Hydrobiologia (2007) 576:83–93
DOI 10.1007/s10750-006-0295-9

SALINE WATER

Changes in the biota of Chany Lake along a salinity gradient

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Abstract Relationships among salinity and diversity, abundance, biomass of major biological components of Chany Lake (western Siberia, Russia) are examined across a salinity gradient. As salinity increased from 0.8 to 6.4 g l^{-1}, the species richness of aquatic vascular plants decreased from 16 to 2 species, of phytoplankton from 98 to 52 species, and of zooplankton from 61 to 16 species, but changes in species diversity of zoobenthos were negligible.

Keywords Chany Lake · Salinity gradient · Phytoplankton · Macrophytes · Zooplankton · Zoobenthos

Introduction

Differences in diversity and other aspects of the biological structure of saline lakes with different salinities raise interesting ecological questions (Hammer, 1986; Colburn, 1988; Dalton-Morgan, 1992; Williams, 1998). However, it is rarely possible to observe a salinity gradient in one lake, as it is in Chany Lake, where two rivers (Chulym and Kargat), flow into the lake and create a gradient from 0.8 to 6.5 g l^{-1}. The aim of this paper is to examine effects of salinity on diversity, abundance and biomass of aquatic organisms in Siberian Chany Lake.

Guest Editor: John M. Melack
Saline Waters and their Biota

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Materials and methods

Chany Lake is the largest lake in western Siberia and varies in water level, area and salinity. It is situated in the forest-steppe of the Novosibirsk region, Russia (Fig. 1). The lake's average area is 1,800 km^2, and average depth 2.1 m.

Samples of water, phytoplankton, zooplankton and zoobenthos were obtained and collections of aquatic vascular plants were made at about 100 points near six stations in July–August 2001 (Fig. 2), and additional zooplankton samples were obtained in 2002 (Fig. 3). The six stations were located at the mouth of the Chulym and Kargat rivers (1), Small Chany Lake (2), Chinyaikhinsky pool (3), Yarkul Lake (4), Tagano-Kazantsevsky pool (5), and Yarkovsky pool (6).

Fourteen chemical measurements were made on each sample: salinity, pH, concentrations of

