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Changes in population structure of branchiopod crustacean *Artemia* sp. in Lake Aktash (Crimean Peninsula) in autumn-winter period (based on data from 2018)

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Abstract. The paper presents the research results of changes in the age (for all ontogenetic groups) and sex structure, as well as the production of cysts, in two populations of *Artemia* sp. living in the different contrasting environmental conditions (by the area of the water body, its depth, water salinity, nature of bottom sediments, level of anthropogenic load) of hyperhaline water bodies of the aquatic complex Lake Aktash. Data on the dynamics of the size structure of each sex or age group (nauplii, metanauplii, juvenile and preadult crayfish, females with ovisacas and without them, males) are presented. The size of cysts (D_{max} and D_{min}) were measured, and their area was calculated. The specificity of the research is the period of conducting the observations: the autumn–early winter period is the time of the population extinction. On the example of two isolated ponds there was studied the relationship of changes in populations under decreasing the water salinity and its temperature – the most significant abiotic environmental factors. Data were obtained on the conditions of cysts production in the water bodies under study. The production of branchiopods (g/m^3) in water bodies does not depend on the volume of water. Populations of *Artemia* sp. in the studied ponds have a wide range of the optimum zone for the environment salinity. It has been found that the main starting indicator for the beginning of the winter pause in the life of the population is the water temperature (8-10°C), while salinity is of lesser importance. There are presented the data on the composition and abundance of other species of invertebrates (*Diptera* larvae, *Coleoptera* imagoes, copepods) living in the studied water bodies during the low-water autumn-winter period.

Keywords: branchiopod crustaceans, *Artemia*, Lake Aktash, population structure, autumn-winter period, cysts, environmental conditions

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Научная статья

Изменение структуры популяции жаброногого рака *Artemia* sp. в Акташском озере (Крымский полуостров) в осенне-зимний период (по данным 2018 г.)

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Аннотация. Представлены результаты исследования изменения возрастной (по всем онтогенетическим группам) и половой структуры, а также продуцирования цист в двух популяциях *Artemia* sp., обитающих в различных контрастно-различающихся (по площади водного объекта, его глубине, солености воды, характеру донных отложений, уровню антропогенной нагрузки) условиях среды гипергалинных водоемов аквального комплекса Акташский. Приведены данные о динамике размерного состава каждой из половозрастных групп (науплиусов, метанауплиусов, ювенильных и предвзрослых раков, самок с овисаками и без них, самцов). Выполнены измерения цист (D_{max} и D_{min}). Особенностью данной работы является время проведения наблюдений (осень-начало зимы) – период «угасания» популяции. На примере двух изолированных водоемов исследовалась взаимосвязь изменений в популяциях в условиях снижения показателей наиболее значимых абиотических факторов среды – солености воды и ее температуры. Получены данные об условиях продуцирования цист для водоемов данной группы. Продукция жаброногих раков (г/м^3) в водоемах не зависит от объема в них воды. Популяции *Artemia* в исследуемых водоемах имееют широкий диапазон зоны оптимума по солености среды. Установлено, что главным пусковым показателем начала зимней паузы жизнедеятельности популяции является температура воды (8–10 °С), при этом соленость имеет меньшее значение. Приведены данные о составе и численности прочих видов беспозвоночных животных (личинок двукрылых, имаго жесткокрылых, копепод), обитающих в исследуемых водных объектах в меженный осенне-зимний период.

