephydra* sp., *Odontomyia* sp., *Palpomyia schmidti*, *Cricotopus salinophilus*, and *Chironomus salinarius* are found at high salinity level, their ecological optimum varies from 18.02 to 41.1 g/L. Certain species from the families Psychodidae and Tabanidae are also tolerant of high water salinity and survive at its levels of up to 25.2 g/L and 21.1 g/L, respectively, (Fig. 2).

Dipterans are an important component of the fauna in highly saline rivers and other arid areas of the

Salinity ranges (min–max) in water areas where benthic species were recorded in rivers of the Lake Elton basin, ecological optimum, and tolerance interval along the salinity gradient for some macrozoobenthic taxa calculated using the Gaussian response curve (GAUS)

Taxon	Salinity, g/L		GAUS	
	min	max	optimum, g/L	tolerance interval, g/L
Oligochaeta				
Limnodriloides dnieprobugensis	10.92	15.77	14.15	10.03–18.26
Limnodrilus hoffmeisteri	6.82	13.34	6.50	6.50–13.35
L. profundicola	5.20	14.01	6.55	6.55–8.79
Limnodrilus sp.	6.82	16.38	8.58	6.50–18.61
Nais communis	6.82	16.78	14.77	8.75–20.76
N. elinguis	3.97	26.32	11.14	9.23–13.0
Paranais simplex	3.97	26.32	14.67	6.50–23.45
Uncinais uncinata	13.83	16.68	15.12	13.90–16.29
Crustacea				
Gammarus lacustris	5.20	15.77	7.33	6.55–13.11
Insecta				
Heteroptera				
Callicorixa gebleri	6.81	6.82	6.80	6.50–6.90
Sigara assimilis	17.17	31.6	30.12	29.67–30.57
S. lateralis	8.04	29.00	13.30	10.55–23.10
Sigara sp.	7.46	30.80	20.82	15.43–26.19
Coleoptera				
Berosus bispina	12.00	31.59	28.12	14.60–33.40
B. fulvus	6.82	31.60	13.8	6.50–21.30
Berosus sp.	8.30	31.60	20.44	14.35–26.53
Enochrus sp.	7.46	28.50	14.87	13.39–16.36
Hygrotus enneagrammus	7.17	29.00	18.78	10.72–26.81
Paracymus aeneus	6.99	27.60	6.90	6.50–11.27
Diptera				
Cricotopus ornatus	7.10	15.77	11.69	7.30–16.08
C. salinophilus	3.97	31.70	23.21	13.94–32.45
C. gr. *sylvestris*	3.97	30.0	6.50	6.50–11.76
Culicoides sp.	3.97	31.70	14.42	6.55–24.88
Ephydra sp.	7.0	89.5	41.1	36.43–41.1
Glyptotendipes paripes	9.75	14.40	10.89	9.92–11.86
G. salinus	3.97	28.58	6.55	6.55–16.40
Chironomus aprilinus	3.97	16.90	14.32	11.93–16.67
C. gr. *plumosus*	3.97	9.57	7.30	6.50–8.58
C. salinarius	6.55	41.06	18.02	6.50–32.17
Microchironomus deribae	4.64	28.58	10.6	6.5–21.0
Odontomyia sp.	6.99	30.90	25.40	8.50–32.10
Tanytarsus kharaensis	4.64	26.32	12.90	8.62–17.20
Palpomyia schmidti	8.30	31.70	26.95	20.76–33.14
Sphaeromias pictus	4.64	12.00	8.71	6.64–10.79