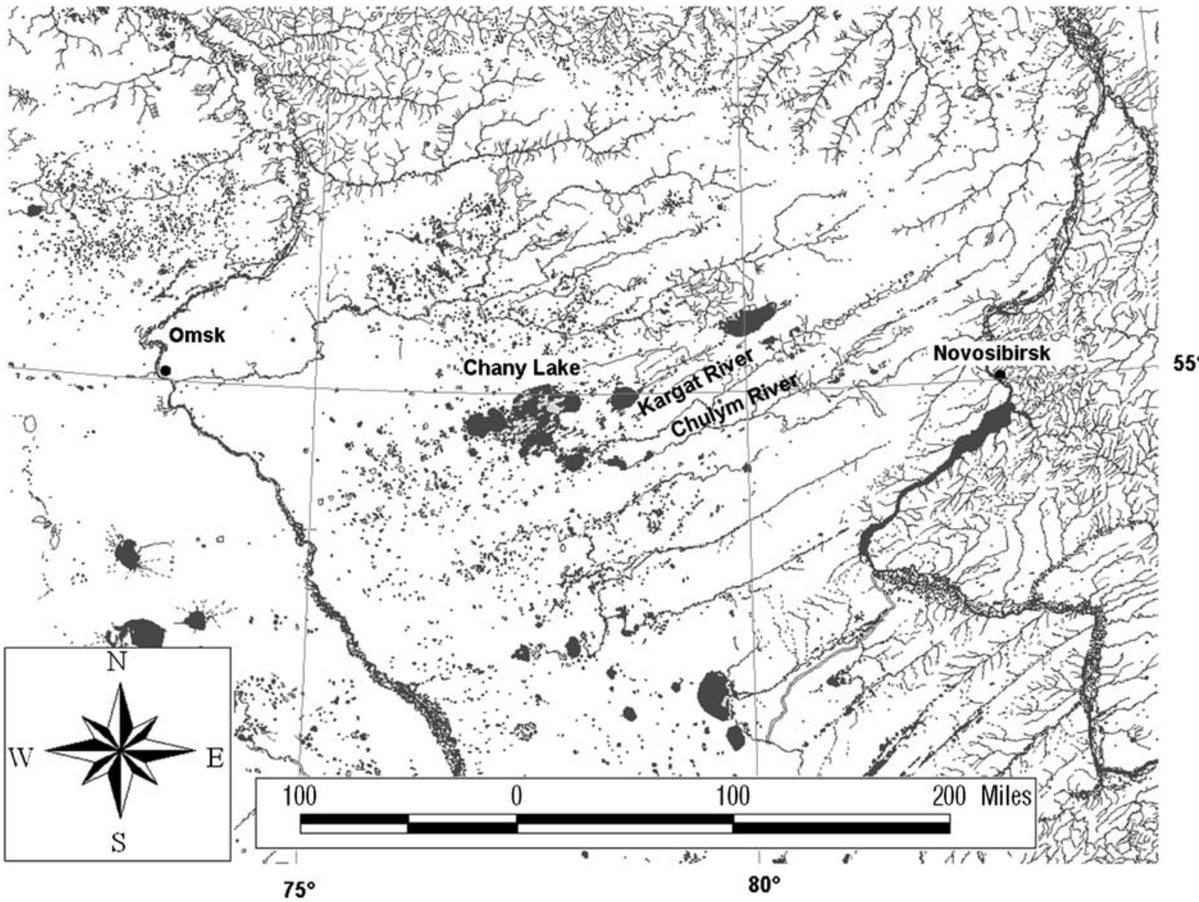


Fig. 1 Geographical location of Chany Lake

sodium and potassium (by ionometry using the ANION-7051), concentrations of ammonium, nitrite, nitrate and phosphate (by colorimetry), calcium, magnesium and alkalinity (by titration), sulfate (by turbidimetric method), chloride (by titration of the silver-ions excess after precipitation of chloride with $AgNO_3$), and residual solids (by weight).

Thirty-nine surface samples of phytoplankton were examined in a Nazhott chamber. Fifty-five releves of macrophyte vegetation were made. Zooplankton were sampled by passing 50 liters of water through a net with mesh of 0.024 mm^2 and preserved in 4% formalin. The samples were processed with the countable-weight method in Bogorov's chamber. The weights of cladocera and rotifers were determined based on body lengths using the equations in Balushkina & Vinberg (1979). In total, 93 quantitative zooplankton samples were processed in year 2001, and about 150 in 2002.

Quantitative zoobenthos samples were taken by dredge with an area 0.01 m^2 twice at each site. Qualitative samples were obtained by scraper or net. The samples were washed through a net with 0.16 mm^2 mesh and fixed in 70% ethanol. Mass of the organisms was measured on a torsion balance. Seventy-three zoobenthos samples were processed.

The statistical software package, STATISTICA, was used for correlation analysis of interrelations between the biota and environmental factors. Values of correlation coefficients are presented for $P < 0.05$.

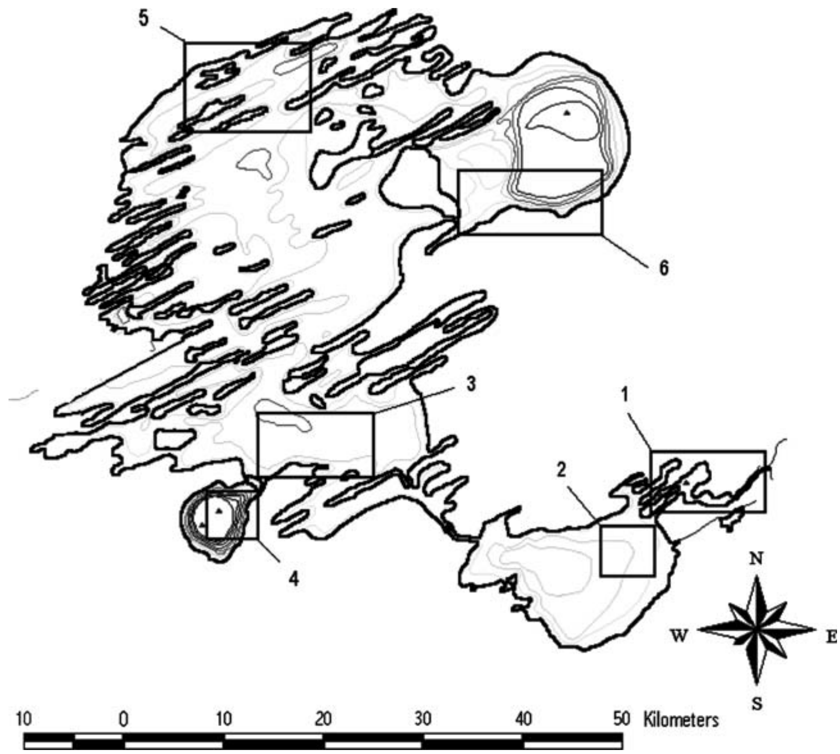


Fig. 2 Sampling locations in 2001 (1 – mouth area of Chulym and Kargat rivers, 2 – Small Chany Lake, 3 – Chinyaikhinsky pool, 4 – Yarkul Lake, 5 – Tagano-Kazantsevsky pool, 6 – Yarkovsky pool)

Results

Hydrochemistry

As the distance from the rivers' mouth increases in the sequence Small Chany Lake–Chinyaikhinsky pool–Yarkul Lake–Tagano–Kazantsevsky pool–Yarkovsky pool, salinity increases as follows 0.9–0.8–3.1–3.6–5.6–6.4 g l^{-1}. The Chany Lake system can be divided into three area with respect to salinity: (a) rivers' mouth and Small Chany Lake with the lowest values, (b) Chinyaikhinsky pool and Yarkul Lake with somewhat higher salinity, and (c) Tagano-Kazantsevsky and Yarkovsky pools with the most saline water (Fig. 4).