Ключевые слова: жаброногие раки, *Artemia*, Акташское озеро, структура популяции, осенне-зимний период, цисты, условия среды

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Introduction

Branchiopods *Artemia* Leach, 1819 (Crustacea: Branchiopoda: Anostraca), or brine shrimp, are inhabitants of continental hyperhaline water bodies. Inhabiting water bodies with sometimes extreme living conditions, having an incompletely elucidated species composition of the genus, possessing a complex ontogenetic development cycle, amazing viability of dormant eggs (cysts), as well as alternating sexual and parthenogenetic ways of reproduction, this group of living creatures has always attracted the attention of biologists [1-18]. The increased interest in crustaceans *Artemia* is also emphasized by the fact that their cysts are of commercial importance, being a strategically important starting (primary) fodder for juveniles of most fish species rearing in aquaculture. The ever-increasing economic need for the brine shrimp cysts is realized exclusively by their removal (catch) from natural populations [16-19]. Dynamically changing climatic conditions lead to sharp fluctuations in the number of brine shrimp in water bodies throughout the season, contributing to a certain unpredictability in forecasting and providing of its catch. At the same time, attempts to cultivate brine shrimp in artificial conditions in order to produce their cysts on an industrial scale have not yet overcome the scope of laboratory experiments. In this regard, the study of the nature of changes in population processes in natural water bodies, as well as their relationship with the main abiotic and biotic processes, the results of which make it possible to justify the rational use of *Artemia* sp. stocks, do not lose their relevance today.

Spreading of crustaceans *Artemia* in the water bodies of Crimea is extremely uneven, both geographically in terms of the location of hyperhaline water bodies and in time. Often water bodies in which these crustaceans live mostly have extremely shallow depths due to the seasonal distribution of precipitation. They quickly desalinate during heavy rains or, conversely, dry up during long dry periods, which leads to the cessation of the development of brine shrimp and its disappearance [1, 2, 8-11].

In the eastern part of the Crimean Peninsula *Artemia* sp., or brine shrimp, lives in almost all water bodies with permanent or seasonal high water salinity with values from 40 to 300‰. For some water bodies, with contrasting hydrological characteristics changing throughout the year, the development of *Artemia* sp. is characterized by short-term outbreaks of population development. For other water bodies with relatively constant conditions the long period of populations existence can take place.

Lake Aktashskoe is located in the northern part of the Kerch Peninsula (Crimea). As a result of its economic use, it is divided into a number of separate reservoirs with contrastingly different morphological characteristics (area, depths, nature of the banks and bed, interconnection with other water bodies) and hydrological regime (provision of surface runoff, water level dynamics) [20]. So, having the complicated structure, this complex is a typical hyperhaline reservoir and is most suitable for performing model population studies.

The object of our study was the population of the branchiopod crustacean *Artemia* sp. inhabiting the reservoirs of the hyperhaline aquatic complex – Lake Aktashskoe. And the subject of the study is the structure of the population of this crustacean and its relationship with abiotic environmental factors.

The novelty of this research lies in the fact that, despite the seemingly high degree of study of the brine shrimp, there can be found very poor data on the state of the populations of branchiopod crustacean in the lakes of the Crimea in the autumn-winter period, and there is no data at all on the complex of hyperhaline reservoirs of the Kerch Peninsula. Studies of the brine shrimp in the framework of the rational use of its commercial stocks are limited only to the period of late spring – early autumn.

The aim of this work is to study the population structure of the branchiopod crustacean *Artemia* sp. in non-drying water bodies of the hyperhaline aquatic complex of Lake Aktashskoe in the autumn-winter period of 2018/2019.

To achieve this aim, the following tasks were formulated:

1. To determine control stations (typical parts of the reservoir that are contrasting in terms of abiotic conditions) and carry out sampling of the brine shrimp in the autumn-winter period, as well as to collect data on the habitat environment (salinity, temperature) in the reservoir.

2. To perform cameral processing of collected samples of the brine shrimp to determine their qualitative (population structure by age groups and sex) and quantitative (number and biomass of each of the groups) structure.

3. To analyze the relationship of changes in the structure of the brine shrimp population (by age and sex) under the influence of the key abiotic environmental factors (salinity and water temperature) occurring in the autumn-winter period. To study the size structure of the *Artemia* sp. population and its changes in the second half of the vegetation season.

4. To determine the composition of other species of invertebrates living in the control hypersaline reservoirs of Lake Aktashskoe complex.

Materials and methods

The material for the study was seven series of zooplankton samples from two water bodies of Lake Aktashskoe complex (Fig. 1), sampled in September-December 2018.

