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Climate Change Impact on the Marine Lakes and their Crustaceans: The Case of Marine Hypersaline Lake Bakalskoye (Ukraine)

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Abstract

All over the world hypersaline lake/lagoons are threatened by climate change. The marine Bakalskoye Lake (Ukraine) was studied in 2000-2012. The paper considers changing crustaceans within the context of the lagoon changes. A sharp drop of salinity occurred in 2004 due to a changed wind rose because the strong winds of Western direction began to dominate, and as a result, washing away of the spit began to be more intensive; and marine water inflow into the lake increased. The structure of primary productivity has changed completely; the total primary production decreased. A list of crustacean species found in the lake includes 19 species. In 2004 there was a change of the composition of crustaceans due to three factors - a change of salinity, an increase of erosion, and massive transport of marine organisms into the lake. Integral characteristics of zooplankton also significantly changed. Impact of climate change on crustaceans is not only direct, but through an extensive network of intermediate effects which are discussed. The study results are of more than local relevance; it has a general ecological importance because can help to better understand that the realizations of general climate change impacts on local level are diverse.

Keywords: Crustacea, lagoon, climate change, Black Sea, sand spit dynamics.

Introduction

There is now ample evidence of the impacts of recent climate change on different terrestrial and aquatic ecosystems (Walther *et al.*, 2002; O'Reilly *et al.*, 2003; Smol *et al.*, 2005; Hawkins *et al.*, 2009; Drinkwater *et al.*, 2010). It is impossible to speak about a global trend and the mechanisms of responses of ecosystems without understanding how specific ecosystems are responding to global climate change. Hypersaline lakes and lagoons, being most numerous in arid and semi-arid zones, which make up about one-third of the world land, are an essential, integral and dynamic part of the biosphere. The biogeochemical processes occurring in their unique ecosystems have considerable environmental, social and economic value (Zheng, 2001). All over the world salt/hypersaline lakes and lagoons are threatened by climate change, water diversions upstream for agricultural purposes, watershed changes, etc. that result in catastrophic changes of the lakes (Aladin *et al.*, 1998; Salameh and El-Naser, 2000; Piovano *et al.*, 2002; Mulchin, 2007; Carrasco and Perissinotto, 2012; Abbaspour *et al.*, 2012). Human communities suffer many negative consequences as a result of this, and a lost of valuable biological resources among them. The changes of hypersaline lakes are characterized by wide fluctuations in salinity, leading to a significant restructuring of their biodiversity and ecosystem functioning (Aladin and Potts, 1992; Mirabdullayev *et al.*, 2004; Velasco *et al.*, 2006; Balushkina *et al.*, 2009; Carrasco and Perissinotto, 2012).

Such changes were more or less well studied in large saline lakes, however much less attention is paid to the study of similar changes in smaller, shallow lakes. Lake size and morphometry influence almost all processes in lakes (Rawson, 1955; Håkanson, 2010). For example, there was shown that the morphometric dimensionless index of water body – MI (MI ~ Ll /Dmv, where Ll - the shoreline length and Dmv - the mean depth) influences on several important abiotic and biotic lake characteristics (Shadrin, 1985, 2003; Håkanson, 2010). This index is very different for large and small water bodies; that's why we can't directly use data and peculiarities found for large lakes to understand and predict dynamics of small ones.

In the Crimea (Ukraine) - the largest peninsula of the Black Sea - there are more than 50 different hypersaline lakes of marine and continental origin (Kurnakov *et al.,* 1936; Shadrin, 2009). One of these, the Bakalskoye Lake was the subject of our research during several years (2000-2012). The main objective of this work is to consider the changes of taxocene of crustaceans within the context of Lake Bakalskoye changes. We look on a taxocene of crustaceans as on a subsystem of a whole biocoenosis; a taxocene is a group of species that belong to particular supraspecific taxon and occur together in the same ecosystem (Hutchinson, 1978; Kwak and Peterson, 2007). For this task our own data, as well as that collected from literature were used.

Hypersaline Lake Bakalskoye - a closed lagoon (45° 44' 45" N, 33° 10' 30" E) is located in the north-western part of Crimea peninsula on Tarkhankut peninsula (Figure 1). There are published data of observations of this lake (Kurnakov *et al.,* 1936; Zenkovich, 1960; Shadrin *et al.*, 2001; Zagorodnyaya *et al.,* 2008); which we will summarize here. It is located in the extended part Bakalskaya Spit formed by merging two branches - tombolos composed of shell fragments and sand mostly. These spits separate the lake from the Black Sea. The East Spit is much broader than the West one and both of them are adjacent to clay cliffs, which demonstrate an intensive abrasion. Total length of the accumulative landform from the base to the distal end is about 9 km. The lake is oval. Its length from north to south is 4 km, and from west to east - 3.5 km. Water area of the lake is not constant depending on the hydrologic balance; it fluctuates between 6.5 and 8.5 km^2 (Kurnakov *et al.*, 1936; Zenkovich, 1960; Zagorodnyaya *et al.*, 2008; Goryachkin *et al.*, 2012).