Salinity was positively correlated with sodium (r = 0.99), potassium (r = 0.98), chloride (r = 0.99) magnesium (r = 0.99), sulfate (r = 0.77), nitrate (r = 0.75), solid residual (r = 0.98), hardness (r = 0.99), alkalinity (r = 0.91), and pH (r = 0.74), while negatively correlated with calcium (r = –0.88) and phosphate (r = –0.50). Salinity is mainly determined by sodium and chloride (Fig. 5).

Phytoplankton

230 algal species have been identified in Chany Lake: Cyanophyta – 49 species, Chrysophyta – 4, Bacillariophyta – 47, Xanthophyta – 3, Cryptophyta – 1, Dinophyta – 3, Euglenophyta – 18, and Chlorophyta – 105 species (Ermolaev & Vizer, 2001). Phytoplankton species richness was reported by Safonova & Ermolaev (1983) to decrease from 98 to 52 species from Small Chany to Yarkovsky pool as salinity increased. There is a gradual decrease in number of phytoplankton species (Fig. 6) and biomass of phytoplankton in midsummer along the gradient line: 180.99–51.76–2.36–9.12–4.33 g m^{-3} (Ermolaev, 1986).

The lowest phytoplankton abundance was observed in the most saline parts of the lake, and the largest abundance in the least saline waters. The results of the correlation analysis of the abundance indicate that the high salinity decreases phytoplankton (r = –0.76), and that algal abundance negatively correlates with pH (r = –0.55) and concentrations of HCO_3^- (r = –0.61), NO_3^- (r = –0.67), SO_4^{2-} (r = –0.69), Cl^- (r = –0.75),

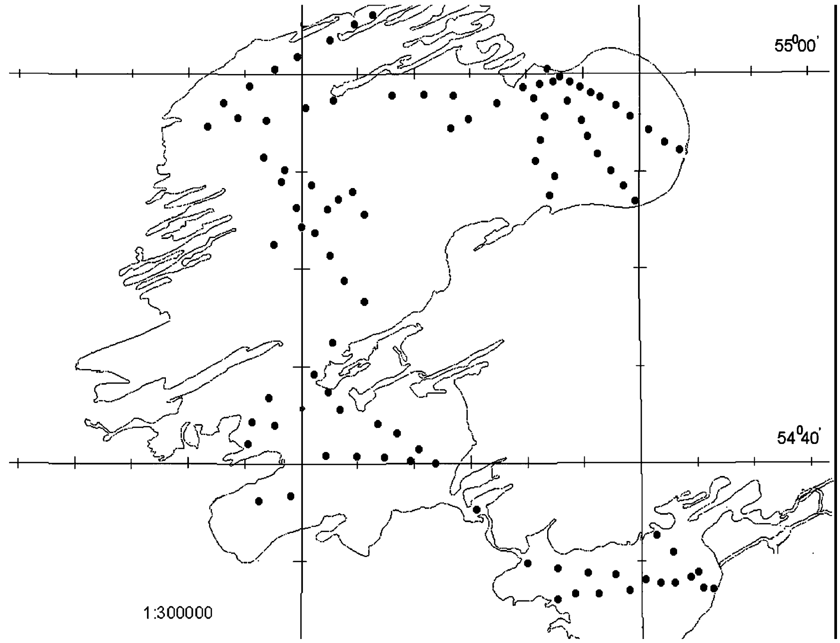


Fig. 3 Zooplankton sampling sites in 2002

Mg^{2+} (r = –0.77), and NH_4^+ (r = –0.49), and positively with Ca^{2+} (r = 0.65).

Aquatic and littoral macrophytes

Twenty-one species of vascular plants and 4 macroalgal species were found in Chany Lake (algae forming the macrophyte cenosises were taken into account). Phytocenosis diversity of Chany Lake's aquatic and littoral vascular vegetation is equal to 16 syntaxa (types of plant communities) of the association rank using the Braun–Blanquet approach.

As salinity increased, species richness of aquatic and littoral vascular plants decreased: 16–10–8–4–2–2, as did cenotic diversity of vascular macrophyte vegetation: 13–5–5–4–2–2. Species richness of macrophytes fell by up to 20% of its maximum value when moving from Small Chany Lake (2) to Yarkovsky pool (6); whereas phytoplankton species richness decreased at most by 50% (Fig. 6).

Macroalgal cover correlated positively with all characteristics related to salinity (for total salinity, r = 0.66) and transparency (r = 0.42), while vascular plants cover correlated positively only

