Elena ANUFRIIEVA, 2014. Copepods in Hypersaline Waters Worldwide: Diversity, Environmental, Social, and Economic Roles. *Acta Geologica Sinica* (English Edition), 88(supp. 1): 43-45.

Copepods in Hypersaline Waters Worldwide: Diversity, Environmental, Social, and Economic Roles

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1 Introduction

Copepods are a group of small crustaceans, which play an important ecological role in aquatic ecosystems. They occupy different ecological niches in aquatic food webs, contributes to biogenic element cycles, and transfer of organic matter from primary producers to higher secondary consumers. Copepods also have the potential to act as control mechanisms for malaria by consuming mosquito larvae, and contrariwise are intermediate hosts of many human and animal parasites. Some 21,000 species of copepods are known; they dwell marine and continental aquatic habitats. A small number of copepod species are able to adapt to an existence in such extreme habitats as hypersaline waters (Bayly and Boxshall, 2009; Shadrin, 2012). *Hypersaline systems are harsh environments that have salt concentrations much greater than that of seawater,* often close to or exceeding salt saturation. Copepods are found in hypersaline water bodies worldwide. We studied Copepoda in the Crimean hypersaline waters. Crimea is the largest peninsula in the Black Sea; fifty relatively large lakes and numerous small (from several to hundreds meters long) hypersaline water bodies are in the peninsula (Shadrin, 2009). We try to summarize and discuss our Crimean and available in literature data here.

2 Material and methods

During 2010-2013 we sampled zooplankton in different hypersaline water bodies of Crimea. In total 205 samples from 30 water bodies were analyzed. Data from literature were also used.

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3 Results and discussion

We found 8 (10?) copepod species in hypersaline waters of Crimea (Table 1). Taking into account also data of

Table 1 Copepoda in hypersaline waters

Species	S, ‰	Region	R
Order Calanoida			
Acartia tonsa Dana, 1849	55	Crimea	1
Arctodiaptomus salinus (Daday, 1885)	300	Crimea	1
	280	Siberia	2
	250	Kazakh-stan	3
Calamoecia trilobata Halse and McRae, 2001	240	Australia	4
Order Harpacticoida			
Cletocamptus retrogressus Shmanke-vitch, 1875	360	Crimea	1
	280	Siberia	5
	225	Algeria	6
	217	France	7
Cletocamptus confluens (Schmeil, 1894)	>100	Africa	8
Mesochra nr. *flava* Lang, 1933	130	Australia	4
Metis ignea ignea Philippi, 1843	195	Crimea	1
	89	France	7
Order Cyclopoida			
Acanthocyclops sp.	212	Crimea	1
Acanthocyclops americanus (Marsh, 1893)	80	Crimea	9
Apocyclops dengizicus (Lepeshkin, 1900)	130	Kazakh-stan	3
Cyclops sp.	300	Tibet, China	10
Cyclops furcifer (Claus, 1857)	150	Crimea	1
	>100	Spain	11
Cyclops strenuus Fischer, 1851	79	China	12
Diacyclops sp.	150	Crimea	1
Diacyclops bisetosus (Rehberg, 1880)	150	Crimea	1
	100	Germany	13
Diacyclops bicuspidatus (Claus, 1857)	107	Canada	14
Eucyclops sp.	150	Crimea	1
Meridiecyclops bayly Fiers, 2001	240	Australia	4

Note: S – upper limit of salinity; R - reference: 1 - own data; 2 - Vesnina, 2003; 3 - Krupa, 2010; 4 - Pinder et al., 2005; 5 - Litvinenko et al., 2009; 6 - Amarouayache et al., 2012; 7 - Britton and Johnson, 1987; 8 - Carrasco and Perissinotto, 2012; 9 - Anufriieva and Shadrin, 2012; 10 - Wen et al., 2005; 11 - Hammer, 1986; 12 - Zhihui et al., 1989; 13 - Zernov, 1949; 14 - Moore, 1952.

other researches (Kolesnikova et al, 2008; Zagorodnyay et al., 2008) we summarize that 12 (14?) species of copepods inhabit hypersaline waters in Crimea. Collecting data from literature we may compose a long list of copepod species dwelling hypersaline waters worldwide (>35 ‰). Only some data on most halotolerant copepod species were included in Table 1. Conclusion: several species of copepods can exist under salinities up to 250-300 ‰.

High salt concentrations are toxic for most organisms because it greatly reduces the availability of water, a requirement for life. Thus, halophiles and halotolerants have evolved highly specialized physiological adaptations for maintaining a proper osmotic balance in such a hostile environment. Aquatic organisms with various salt tolerances adapt to their environments through osmoregulation and osmoconformation. Many copepods are osmoconformers (Bayly and Boxshall, 2009; Svetlichny et al., 2012).

The osmoconformers do not possess mechanisms at the organismal level to regulate the solutes in their body fluids at a concentration different from that of the external medium. An osmotic regulation therefore occurs at the cellular level by increasing the intracellular concentration of organic compatible osmolytes (small organic molecules) which are either synthesized in the cell or transported into it from the external environment (Yancey, 2001). Life at high salt concentrations is energetically expensive. The upper salt concentration limit in which different copepods can live in nature appears to be determined to a large extent by bioenergetic constraints. The main factors that determine whether a certain type of organism can live in high salinities are the amount of energy generated during its dissimilatory metabolism and the amount of energy needed for osmotic adaptation (Oren, 2011). The highly halotolerant unicellular green alga *Dunaliella* synthesizes glycerol in response to salinity stress; its content in the cell is proportional to the medium salinity and can reach 80 % of the dry weight of their cells (Ben-Amotz et al., 1982). It should be noted that all observations of *Arctodiaptomus salinus* (Daday, 1885) and *Cletocamptus retrogressus* Schmankevitsch, 1875 in the Crimea at very high salinities occurred during intense blooms of *Dunaliella* with concentration reaching $6 \cdot 10^7$ cells L^{-1} and 60 $g \cdot m^{-3}$ when water was orange-red. We hypothesized (Shadrin and Anufriieva, 2013) that such high halotolerance in these osmoconforming copepods is determined by the consumption of exoosmolytes, mainly with food. Copepods can attain sufficient osmolytes by consuming *Dunaliella,* enabling them live under high salinities. The salinity ranges of copepod species in natural water bodies are therefore may be determined by both physiological and ecosystem factors.

Natural role. Copepods often are most diverse and abundant animal group in hypersaline waters, which participate in all food chains, in cycling of nutrients, etc. Hypersaline lakes are the homes for many bird species nesting here and seasonal settlement for many thousands of migrating birds. Copepods are among main food items for many of them. Copepods are intermediate hosts of fish and bird parasites.

Social and economic role. (1) For aquaculture and biotechnology; (2) A nontoxic and inexpensive form of biological mosquito control (Mesocyclops); (3) Support of bird-watching tourism (main food source for different birds); (4) Resources for pharmaceutical and cosmetic industries (chitin, chitosan, carotenoids, etc.); (5) Object of study for science development (including for paleoreconstruction).

Aquaculture is one of the key elements of a new approach to saline lake and its watershed integrated management. Aquaculture development is now largely inhibited by deficiency of live food for larvae of commercially important fish and invertebrates. Cultivation of larvae (larviculture) is a bottleneck in a cultivation of the different organisms. Species, which inhabit extreme hypersaline habitats, are best as the live food organisms – they are high tolerant, can reach high densities, have resting stages. Copepods of two orders (Calanoida and Harpacticoida) may be effectively used in aquaculture. Wide distributed *C. retrogressus* and *A. salinus* are among such copepods.

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