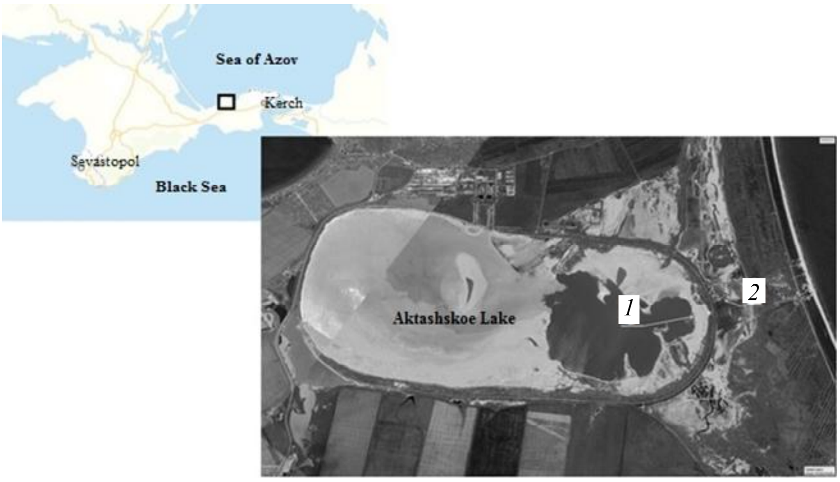

Fig. 1. Sampling sites at Lake Aktashskoe: *1* – cooling pond; *2* – natural part

The first pond (No. 1 – the cooler) is a hydrotechnical structure lined with an artificial dam, intended for cooling heat-exchange waters of the Crimean nuclear power plant designed at the end of the 20th century (construction was not finished). It is characterized by a significant water surface area (7-9 km^2) and comparatively big depth (2.0 m). Its bottom is relatively hard and clayish. The second pond (No. 2 – the natural part) is a part of the lake practically untouched by human activity. It is of much smaller area (up to 1.5 km^2) and average depth (0.7 m). Bottom of this water body is covered with thick layer of silt.

The control water bodies practically do not have their own catchment area, their water supply occurs mainly with the groundwater and, to a much lesser extent, from atmospheric precipitation. Pond No. 2 has an intermittent connection with the waters of the Kazantip Bay (Sea of Azov) through an artificial channel. Despite significant fluctuations in the water level in both reservoirs (during the time of observations of the authors in No. 1-0.7 m; in No. 2-0.5 m), they do not dry out throughout the year, and therefore it is possible to study the entire annual cycle of development of the *Artemia* sp. population.

Basic characteristics of water environment in the ponds when zooplankton was sampled are shown in Table 1.

Table 1

Water temperature and salinity in the ponds when sampling zooplankton

Pond	Parameters	Dates of zooplankton sampling			
		30.09.2018	15.10.2018	18.11.2018	15.12.2018
No. 1	Temperature, °C	19.0	16.0	7.8	3.0
	Salinity, ‰	204	196-200	208	186
No. 2	Temperature, °C	26.0	–	9.4	4.0
	Salinity, ‰	140	–	112	76

Sampling was carried out using the Plankton Net acc. to Apstein by filtering 100 liters of water from the water body, taken along a transect with a length of at least 100 m. The samples taken were fixed immediately with a 4% formaldehyde solution. The water temperature (with a mercury thermometer) and its salinity (with a Kelilong RHS-28ATC refractometer) were determined at the same time.

Sample processing was carried out in the laboratory according to the generally used methods. Quantitative accounting of different sex and age groups of brine shrimp was carried out using a Bogorov camera, the determination of the individual weight of brine shrimp was carried out using reference tables of the Russian Federal Research Institute of Fisheries and Oceanigraphy [19].

The size of the brine shrimp was determined by measurements of at least 20 specimens of each of its size and age groups in each of the samples in the divisions of the eyepiece micrometer. The actual dimensions in micrometers were calculated after calibrating the division value against the micrometer object.