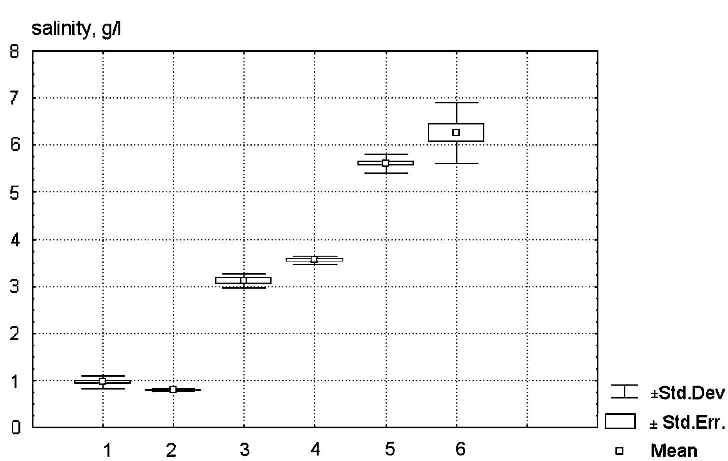


Fig. 4 Salinity in the main parts of Chany Lake

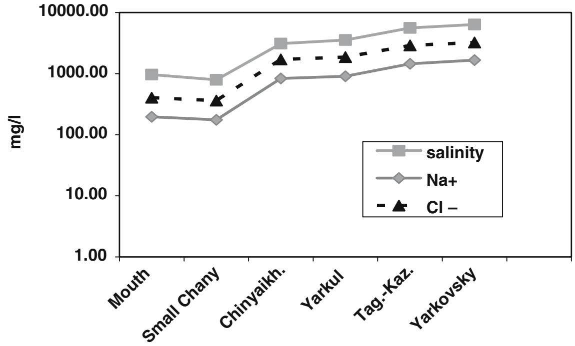


Fig. 5 Salinity, Na^{+} and Cl^{-} in Chany Lake

with PO_4^{3-} ($r = 0.44$). The correlation analysis indicates that the total cover of macrophytes does not appear to be influenced by salinity of the water. This can be explained by the presence of species with wide ecological tolerance: *Cladophora fracta* (Mull. ex Vahl) Kutz. and *Potamogeton pectinatus* L. The associations Phragmitetum communis and Potametum pectinati were widespread and dominated in all the pools of Chany Lake. The presence of *Najas marina* L. and *Chara canescense* Desv. et Lois in Chinyaikhinsky pool and Yarkul Lake with a salinity range from 3 to 4 g l^{-1} is notable. *Cladophora fracta* communities become common in Tagano-Kazantsevsky (5.6 g l^{-1}) and productive in Yarkovsky pool (6.4 g l^{-1}).

Zooplankton

In 2001, we identified 65 zooplankton species in Chany Lake (Table 1) and observed a substitution of fresh-water zooplankton for brackish-water zooplankton as salinity increases. The species richness of zooplankton decreased from 61 in Small Chany Lake to 16 in Yarkovsky pool (Fig. 6). Salt-tolerant species did appear as salinity increased from 3.5 to 5.5 g l^{-1}.

We have analyzed the distribution of some zooplankton species along a salinity gradient (Fig. 3): *Diaphanosoma brachyurum* (Lievin) was encountered in 2002 within a salinity range 0.75–5.83 g l^{-1}, whereas *Leptodora kindtii* (Focke) was not observed in waters with salinity exceeding 0.85 g l^{-1}. *Daphnia longispina* Müller, which is typical for fresh waters, is substituted for *Moina*

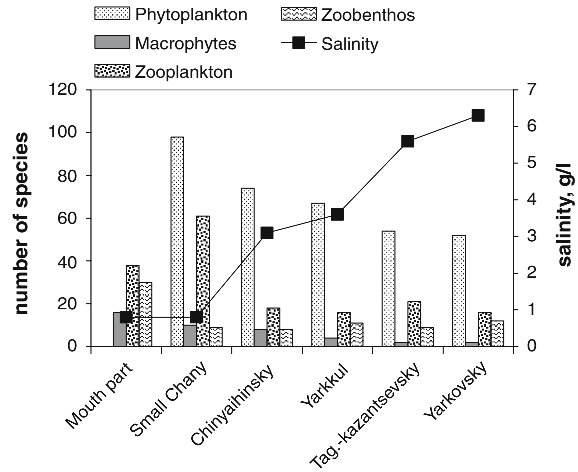


Fig. 6 Species diversity along salinity gradient in Chany Lake

microphthalma Sars and *Daphnia magna* Straus as salinity increases (Fig. 7a). *Bosmina longirosris* (Müller), which is a species of normally broad ecological range, was detected only in water with low salinity: 0.81–3.41 g l^{-1}. *Chydorus sphaericus* (Müller), decreased in abundance and biomass along the salinity gradient (Fig. 7b). Two systematically close species, *Ceriodaphnia quadrangula* (Müller) and *C. reticulata* (Jurine) are distributed in the different ranges of salinity (Fig. 7c).

The freshwater species *Eudiaptomus graciloides* (Lilljeborg) was substituted by saline species, *Arctodiaptomus salinus* (Daday) (Fig. 8a), and *Acanthocyclops viridis* Jurine by *Cyclops strenuus* Fisch. (Fig. 8b).