A balance of water in the lake consists of filtrated marine waters - main input; marine storm waters, which are thrown through the West spit during strong storms of western or south-western directions; precipitation on the lake surface and on the basin area; ground water inflows (near east and south coasts), and evaporation is the only output. The winds have a significant impact on the water balance of the lake (inflow of sea water) because of open space around it. Waves caused by the strong eastern and north-eastern winds (autumn and winter) may throw marine water in the lake across the East spit, and waves caused by the western and south-west winds - through West one. In some years, spring and summer storms (Western winds) erode the Western spit making small channels, and marine water enters into the lake in large quantities. As a consequence, Lake Bakalskoye is characterized by high sensitivity to the variability of the wind regime, which causes changes in the structure and functioning of the biota, sedimentation, etc. (Shadrin *et al.*, 2004; Zagorodnyaya *et al.,* 2008). The diversity of microalgae in plankton was low. *Dunaliella salina*, *Gleocapsa minor*, *G. vacuolata*, *G.* sp., *Gymnodinium* sp. *Peridinium sabsalsum*, *Cromonas acuta*, *Chlorella vulgaris* as well as numerous tiny benthic diatoms were dominant species during our study (Senicheva *et al.*, 2008). The diversity of benthic microalgae (cyanobacteria and diatoms) is significantly higher than in plankton (Nevrova and Shadrin, 2005; Shadrin *et al.*, 2008). In some years, filamentous green alga *Cladophora* spp. (benthic and floating mats), and flowering plant *Ruppia cirrhosa* intensively developed in the lake (Shadrin *et al.*, 2001). Fauna in the lake consists of representatives of the following groups of organisms: Foraminifera, Nematoda, Turbellaria, Rotifera, Polychaeta, Gastropoda, Bivalvia, Diptera, Coleoptera, Crustacea (Zagorodnyaya *et al.*, 2008; Balushkina *et al.*, 2009; Belmonte *et al.*, 2012). It should be noted that in plankton there are a lot of

Figure 1. The hypersaline Lake Bakalskoye in the Crimea (Ukraine).

benthic forms; in shallow hypersaline lakes there is no clear division between plankton and benthos.

Materials and Methods

The results of own long-term studies of the lake and Bakalskaya Spit (2000-2012) were used for this paper. The data (2000-2007) was partly published previously (Shadrin *et al.*, 2001, 2004, 2008, 2012; Nevrova and Shadrin, 2005; Senichevea *et al.*, 2008; Zagorodnyaya *et al.*, 2008; Belmonte *et al.*, 2012).The results obtained in 2008-2012, however have not been previously analyzed and published. The methods used are described in our earlier papers (Zagorodnyaya *et al.*, 2008; Anufriieva and Shadrin, 2012; Belmonte *et al.*, 2012); we give only a briefly their description here. Quantitative samples of zooplankton were collected at several points of the lake. 50-100 L of water were filtered through Epstein net (pore size 110 μm). Samples were preserved by 4% formalin solution. 54 samples were taken and analyzed. Parallel with sampling the salinity, temperature and pH were determined. A special tube (diameter 50 mm, length 250 mm) was used to collect the bottom sediments. In data processing we used standard statistical methods. For pairs of species, we determined whether the frequency of their co-occurrence was a non random event; this method is used in geobotany and hydrobiology (Anufriieva and Shadrin, 2012). For a random event the frequency of co-occurrence was calculated as the product of the frequencies of 1st and 2nd species (T), was compared to an observed value of the frequency of their co-occurrence (O). If O≈T, we made the conclusion that their co-occurrence was a random event. To characterize the changes in the lake we used our own data in addition to long-term satellite data (1999-2011), which are available to the public on the website of U.S. Geological Survey (http://landsatlook.usgs.gov/). For analysis we used the available August pictures for every year. We determined the latitude and longitude of the given points, measured the distances and area of the lake.

Results

During the period of our study in the lake there were pronounced changes. In 2000-2012 salinity in the lake fluctuated between 20 and 106 ‰, variation of pH range was also enough wide - 7.52 - 9.7. Variability of abiotic factors (salinity, temperature, pH) is shown in Figure 2; those data never was summarized before. Temperature and pH did not change in these years as dramatically as salinity, a sharp drop of which occurred in the lake in 2004. This can be primarily explained by changed wind patterns, the strong winds of Western directions (from the sea to the spit) began to dominate (Shadrin *et al.*, 2004). As a result, washing away of the Western Spit began to be more intensive, and the flow of sea water into the lake increased. In the summer of 2004 during the frequent strong storms the sea waves regularly