Statistical processing of the obtained data was carried out using the Microsoft Excel 2010 and IBM SPSS Statistics v. 22 software packages.

Results

Status of the Artemia sp. population in the cooling pond (No. 1) of Lake Aktashskoe. The *Artemia* sp. population in the part of Lake Aktashskoe that is transformed into a cooling reservoir is of a complex structure, as it is proved by the data on number and biomass of its different sex and age groups (Table 2).

Table 2

Change in the number and biomass of the *Artemia* sp. by age groups in the cooling pond (No. 1) during September-December 2018

Ages groups, gender	Number, ind./m^3				Biomass, g/m^3			
	30.09.2018	15.10.2018	18.11.2018	15.12.2018	30.09.2018	15.10.2018	18.11.2018	15.12.2018
Cysts	1 053	6 695	4 455	205 922	0.01	0.07	0.04	2.06
Nauplii	21	32	560	0.00	0.00	0.00	0.01	0.00
Metanauplii	80	858	1 643	0.00	0.01	0.13	0.25	0.00
Juvenile	210	242	47	0.00	0.11	0.13	0.03	0.00
Pre-adult	1 941	137	2 699	553	3.32	0.23	4.62	0.95
Females without ovisacs	312	137	5	9	0.80	0.35	0.01	0.02
Females with ovisacs	244	447	68	12	0.90	1.65	0.25	0.04
Females	556	584	73	21	1.70	2.00	0.26	0.06
Males	240	258	1 251	141	0.66	0.71	3.45	0.39
Total	*4 101*	*8 801*	*10 732*	*206 637*	*5.81*	*3.27*	*8.66*	*3.46*

In the samples, except the sample taken in December, all age stages are recorded. The number of individuals per 1 m^3 in groups is different, according to the dates of sampling.

In September-October under conditions of a gradual but insignificant temperature decrease and a relatively stable salinity within 200‰, the number of younger (except for metanauplii) and older age groups changed little (Fig. 2). In early November there was a rapid increase of brine shrimp number in general – the proportion of younger groups increases many times (Table 2, Fig. 2).

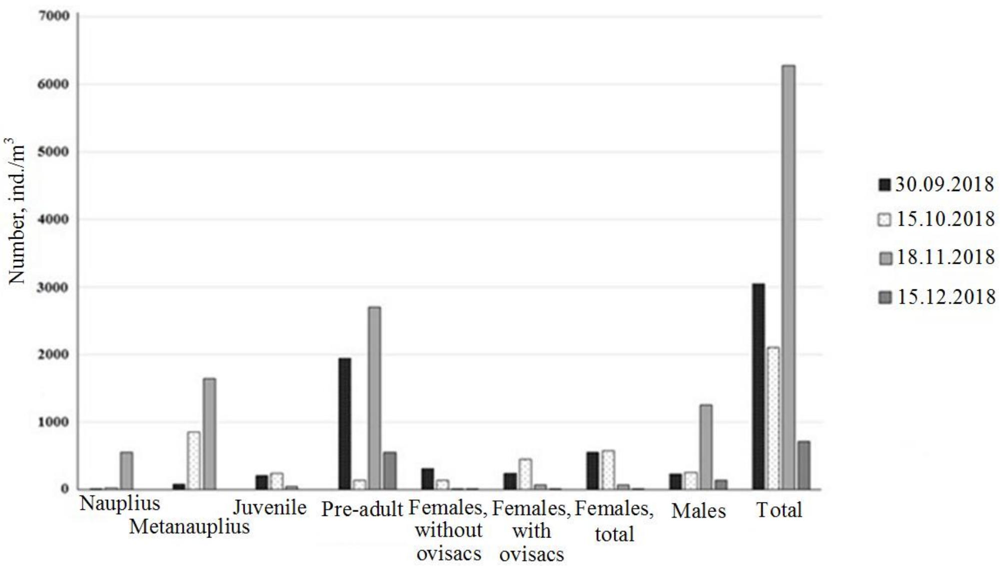

Fig. 2. Change in age structure of the *Artemia* sp. population in the cooling reservoir (No. 1)

In November, there is a sharp (more than 2 times) decrease in temperature, which affects the structure of the branchiopod population. In the November plankton a huge amount of dead *Artemia* sp. is recorded, especially in older age groups. Subsequently, juveniles also die in the mass, and the number of brine shrimp in December goes to zero.