Among rotifers an interesting change in *Brachionus* species occurred (Fig. 9a) along the salinity gradient: *Brachionus quadridentatus* Hermann (0.78–3.28 g l^{-1}) was gradually substituted by *Br. variabilis Hempel* (0.81–5.52 g l^{-1}), then *B. quadridentatus var. melheni* Bar.et.Dad. (3.41–6.55 g l^{-1}) appears, and finally, *Br. plicatilis* Müller occurs, at highest salinities 5.78–7.85 g l^{-1}. *Keratella cochlearis var. macrachantha* (Lauterborn) was found in Small Chany Lake and Chinyaikhinsky pool at salinity less than 0.97 g l^{-1}, *K. quadrata* (Müller) was distributed much more widely and occurred in Yarkovsky pool (Fig. 9b). At higher concentration of salts the genus *Keratella* disappears from zooplankton but the genus *Hexarthra* appears. The salinity 5.50–5.67 g l^{-1},

Table 1 Dominant species of different groups in Chany Lake. In bold are phytoplankton species that are dominant in abundance and biomass

	Mouth area	Small Chany	Chinyaikchinsky Pool	Yarkul Lake	Tagano-Kazantsevsky Pool	Yarkovsky Pool
Phytoplankton						
In abundance						
Gloeocapsa minima (Keissl.) Hollerb.	+++					
Aphanothece clathrata W. et G.S.West	+++	+++				
Microcystis pulveraea (H. Wood) Forti emend. Elenk.	+++	+++			+++	
Merismopedia tenuissima Lemm.		+++			+++	
Coelastrum microporum Näg.		+++	+++			
Dictyosphaerium pulchellum Wood			+++			
Pediastrum boryanum *(Turp.) Menegh*.			+++		+++	
Lyngbya contorta *Lemm.*						
Lyngbya lutea (Ag.) Gom.						
Phormidium tenue (Menegh.) Gom.						
In biomass						
Gomphosphaeria lacustris f. compacta (Lemm.) Elenk.	+++					
Oscillatoria amphibia Ag.		+++				
Pediastrum boryanum *(Turp.) Menegh.*	+++	+++	+++		+++	
Lyngbya contorta *Lemm.*	+++	+++			+++	
Euglena polymorpha Dang.		+++				
Dictyosphaerium pulchellum Wood			+++			
Pediastrum kawrajskii Schmidle			+++			
Gomphosphaeria lacustris f. lacustris Chod.					+++	
Scenedesmus quadricauda (Turp.) Bréb.						
Macrophytes						
Phragmites australis Cav. Trin ex Steud.	+++	+++	+++	+++	+++	+++
Potamogeton pectinatus L.	+++	+++	+++	+++	+++	+++
Cladophora fracta (Mull. ex Vahl) Kutz.					+++	+++
Zooplankton						
Rotatoria						
Euchlanis dilatata Ehrenberg	+++					
Brachionus angularis bidens Plate	+++	+++				
Asplanchna priodonta Gosse	+++	+++	+++			
Keratella quadrata quadrata (Müller)	+++	+++	+++			
Brachionus quadridentatus var. melheni Bar.et.Dad.					+++	+++
Cladocera						
Chydorus sphaericus (Müller)	+++	+++				
Daphnia longispina (Müller)	+++	+++	+++			
Diaphanosoma brachyurum (Lievin)		+++	+++	+++	+++	+++
Ceriodaphnia reticulata (Jurine)			+++	+++	+++	
Daphnia magna Straus					+++	+++
Moina microphthalma Sars					+++	+++

Table 1 continued

	Mouth area	Small Chany	Chinyaikchinsky Pool	Yarkul Lake	Tagano-Kazantsevsky Pool	Yarkovsky Pool
Copepoda						
Mesocyclops leuckarti (Claus)	+++	+++	+++			
Cyclops strenuus Fisch.			+++			
Arctodiaptomus salinus (Daday)			+++	+++	+++	+++
Zoobenthos						
Limnodrilus hoffmeisteri Clap.	+++					
Glyptotendipes glaucus Meig.	+++			+++		
Euglesa sp.		+++				
Chironomus ex. gr. plumosus		+++				
Chironomus pallidivittatus Mall.			+++		+++	+++
Glyptotendipes paripes Edw.				+++		
Hesperocorixa sahlbergi (Fieber)						

was favorable for *Hexarthra mira* (Hudson), but *H. fennica* (Levander) was found only in a range 6.07–6.83 g l^{-1}. *Filinia terminalis* (Plate) is present in all areas of Chany Lake, and was most abundant when salinity exceeded 1.19 g l^{-1}. *F. major* Golditz did not occur in Small Chany Lake and was found only at salinities of 5.50–5.67 g l^{-1} (Fig. 9c).

Asplanchna priodonta Gosse was limited to fresh and slightly saline waters. It reached as many as 5200 individuals per cubic meter at salinity of 0.95 g l^{-1}, but was not detected in waters with salinity above 3.41 g l^{-1}. *Euchlanis dilatata* Ehrenberg was present only in Small Chany Lake and in Chinyaikhinsky pool with salinity lower than 1.11 g l^{-1}.