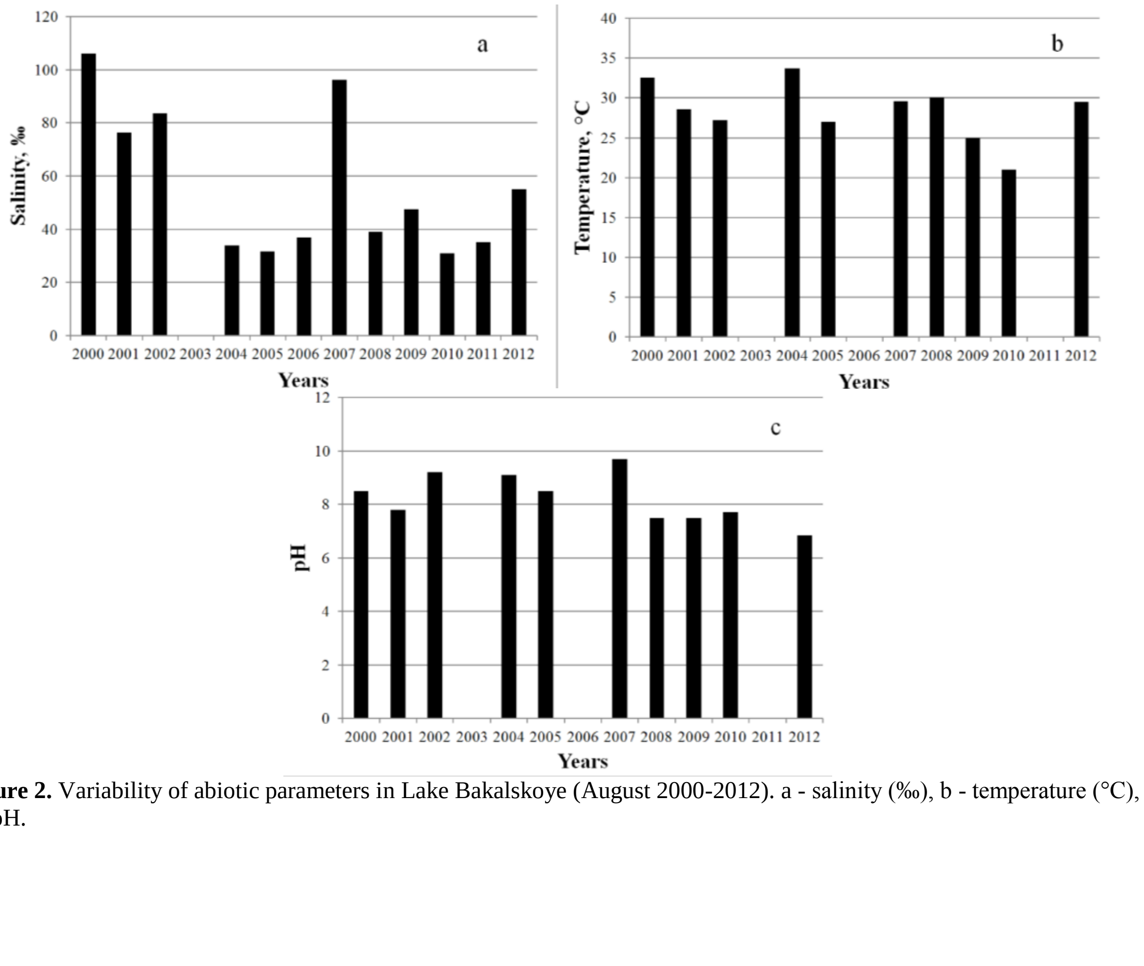

Figure 2. Variability of abiotic parameters in Lake Bakalskoye (August 2000-2012). a - salinity (‰), b - temperature (°C), c - pH.

crossed the narrow spit on nearly one-third of its length. During a period of our study an increase of the maximal depth was observed from 50-60 cm in 2001-2002 up to 120 cm in 2004 and later.

In those years there was a shift of the spit into the lake. In particular, the concrete pillars that were 50-80 m from the water, were flooded and are now in the sea; more than 50 meters from the water edge. We used of the satellite images of the Lake Bakalskoye of U.S. Geological Survey to confirm this; our analysis of the images had demonstrated a change of coordinates of the spit center; it moved in a south-eastern direction. During the period from 2001 to 2011, there was a shift of the south at 0.0015˚ and 0,001˚ to the east. Spit moved into the lake 100-200 m during this period, which led to a decrease of the area of the lake about 0.4 km^2 - from the average area of the lake in August 6.7 - 6.8 km^2 (2000-2003) to 6.3 - 6.6 km^2 (2007-2011).

After 2003 we visually observed an increase of sand input into the lake from the spit body, as well as an acceleration of an abrasion of East and South lake cliffs. We can't quantify this effect now. It should be noted that a changed wind pattern led to the growing influence of storms on the lake; big waves from the west began to reach the eastern shore of the lake and this has led to increased abrasion of the cliff here. Abrasion of the southern shore cliff in the lake intensified also. Increased cliff erosion has led to the lake receiving more clay particles.

Bottom sediment samples taken in 2007-2011 at various points in the lake have showed that the thickness of the upper clay-sand layer covered a black mud layer was up to 5-10 cm, but in 2004, the thickness of this layer was 1-2 cm (Shadrin *et al.*, 2004). The character of bottom sediments was completely changed - in previous years sediments (including top layer) were black with smelt of H_2S, and much less dense than in 2004 - 2012. In 2004 and later, sediments were gray, oxidized to a depth of 5 - 10 cm.

In 2001-2003, the lake was occupied by large areas of floating and bottom mats of green filamentous algae *Cladophora siwaschensis* C. Meyer, which were the main supplier of organic matter for the lake bottom. Incidentally, these mats are clearly visible on satellite images of summer 2000-2002 (http://landsatlook.usgs.gov/). As from 2004, *Cladophora* mats (floating and bottom) in the lake had completely disappeared. Before 2004 in some parts of the lake, floating mats created the illusion of a false shore and quenched waves, drastically reducing coastal erosion.

Our study of crustaceans has allowed us to compose a list of crustacean species found in the lake from 2000 to 2012. 19 species of crustaceans (2 species not identified) from four classes, 10 orders and 15 families were found in total. The list of them is given below. Species names are given in accordance with The World Register of Marine Species (http://www.marinespecies.org/index.php).