An analysis of the data on sex structure of the *Artemia* sp. population is shown at the Fig. 3.

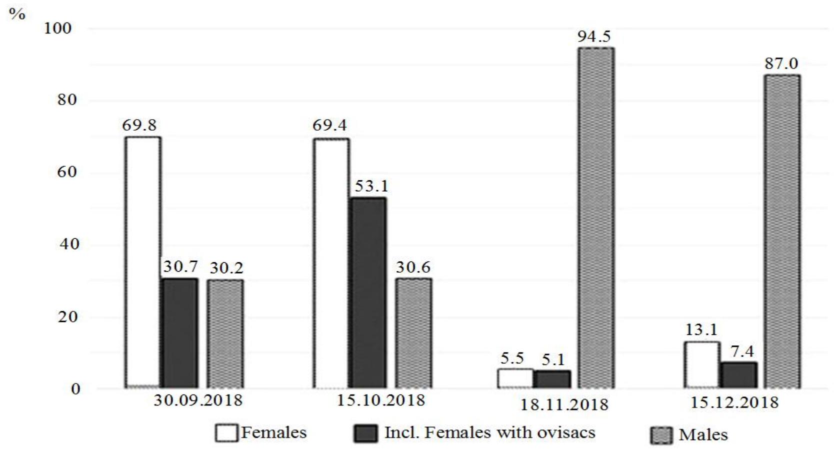

Fig. 3. Change in sex structure of the *Artemia* sp. population from the cooling pond (No. 1)

Their ratio also changed when the main abiotic factors (temperature, salinity) changed during the study period. At the same time, the proportion of females, including those with ovisacs, as well as males, their ratio, may indicate a change (predominance) of parthenogenetic or sexual reproduction in the population.

During September parthenogenetic reproduction prevails in the brine shrimp population at the water body No. 1. The presence of cysts in plankton indicates the existence of a sexual mode of reproduction in this period. The ratio of females and males in September and October is stable, at the level of 2 : 1 (Fig. 3). At the same time, females with ovisacs make up about half of their number in September, but in October the part of females with ovisacs is already more than 75% (Fig. 3).

With abrupt decrease in temperature in the water body in November, the proportion of adults is significantly reduced by less than 10% of their earlier number. But at the same time, the ratio of females and males changes vice versa amounting to 1 : 17. Perhaps, this fact indicates an increasing role of sexual reproduction. Parthenogenetic females die, and their place is taken by growing females that reproduce bisexually. This is also confirmed by the increasing number of the brine shrimp cysts in plankton. It is important that females predominated in the mass of dead mature individuals in November, and proportion of males was disproportionately smaller. In December the proportion of females slightly increases.

The number and biomass of the *Artemia* sp. cysts in the cooling pond (No. 1) during the autumn-winter period changes significantly (Fig. 4).