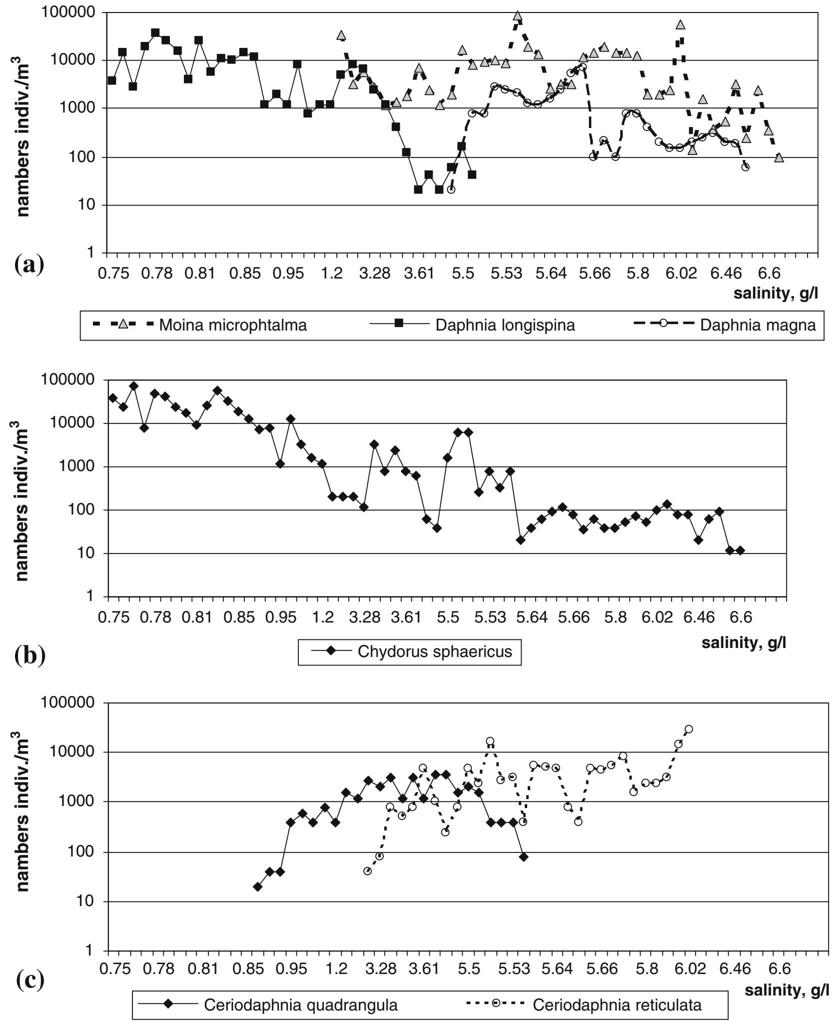
Presumably, the restrictions in distribution of some species (in particular, *C. strenuus* and *B. longirosris*), may be determined by specific ions, rather than by total salinity, but this hypothesis requires further research. The critical level of salinity for a number of species was found to be about 5.5 g l^{-1}, e.g., *B. variabilis*, *K. quadrata*, *D. longispina*, *C. quadrangu* disappear, but *H. mira*, *F. major*, *C. strenuus*, *D. magna* appear, and species such as *C. reticulata* and *M. microphthalma* increase in abundance.

The negative correlation of zooplankton species diversity (counted as the number of species in a 50 l sample) with salinity was found ($r = -0.74$). Moreover, the species diversity of all three zooplankton groups (Cladocera, Copepoda and Rotatoria) was negatively correlated with salinity ($r = -0.66$, $r = -0.67$, $r = -0.62$, respectively). In contrast, while abundance ($r = -0.37$) and biomass ($r = -0.26$) of Cladocera and biomass of Rotatoria ($r = -0.44$) was negatively related to salinity, abundance ($r = 0.30$) and biomass ($r = 0.40$) of Copepoda was positively correlated with salinity, owing to brackish-water species *Arctodiaptomus salinus* (Daday), which was the main contributor to zooplankton biomass in Yarkovsky pool.

Zoobentos

Seventy species of benthic invertebrates were found, including Oligochaeta – 2, Hirudinea – 4, Mollusca – 16, Crustacaea – 2, Arachnida – 2,

Fig. 7 Changes in Cladocera along salinity gradient



Trichoptera – 3, Ephemeroptera – 3, Odonata – 3, Heteroptera – 2, Coleoptera – 4, Diptera – 29 (among them Chironomidae – 17). The species diversity of benthic invertebrates changed in the sequence: 31–13–9–11–11–15 as salinity increased. There was a tendency for some of the zoobenthic species to be eliminated as salinity increased, while eurybiontic species adapted to the new conditions, but halophytic species were not observed (Fig. 10). The species diversity of zoobenthos in the area of the Chulym and Kargat river mouths was greater than that in other places within the lake, perhaps, in part, because of the wide variety of habitats.

The average biomass increased 35–147 times as the salinity increased from 0.8–1.0 g l^{-1} (Small Chany) to 5.6–6.4 g l^{-1} (Yarkovsky and Tagano-Kazantsevsky pools) (Fig. 11).

The zoobenthos abundance and biomass correlated negatively with sampling depth (r = –0.29 and –0.32, respectively). Moreover, zoobenthos biomass correlated positively with concentrations of NH_4^+ (r = 0.61) and PO_4^{3-}(r = 0.53).