Class Branchiopoda
Order Anostraca
Family Artemiidae
Artemia spp.
Artemia (parthenogenetic population)
Family Thamnocephalidae
Branchinella spinosa (H. Milne Edwards, 1840)
Order Cladocera
Family Moinidae
Moina salina (Daday, 1888)
Class Maxillopoda (Subclass Copepoda)
Order Calanoida
Family Acartiidae
Acartia tonsa (Dana, 1849)
Order Cyclopoida
Cyclopoida gen. sp.
Order Harpacticoida
Family Canuellidae
Canuella perplexa (T. & A. Scott, 1893)
Family Canthocamptidae
Cletocamptus retrogressus (Schmankewitsch, 1875)
Family Harpacticidae
Harpacticus sp.
Family Canthocamptidae
Mesochra aestuarii (Gurney, 1921)
Family Ameiridae
Nitocra sp.
Class Ostracoda
Order Podocopida
Family Cyprididae
Eucypris inflata (Sars, 1903)
Class Malacostraca
Order Mysida
Family Mysidae
Mesopodopsis slabberi (van Beneden, 1861)
Order Amphipoda
Family Gammaridae
Gammarus aequicauda (Martynov, 1931)
Family Corophiidae
Monocorophium insidiosum (Crawford, 1937)
Corophiidae gen. sp.
Family Talitridae
Talorchestia deshayesii (Audouin, 1826)
Order Decapoda
Family Hippolytidae
Hippolyte leptocerus (Heller, 1863)
Order Isopoda
Family Idoteidae
Idotea baltica (Pallas, 1772)

At different years the species compositions were quite different; with some species occurring regularly, others were met sporadically. Further, from the analysis species encountered only 1-2 times were excluded as well as the bottom species hermit crab *H. leptocerus* that never rises up in plankton. The amphipod *T. deshayesii* - species that lives in damp sand at the water's edge, is also not taken into account in the further analysis. In some years *I. baltica* was very abundant, and in others - met sporadically or absent, which coincides with the level of its development along the coast of the Bakalskaya Spit in the sea. From this it was concluded that its presence or absence as well as population density depended on factors outside of the lake, in the sea. So it is also not taken into account in the further analysis. The presence of the common species of zooplankton and their abundance in different years is given in the Table 1.

The most permanent components of zooplankton were representatives of Harpacticoida (in 83% of samples) and Ostracoda *E. inflata* (56%). Other species are met with lower frequency: *Artemia* - 50%, *M. salina* - 44%, *A. tonsa* - 38%. In 2004-2005 there was a sharp change of the composition of the planktonic crustaceans - marine species of copepod such as *A. tonsa* and mysid *M. slabberi* became widespread, while *M. salina* completely disappeared from the plankton, and *Artemia* practically disappeared. Table 2 shows the salinity ranges at which the different species of Crustacea were available in the lake. See from the table 2 that all organisms according to the salinity ranges can be divided into three main groups: 1. marine species, which were not encountered at salinities above 55 g/L; 2. halophilic species that live only at salinities above 30-55 g/L; and 3. halotolerant species that are found throughout the range of the marked salinities. Graphical and correlation analysis of our data don't give us possibility to constructively discuss relationships between salinity, temperature, pH and densities of crustacean species.

Analyses of the co-occurrence of different species were carried out in three versions: 2000-2002, 2000-2004, and 2004-2012 (excluding hot, less rainy and windy 2007, which was quite different from other years according to salinity and the taxocene structure –Table 1). In most cases a frequency of co-occurrence of two species did not differ significantly from

Table 1. The presence and average abundance (ind. / m^3) of different groups of crustaceans in the plankton of Lake Bakalskoye in different years

№	Date	Amphipoda	*Artemia* nauplii	*Artemia* adult	*Acartia tonsa*	Harpacticoida	*Moina salina*	*Mesopodopsis slabberi*	*Eucypris inflata*
1	August 2000	0	0	4567.5	0	915.2	2472.9	0	1759.7
2	August 2001	0	14898.4	14582.0	0	263223.3	1558041.1	0	15172.4
3	August 2002	0	60.0	414.7	0	114.0	10.5	0	1.0
4	August 2004	47.6	0	0	13016.3	1779.5	191.3	1121.9	277.4
5	March 2005	0	0	0	787.5	0	0	0	0
6	August 2005	0	0	0	+	0	0	0	0
7	August 2007	0	20.0	0	0	144.4	0	0	46.7
8	May 2008	0	0	0	7000.0	6000.0	0	0	200.0
9	May 2009	0	0	0	30.0	10.0	0	0	5.0
10	August 2009	20.0	0	10.0	260.0	210.0	0	620.0	0
11	May 2010	100.0	0	0	100000.0	0	0	0	20.0
12	August 2010	0	0	0	200.0	0	0	0	0
13	August 2012	40.0	0	+	0	1970.0	0	0	0
	Occurrence %	19.0	23.0	29.0	38.0	83.0	44.0	25.0	56.0

Table 2. Salinity ranges in which different species of crustaceans in Lake Bakalskoye were found