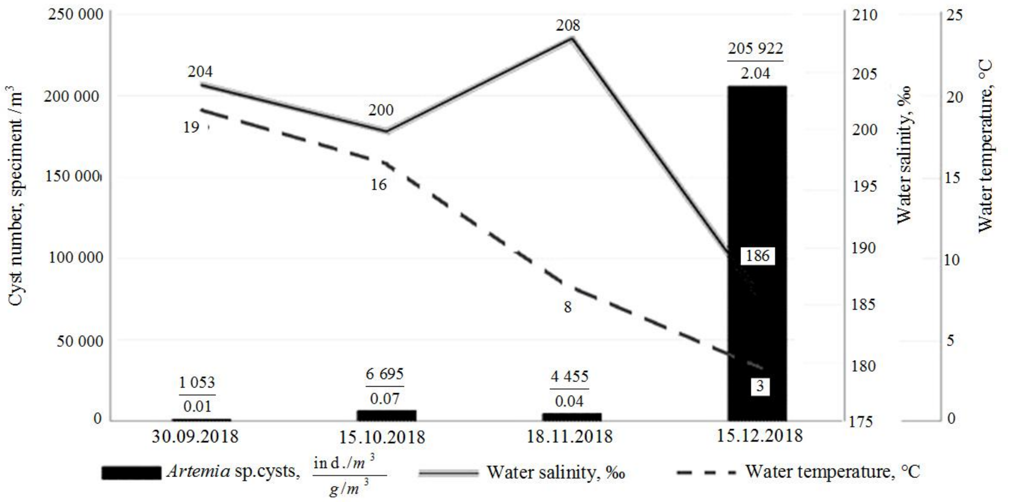

Fig. 4. Change in the number and biomass of the *Artemia* sp. cysts in the cooling pond (No. 1)

In September, the smallest number of cysts was recorded (1 053 cysts/m^3), in October, as the water temperature decreases, the proportion of cysts increases (6 695 cysts/m^3), and in November it again slightly decreases (4 455 cysts/m^3). This may be a consequence of the death of most of the females, including those bred bisexually. The maximum number of cysts was recorded in December 2018 (205 922 cysts/m^3). Thus, during the study, the biomass of brine shrimp cysts from September to December increased 204 times and amounted to 2.04 g/m^3.

According to the data obtained from the reservoir No. 1 (part of Lake Aktashskoe), it should be noted that the starting point (limiting condition) for the beginning of changes in the structure of the population (by age groups and sex), preceding the winter pause, is a decrease in water temperature up to 10°C and lower at relatively stable salinity values (at the level of 200‰). Under these conditions, Artemia begins an increased production of dormant eggs – cysts.

Status of the *Artemia* sp. population at the natural part of Lake Aktashskoe (pond No. 2)

The brine shrimp population at the natural, no transformed part of Lake Aktashskoe (pond No. 2) also is of a complex age structure represented by all groups. However, their one-time ratio and quantitative indicators are different (Table 3).

Table 3

Change in the number and biomass of the *Artemia* sp. by age groups during September-December 2018 at the natural part of Lake Aktashskoe (pond No. 2)

Ages groups, gender	Number, ind./m^3			Biomass, g/m^3		
	30.09.2018	18.11.2018	15.12.2018	30.09.2018	18.11.2018	15.12.2018
Cysts	85 404	94 823	1 068 263	0.85	0.95	10.68
Nauplii	22	20	32	0.00	0.00	0.00
Metanauplii	4 730	20	64	0.71	0.00	0.01
Juvenile	19 004	109	127	10.45	0.06	0.07
Pre-adult	3 860	40	0.00	6.60	0.07	0.00
Females without ovisacs	1 404	385	158	3.59	0.99	0.40
Females with ovisacs	4 969	1 283	600	18.38	4.75	2.22
Females	6 373	1 668	758	21.97	5.74	2.62
Males	183	356	63	0.50	0.98	0.17
Total	*119 576*	*97 036*	*1 069 307*	*41.08*	*7.80*	*13.55*

The largest number of all groups (except cysts) was registered in September at water temperature of 26°C and salinity of 140‰ (Fig. 5).