Discussion

Despite the significant inverse correlation found between species richness of vascular plants and salinity, it is important to recognize that both species richness (16) and cenotic richness (13) of vascular vegetation was higher in the vicinity of

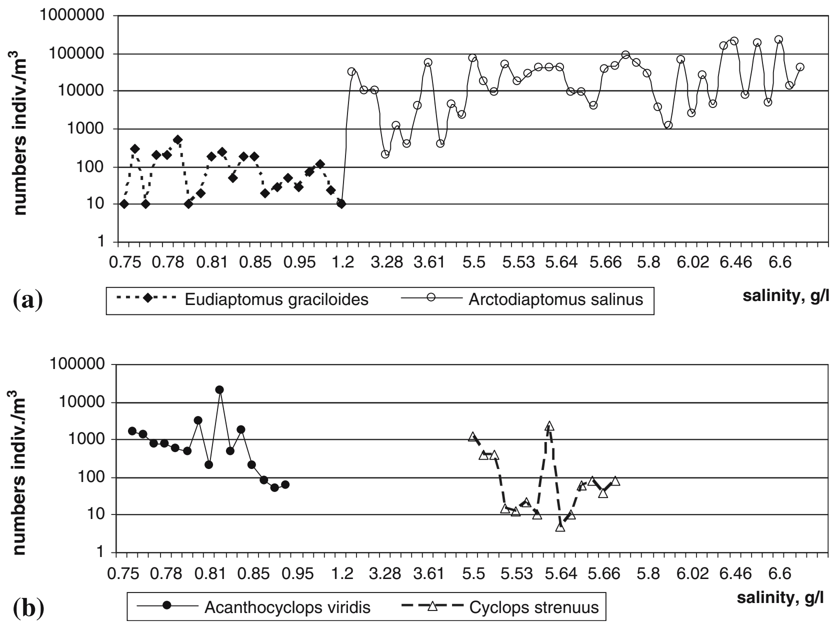


Fig. 8 Changes in Copepoda along salinity gradient

the river mouths in comparison with Small Chany Lake. This difference probably reflects the greater variety of habitats, such as shallow habitats with alluvial sediments, and conforms to the conclusion about the lesser importance of salinity over intermediate salinity ranges (Hammer & Heseltine, 1988; Williams, 1998). Moreover, phytoplankton, over the range of salinities observed, did not exhibit a large decrease the number of species. This pattern was noted for diatoms (Servant-Vildary & Roux, 1990), for which a correlation between a decrease in a number of species and an increase of salinity was not been observed in Bolivian saline lakes.

Our results for zoobenthos are in agreement with data obtained by Williams (1990) showing the species richness of freshwater species decreases with salinity strongly in the range 0.3–3.0 g l^{-1} but weakly (with alteration in community composition) at higher salinity. According to Hammer (1990), the quantitative diversity of zoobenthos is of almost the same value (29–31) for all lakes with salinity of less than 6‰. In this salinity range, some other environmental factors such as sediment type, vegetation type, and organic matter must be important. At 15‰ salinity, and higher, the species diversity was observed to be steeply decline (Hammer, 1990).

A comparison of Chany Lake with lakes of other regions has revealed the similarity of zooplankton species composition in western Siberian postglacial lakes and Canadian (Hammer, 1993) as well as Spanish saline lakes (Alonso, 1990). In the Canadian and Spanish lakes, there are many endemic species of zooplankton, but it is possible to compare some cosmopolitan Rotatoria and Cladocera in respect to salinity tolerance. Hammer (1993) noted the salinity value 7 g l^{-1} as a lower limit of *Brachionus plicatilis* distribution, while in Chany Lake *B. plicatilis* was found at salinity 5.8 g l^{-1}. In Canadian lakes *Keratella cochlearis* was found at salinity up to 25 g l^{-1}, and *Keratella quadrata* up to 100 g l^{-1}. In Chany Lake *K. cochlearis* disappears at 1.1 g l^{-1}, *K. quadrata*– at 5.5 g l^{-1}. The differences in the ranges of distribution of these species in various regions may be ascribed to other factors, e.g., relative concentrations of mono- and divalent-cations (Williams, 1998). A statement of Hammer (1993) and Alonso (1990) about 5 g l^{-1} lower limit of salinity in mesosaline lakes, where ‘‘true halobionts’’ appear, may well be applied to Chany Lake zooplankton.