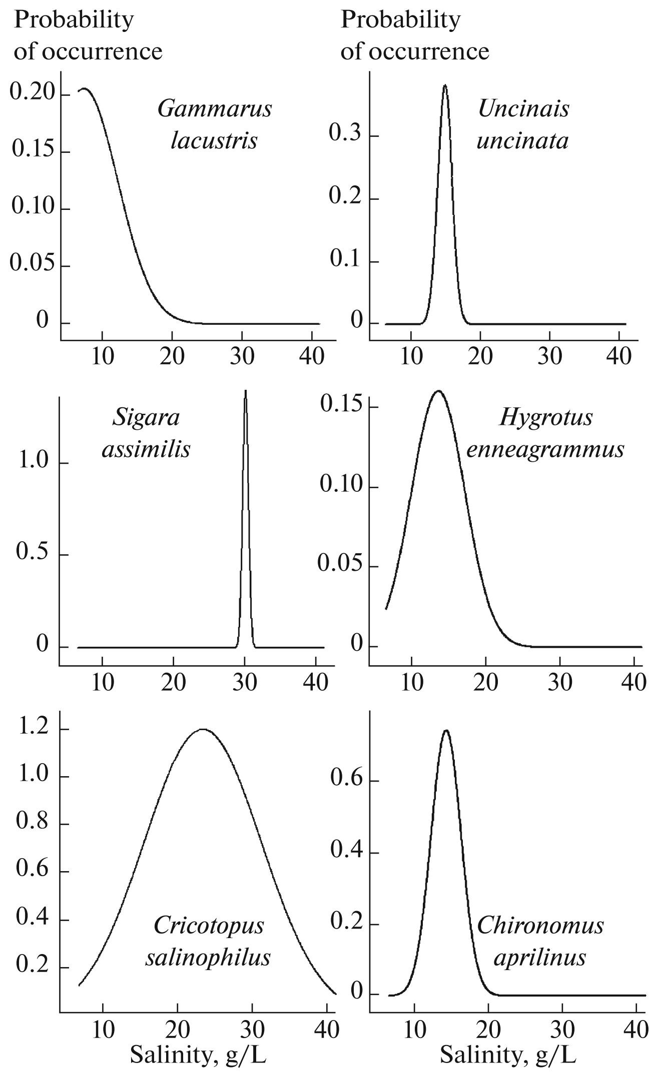

Fig. 3. Assessment of the probability distribution of occurrence of some macrozoobenthic species on the salinity scale using the Gaussian response curve.

world (Armitage et al., 1994; Velasco et al., 2006). The high tolerance is demonstrated by families such as Ceratopogonidae (up to 108 g/L), Ephydridae (up to 100 g/L), and Chironomidae (up to 115 g/L) (Short et al., 1991; Kay et al., 2001; Rutherford, Kefford, 2005; Velasco et al., 2006).

Therefore, insects, oligochaetes, and crustaceans in rivers of the Lake Elton basin live in a wide range of salinities, from 3.97 to 89.5 g/L. Application of mathematical models has made it possible to more accurately estimate ecological preferences of species and taxa for a certain level of water salinity. The highest tolerance to salinity is demonstrated by dipterans (Ephydridae, Chironomidae, Stratiomyidae, and Ceratopogonidae), beetles (Hydraenidae, Hydrophilidae, and Dytiscidae), and bugs (Corixidae), while some groups of hydrobionts widely occurring in fresh waters (stone flies, mayflies, caddis worms, etc.), are not found in salt rivers. The analysis of the obtained data shows that there are significant differences in salinity tolerance between species within genera, between genera within families, and between families within classes. For example, such differences are observed between the tolerance intervals of chironomids of the same genus (*Chironomus* gr. *plumosus* and *C. salinarius*), bugs of the family (Corixidae: *Callicorixa gebleri* and *Sigara assimilis*), etc. Species have been identified that have the highest tolerance to water salinity and develop en masse in the rivers of the Lake Elton basin: *Palpomyia schmidti*, *Cricotopus salinophilus*, *Chironomus salinarius*, *Ephydra* sp., and *Sigara assimilis*.

Comparisons between saline rivers of the Lake Elton basin and rivers of different arid regions of the world show that their faunas of macrozoobenthos are similar at the level of families, which is evidence for high specialization of certain taxa to the extreme habitat conditions. It is noteworthy that species inhabiting arid regions of the world with prevalence of salinized rivers (such as the Lake Elton basin and southwestern Australia) are better adapted to high salinity than those from territories where fresh waters prevail, which is due to the long period of adaptation of animals to the highly mineralized aquatic environment (Armitage et al., 1994).

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