Species	The range of salinity, ‰
Amphipoda	22.0-55.0
Artemia nauplii	76.3-101.0
Artemia adult	55.0-106.0
Branchinella spinosa	83.5
Acartia tonsa	20.0-55.0
Hippolyte leptocerus	22.0-55.0
Harpacticoida	20.0-106.0
Idotea baltica	30.0-75.0
Moina salina	33.7-106.0
Mesopodopsis slabberi	33.7-55.0
Eucypris inflata	20.0-106.0

random. The frequency of co-occurrence of *Moina* and *Artemia* was higher than that for a random co-occurrence in the case of data set for 2000-2004 (31 samples), but did not differ from random in the case of the analysis of data for 2000-2002 (15 samples). 2004 was a year of transformation of the community, its transition to a new state, i.e. we analyzed a mixture of representatives of two different states of the taxocene of crustaceans. As a result, we found that the frequency of co-occurrence of representatives of one community state was higher than their random coincidence in the sample. In analyzing the data set for the years 2004-2012 co-occurrence of species, except in one case, did not significantly differ from random. For a pair of "calanoid (*Acartia*) and mysid (*Mesopodopsis*)" analysis showed that the observed frequency of co-occurrence of species (33%) is much lower than expected in the case of random meeting of the two species in the sample (46%). This is not surprising, since these species differ greatly according to their habitats and ecology. The estimations of the significance of the pairwise correlation coefficients between the logarithms of numbers of various species under their co-occurrence were made. Significant positive coefficients ($\alpha < 0, 05$) were detected in the pairs: *Artemia* - *Eucypris* - 54%, Harpacticoida - *Moina* – 77%, and Harpacticoida - *Eucypris* – 74%.

Integral characteristics of zooplankton (total number and biomass) also significantly changed - the total abundance has decreased by about 50 times, and the biomass is more than a hundred times. Decrease in the average size of the crustacean in plankton was due to the fact that in 2000-2001 *Artemia* and *Moina* dominated, but now the main contribution to the abundance is provided by Harpacticoida.

Discussion

The observed changes of the Bakalskaya Spit was also confirmed by field studies, which were held by the Marine Hydrophysical Institute (Sevastopol) in 2007-2009 (Goryachkin *et al.*, 2012); rate of displacement of the spit into the lake before 2004 amounted to an average of 30 m per year, and in 2004 the rate of displacement has increased to 60-70 m per year; since 2004 the spit thinned and moved into the lake by 150 m. The interrelationship of climate change and increasing anthropogenic load in the degradation of Bakalskaya Spit was analyzed previously (Shadrin *et al.*, 2012). It was shown that human pressure also contributes to the accelerated degradation of the spit, primarily through the spit de-vegetation. De-vegetation of the spit and its subsequent erosion has resulted in a significant increase of the sand flow from the spit into the lake. Degradation of the spit accompanied by increased influx of seawater into the lake, however, is not the only cause of changes of the water and salt balances. Increased precipitation in 2003 and later resulted in an increase the groundwater level, which increased their infiltration into the lake along the eastern and southern coasts. Summer temperatures in 2003-2004 were lower than before, it also contributed to decrease salinity. All this has led to a twofold increase in the depth of the lake. This has also led to a decrease in the seasonal variability of salinity in the lake in the 2 to 3 times.

As from 2004, *Cladophora* mats (floating and bottom) in the lake had completely disappeared; this created a new situation in the lake. The lake ecosystem transited in a new state. In the lake the structure of primary productivity has changed completely and the total primary production decreased sharply (Zagorodnyaya *et al.*, 2008). In other hypersaline lakes of Crimea, undergoing significant transformations of the structure of production were observed as well; the intensive development of *Cladophora* mats leads to an increase in primary production by five times or more (Balushkina *et al.*, 2009). The transition of the upper layer of sediments from redox state to the oxidation state was due mainly to wind mixing and aeration of the upper layer of sediments resulting from the strengthening western winds, and a decrease in the incoming of newly produced organic matter on the bottom. Previously the alternating black and gray layers in the sediment cores from hypersaline lakes of Crimea were described (Mikhodyuk *et al.*, 2005); this alternation of layers reflects the repetitive changes of states (oxidative, reductive) in the past. Probably those significant changes in the lake have a quasi-cyclic nature. N. Kurnakov *et al.* (1936) wrote about Lake Bakalskoye: "Depending on the supply of surface and marine waters the hydrogeological regime of the lake is exposed to significant fluctuations. There are years when the lake dries up, becoming lake with self-sedimentation of salt, and, conversely, in some year there is fishery in the lake". Likely to these changes are primarily due to the climatic variations in regimes of precipitation, temperatures and winds.