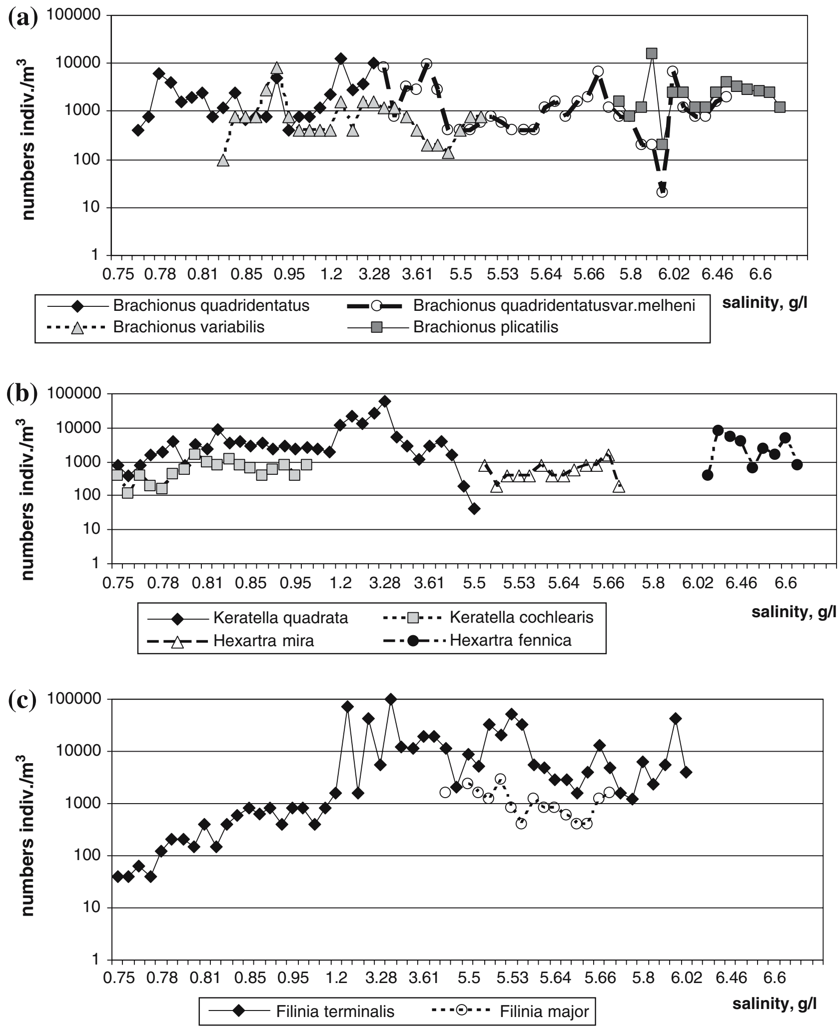


Fig. 9 Changes of specific structure of Rotatoria along salinity gradient

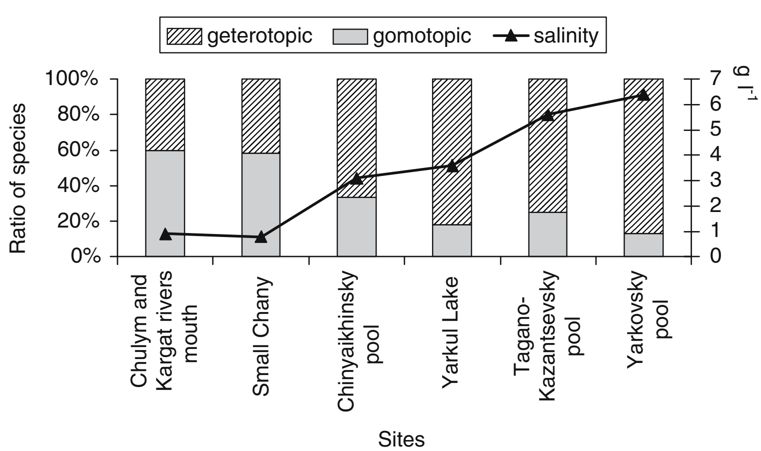


Fig. 10 Ratio of abundance the heterotopic and homotopic zoobenthos in various sites in Chany Lake in 2001

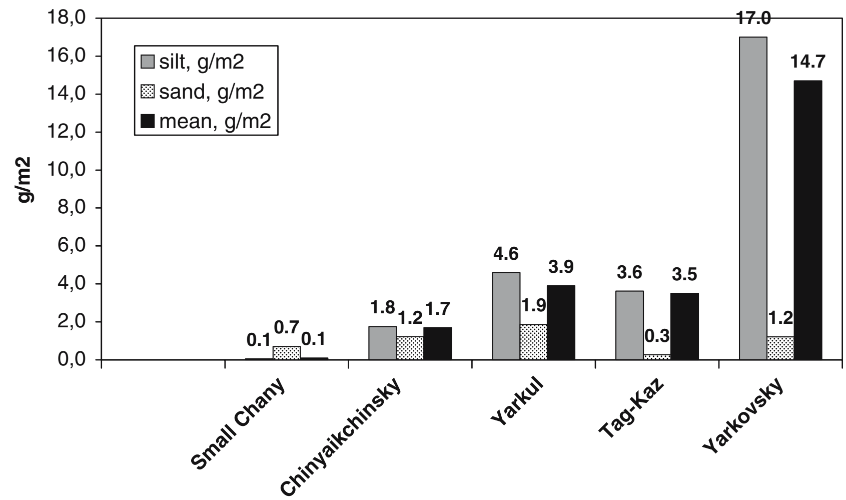


Fig. 11 Zoobenthos biomass in Chany Lake in 2001

Acknowledgements Russian Foundation for Basic Research supported the investigations (grant No. 01-04-49893). John Melack and Koen Martens are thanked for a critical reviewing this manuscript and providing many helpful ideas for improvement. We are grateful to Serge Prokopiev for the further enhancing of the language.

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