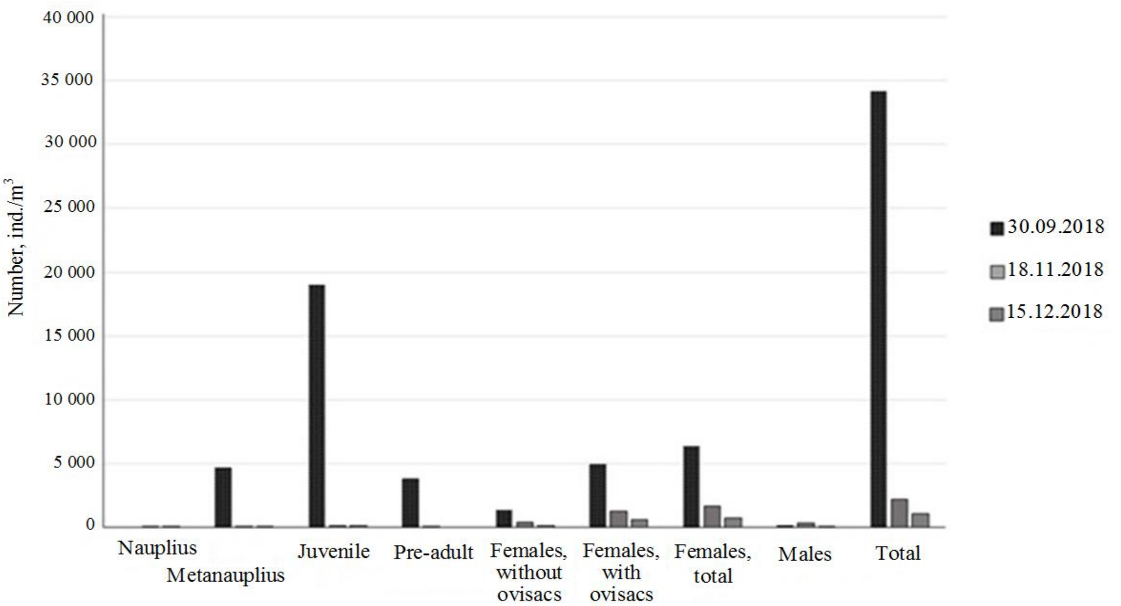

Fig. 5. Change in the age structure of the *Artemia* sp. population at the natural part of Lake Aktashskoe (pond No. 2)

Subsequently, under lower temperatures and desalination (decrease in salinity) of water, the number of each of the groups decreased significantly (by 9 or more times).

The structure of the brine shrimp population by sex in the natural part of the lake has significant imbalance towards females (Fig. 6).

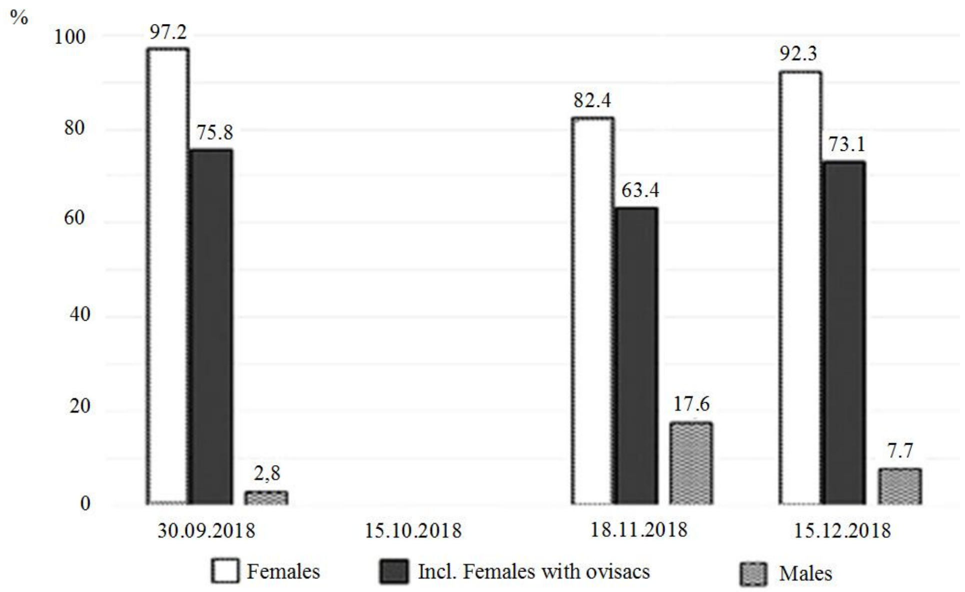

Fig. 6. Change in the sex structure of the *Artemia* sp. population at the natural part of Lake Aktashskoe (pond No. 2)

The ratio of females and males over the control periods varies from 5 : 1 to 34 : 1 with an obvious tendency to increase the proportion of males in the second half of the observation period (November-December 2018). The part of females with ovisacs throughout the entire period is consistently high – 77-79%.