Since 2004, the lake has contained not only marine crustaceans, but also other marine organisms including jellyfish scyphozoans *Aurelia aurita,* and *Rhizostoma pulmo*, ctenophore *Mnemiopsis leidyi*, etc. (Shadrin *et al.*, 2004; Zagorodnyaya *et al.*, 2008). Even fish mullet was encountered. In 2004, in fact, there was a changes in the species composition of the taxocene of crustaceans - a regime shift - a large reconfiguration of system’s structure; it can be explained primarily by three factors - a decrease of salinity, the increase of the spit and cliff erosion, and massive transport of marine organisms in the lake by storm waves. Before 2004 occurrence of species *Artemia* and *Moina* was 100%; in 2004, *Artemia* fell out of plankton, and after 2004 *Moina* was no longer encountered. In hot summer of 2007, the salinity increased again to 100 ‰, as a result, there were no marine species in the lake that summer. However, restoration of the old complex of species has not occurred: *Moina* was absent in the plankton, and there were only few *Artemia* nauplii (no adults) - 14-15 ind./m^3, but in 2000-2001 - from 4600 to 295,000 ind./m^3; such a situation is surprising because *Artemia* and *Moina* have resting eggs, which accumulate on the surface of sediments. These species can very quickly restore their population densities in favorable conditions due to a bank of resting eggs. This is probably due to the fact that increased erosion of spit and abrasion of clay cliffs subsequently lead to the entry of large amounts of sand and clay into the lake. This in turn has resulted in silt, which preserved the bank of resting eggs on top, being covered up by a clay-sand layer. Under such conditions resting eggs from the sediments are unable to enter the water and begin to develop. Consequently, the recovery of *Artemia* and *Moina* populations in the lake is only possible through an importation of resting eggs by birds or wind. Under such conditions restoration of populations requires more time. Since 2004 Chironomidae larvae, *Cladophora* and *Ruppia* also disappeared in the lake; since in the adjacent small hypersaline ponds similar desalination has not led to the disappearance of Chironomidae larvae and *Cladophora* in them; it was concluded that the this occurrence was due to being buried under a layer of sand and clay (Shadrin *et al.*, 2004). Composition of crustacean species changed according to variability of salinity in other Crimean hypersaline lakes during this period but with increasing of salinity *Artemia* quickly restored its abundance in the plankton (Anufriieva and Shadrin, 2012). We can explain this only by the fact that the recovery is due to the bank of resting eggs (cysts) that are not covered by sand and clay layer as in Lake Bakalskoye.

Taking into account results on co-occurrence of different species and correlations between changes of density of different crustacean species we may conclude that the taxocene of crustaceans in the lake has a low level of integrity, and a connectivity of changes of different crustacean species is poor one. We may look on a presence and changes of populations of different species as on independent of each other events with a significant participation of a random factor; irregularities rule the taxocene change largely in this case. Probably, some positive correlations between the number of different species due to their similar dependence on primary production in the lake, which had undergone a big change during studied period (Zagorodnyaya *et al.*, 2008), and not due to any links between species. Co-existing invertebrates in the Great Salt Lake ecosystem (Utah, USA) also demonstrate similar independence (Belovsky *et al.*, 2011).

The decrease of integral characteristics of zooplankton (total number and biomass) can be explained by a dropping of a primary productivity of the lake ecosystem. Interestingly, that in 2004 the marine introduced species demonstrate more abundance in the lake, however in the following years, their numbers in the lake has decreased by 2-3 orders of magnitude. This is probably partly due to the fact that in 2004 the lake still contained quite a bit of organic matter, produced in previous years. Primary production in the lake in August 2005 was about 3 times less than in 2004, but P concentration in water in 2005 was 5 times less (Golubkov *et al.*, 2007). Current P concentration continues to be same as in 2005. Phosphorus flux from sediment into the water has decreased significantly, concentration of P decreased as result and this led to a sharp decline in primary production.

Before 2004 the lake played an important role in maintaining the diversity of birds; many thousands of individuals, including rare species, have used it. In recent years, their number has decreased by 50-100 times, diversity is also reduced, which is due primarily to the reduction of their food (at first - crustaceans) in orders of magnitude (our unpublished data).

Our data and arguments show that the impact of climate change on crustaceans, as well as on the whole biota, is not only direct, but through an extensive network of intermediate effects with the transformation of many processes in the lake and its watershed. For example, in our case the climate change influenced on biota through an increase of erosion of the sand spit primarily that activates the chain of interconnected effects.

Given the current trend of degradation of the western branch of Bakalskaya Spit it's difficult to hope for a stable transition of the lake to the conditions of high salinity and the full recovery of a highly productive hypersaline community. In our opinion, it is also unlikely that the formation of a sustainable maritime community is possible, because it's obvious that years like 2007 will repeat. In addition, it should be noted that the main representative of marine zooplankton in the lake is copepod *A. tonsa* - an invader in the Black Sea (Belmonte *et al.*, 1994) doesn’t present in plankton year-round; it spends the winter on the bottom in the form of resting eggs. Continuing coverage of the bottom by sand would not allow *Acartia* to form an active bank of resting eggs. And it means that the possibility of recovery of its population in the lake will be dependent on annual transport from the sea in the late spring - summer, considering the time of its location in the plankton. The ecosystem of the lake will be in a state of fluctuations with relatively low productivity. We cannot stop the change of the spit completely, but we may reduce the rate of this change. In modern conditions only the mitigation of anthropogenic pressure on Bakalskaya Spit, i.e. a termination of recreational de-vegetation and illegal mining of sand, can somehow improve the situation. At least, it may reduce the import of sand and clay into the lake that allow the lake biota to quickly recover from sharp fluctuations in salinity. Given the current situation of uncontrolled growth in the recreational use of the Bakalskaya Spit and lack of any real fight against the illegal removal of sand, it is unlikely that this solution will ever have a realistic chance. And this chance is dropping further due to continued sea level rise and increased climate instability (McElroy and Baker, 2012).

Currently, most hypersaline lakes around the World, including those links to which were given above in the introduction, demonstrate an increase of salinity due to the climate change. Increasing temperature and reduced rainfall are the main climatic drivers of this. Lake Bakalskoye vice versa currently demonstrates a decrease of salinity; the main reason is the change of the prevailing winds. Likely to for the majority of not very large, shallow lakes of marine origin/closed lagoons with recharge from the sea a change in the prevailing winds is a major driver in changes of their water and salinity balances, as well as the resulting changes in the structure and functioning of ecosystems.

The study results are of more than local relevance; it has a general ecological importance because it can help to better understand that the realizations of general climate change (regimes of winds, temperature, and precipitation) impacts on local level are diverse and complicated ones. Currently we need accumulate the data on the diversity of the concrete realizations to be ready to make the general conclusions about the roles and importance of the local changes in the Global Change.

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References

Abbaspour, M., Javid, A.H., Mirbagheri, S.A., Ahmadi, F.G. and Moghimi, P. 2012. Investigation of lake drying attributed to climate change. International Journal of Environmental Science and Technology, 9: 257-266.

Aladin, N.V., Filippov, A.A., Plotnikov, I.S., Orlova, M.I. and Williams, W.D. 1998. Changes in the structure and function of biological communities in the Aral Sea, with particular reference to the northern part (Small Aral Sea), 1985-1994: A review. International Journal of Salt Lake Research, 7: 301-343.

Aladin, N.V. and Potts, W.T. 1992. Changes in the Aral Sea ecosystems during the period 1960–1990. Hydrobiologia, 237: 67-79.

Anufriieva, E.V. and Shadrin, N.V. 2012. Crustacean diversity in hypersaline Chersoness Lake (Crimea). Optimization and Protection of Ecosystems, 7: 55–61. (in Russian).

Balushkina, E.V., Golubkov, S.M., Golubkov, M.S., Litvinchuk, L.F. and Shadrin, N.V. 2009. Effect of abiotic and biotic factors on the structural and functional organization of the saline lake ecosystems. Zhurnal Obshchei Biologii, 70: 504-14. (in Russian).

Belmonte, G., Mazzocchi, M.G., Prusova, I.Yu. and Shadrin, N.V. 1994. *Acartia tonsa*: a species new for the Black Sea fauna. Hydrobiologia, 292-293: 9-15.

Belmonte, G., Moscatello, S., Batogova, E.A., Pavlovskaya, T., Shadrin, N.V. and Litvinchuk, L.F. 2012. Fauna of hypersaline lakes of the Crimea (Ukraine). Thalassia Salentina, 34: 11–24.

Belovsky, G.E., Stephens, D., Perschon, C., Birdsey, P., Paul, D., Naftz, D. and Allen, D.V. 2011. The Great Salt Lake Ecosystem (Utah, USA): long term data and a structural equation approach. Ecosphere, 2(3), art33: 1-40.

Carrasco, N.K. and Perissinotto, R. 2012. Development of a halotolerant community in the St. Lucia Estuary (South Africa) during a hypersaline phase. PLoS ONE, 7(1): e29927. doi:10.1371/journal.pone.0029927

Drinkwater, K.F., Beaugrand, Gr. and Kaeriyama, M. 2010. On the processes linking climate to ecosystem changes. Journal of Marine Systems, 79: 374–388.

Golubkov, S., Kemp, R., Golubkov, M., Balushkina, E., Litvinchuk, L. and Gubelit, Yu. 2007. Biodiversity and the functioning of hypersaline lake ecosystems from Crimea Peninsula (Black Sea). Fundamental and Applied Limnology / Arch für Hydrobiologie, 169: 79-87.

Goryachkin, Yu.N., Udovik, V.F. and Kharitonov, L.V. 2012. Recreational potential of the Black Sea coast of Ukraine. In: P.F. Gozhik and V.A. Ivanov (Eds), Marine Coastal Resources of Ukraine, Marine Hydrophysical Institute, Sevastopol: 156-181. (in Russian).

Håkanson, L. 2010. Great Lakes – Form and Function, as Exemplified Using Data From Lake Vänern, the Fourth Largest Lake in Europe. In J. S. Donovan (Ed.), Great Lakes: Ecology, Management and Conservation, Nova Science Pub., New York: 1-39.

Hawkins,S.J., Sugden, H.E. and Mieszkowska, N. 2009. Consequences of climate-driven biodiversity changes for ecosystem functioning of North European rocky shores. Marine Ecology Progress Series, 396: 245–259.

Hutchinson, G.E. 1978. An introduction to population ecology. Yale University Press, New Haven, 260 pp.

Kurnakov, N.S., Kuznetsov, V.G., Dzens-Lytovsky, A.I. and Ravich, M.I. 1936. The Crimean salt lakes. AN USSR Publ., Moscow, 278 pp. (in Russian).

Kwak, T.J. and Peterson, J.T. 2007. Community indices, parameters, and comparisons. In: C. S. Guy and M. L. Brown (Eds.), Analysis and interpretation of freshwater fisheries data, American Fisheries Society, Bethesda: 677-763.

McElroy, M. and Baker, D.J. 2012. Climate extremes: Recent trends with implications for national security. Harvard University Center for the Environment, 126 pp.

Mikhodyuk, O.S., Orleansky, V.K., Shadrin, N.V. and Gerasimenko, L.M. 2005. The modern cyanobacterial mats as the analogues of the Precambrian biocenoses. In: A.Yu. Rosanov, A.V. Lopatin and P.Yu. Parkhaev (Eds), Modern Paleontology: classic and newest methods, Paleontological Institute, Moscow: 15-28 (in Russian).

Mirabdullayev, I.M., Joldasova, I.M., Mustafaeva, Z.A., Kazakhbaev, S., Lyubimova, S.A. and Tashmukhamedov, B.A. 2004. Succession of the ecosystems of the Aral Sea during its transition from oligohaline to polyhaline water body. Journal of Marine Systems, 47: 101–107.

Micklin, Ph. 2007. The Aral Sea Disaster. Annual Review of Earth and Planetary Sciences, 35: 47–72.

Nevrova, E.L. and Shadrin, N.V. 2005. Benthic diatoms in Crimean saline lakes. Marine Ecological Journal, 4: 61-71. (in Russian).

Rawson, D.S. 1955. Morphometry as a dominant factor in the productivity of large lakes. Verh. Int. Ver. Limnol., 12: 164-175.

O'Reilly, C.M., Alin, S.R., Plisnier, P-D., Cohen, A.S. and McKee, B.A. 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. Nature, 424: 766-768.

Piovano, E.L., Ariztegui, D. and Moreira, S.D. 2002. Recent environmental changes in Laguna Mar Chiquita (central Argentina): a sedimentary model for a highly variable saline lake. Sedimentology, 49: 1371–1384.

Salameh., E. and El-Naser, H. 2000. Changes in the Dead Sea level and their impacts on the surrounding groundwater bodies. Acta Hydrochimica et Hydrobiologica, 28: 24–33.

Senicheva, M.I., Gubelit, Yu., Prazukin, A.V. and Shadrin, N.V. 2008. Phytoplankton of the Crimean hypersaline lakes. In: Yu.N. Tokarev, Z.Z. Finenko and N.V. Shadrin (Eds), The Black Sea microalgae: problems of biodiversity preservation and biotechnological usage, ECOSI- Gidrofizika, Sevastopol: 5-18. (in Russian).

Shadrin, N.V. 1985. The dependence of production characteristics on morphometric parameters of the water body. In: A.F. Alimov and V.N. Kuzmich (Eds.) The hydrobiology and hydroparasitology of Near Bajkal region, Nauka, Novosibirsk: 201-205 (in Russian).

Shadrin, N.V. 2003. Is it possible to quantitatively assess the role of algobacterial films in a water body? In: W.G. Krumbein, D.M. Paterson and G.A. Zavarzin (Eds.), Fossil and recent biofilms - A natural history of life on Earth, Kluwer Academic Publishers, Dordrech: 353-361.

Shadrin, N.V. 2008. The Crimean hypersaline lakes: general peculiarities. In: Yu.N. Tokarev, Z.Z. Finenko and N.V. Shadrin (Eds), The Black Sea microalgae: problems of biodiversity preservation and biotechnological usage, ECOSI- Gidrofizika, Sevastopol: 85-118. (in Russian).

Shadrin, N.V. 2009. The Crimean hypersaline lakes: towards development of scientific basis of integrated sustainable management. In: Proceedings of 13th World Lake Conference, 1-5 November, Wuhan, China,

Shadrin, N.V., Golubkov, S.M., Balushkina, E.V., Orleansky, V.K. and Mikhodyuk, O.S. 2004. Ecosystem response of hypersaline Bakalskoye Lake (Crimea, Black Sea) on climatic peculiarities of 2004. Marine Ecological Journal, 3: 74-75. (in Russian).

Shadrin, N.V., Mironov, S.S. and Ferat, T.A. 2012. Interrelations between the losses of sandy beaches and biodiversity in seas: Case of the Bakalskaya Spit (Crimea, Ukraine, Black sea). Turkish Journal of Fisheries and Aquatic Sciences, 12: 411-415.

Shadrin, N.V., Zagorodnyaya, Yu.A., Nevrova, E.L., Naidanova, O.G. and Senicheva, M.I. (2001) Hydroecological system of Bakalskaya spit (Crimea): Problems of investigation and preservation of the unique biodiversity. Naukovi Zapiski Ternopolskogo Universiteta, 14: 168–170. (in Russian).

Smol, J.P., Wolfe, A.P. and Birks, H.J.B. 2005. Climate-driven regime shifts in the biological communities of arctic lakes. Proceedings of the National Academy of Sciences, 102: 4397–4402.

Velasco, J., Millan, A., Hernandez, J., Gutierrez, C., Abellan, P., Sanchez, A. and Ruiz, M. 2006. Response of biotic communities to salinity changes in a Mediterranean hypersaline stream. Saline Systems, 12: 1-15. doi: 10.1186/1746-1448-2-12:

Walther G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J., Fromentin, J.M., Hoegh-Goldberg, O. and Bairlein, F. 2002. Ecological responses to recent climate change. Nature, 416: 389–395.

Zagorodnyaya, Yu.A., Batogova, E.A. and Shadrin, N.V. 2008. Long-term transformation of zooplankton in the hypersaline lake Bakalskoe (Crimea) under salinity fluctuations. Marine Ecological Journal, 7: 41-50. (in Russian).

Zenkovich, V.P. 1960. Morphology and dynamics of Soviet Shoreline of the Black Sea. AN SSSR, Moscow, 215 pp. (in Russian).

Zheng, M. 2001. On salinology. Hydrobiologia, 466: 339-347.