According to the structure of the population by sex, it is possible to assume that *Artemia* sp. at the pond No. 2 during the entire period of observations reproduces mainly parthenogenetically. Although the number of cysts is quite high. That is, there are two groups of females in the water body, using different methods of reproduction (reproductive strategies).

Cyst production in the brine shrimp population of the natural part of Lake Aktashskoe remains practically unchanged under conditions of salinity decrease from 140 to 112‰, and water temperature from 26 to 9°C (Fig. 7).

At salinity values below 110‰ and temperatures of 8°C, the number of cysts in plankton rapidly increases.

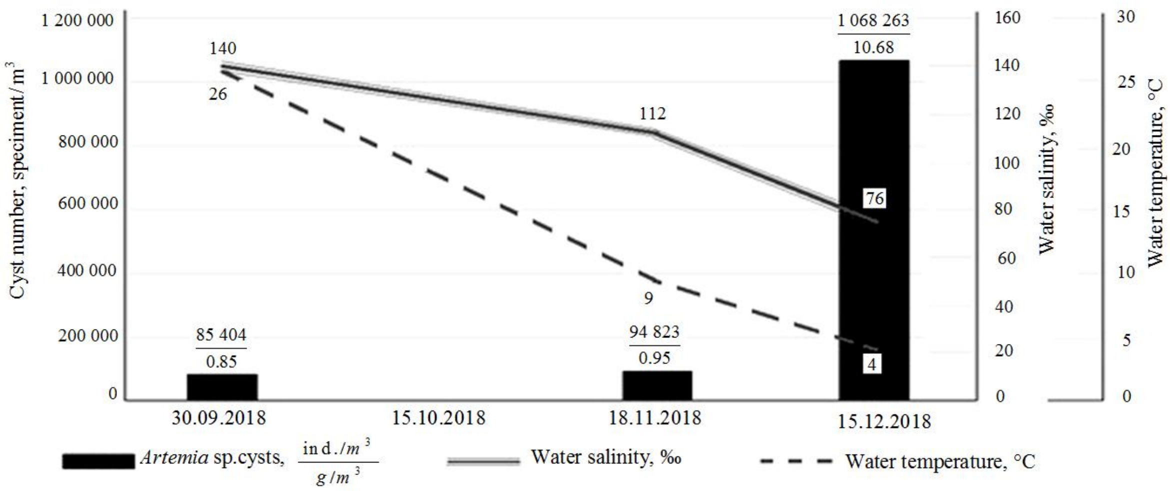

Fig. 7. Change in the number and biomass of the *Artemia* sp. cysts in the natural part (No. 2) of Lake Aktashskoe

Analysis of the size composition of the population in various water bodies of the aquatic complex – Lake Aktashskoe

In processing of samples there were measured the body length of brine shrimp in each of the sex and age groups, as well as the sizes (D_{max}, D_{min}, S) of its cysts. The measurement results are shown in Table 4.

Таблица 4

Size of different sex and age groups of the *Artemia* sp.

Ages groups, gender	Water body of Lake Aktashskoe complex													
	Cooling pond (No. 1)								Natural pond (No. 2)					
	30.09.2018		15.10.2018		18.11.2018		15.12.2018		30.09.2018		18.11.2018		15.12.2018	
	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)	M ± m*	Max-Min (Lim)
Cysts, Dmax**, mm	0.24 ± 0.01	0.30-0.20 (0.10)	0.21 ± 0.01	0.30-0.15 (0.15)	0.21 ± 0.00	0.25-0.15 (0.10)	0.22 ± 0.01	0.25-0.15 (0.10)	0.22 ± 0.01	0.25-0.15 (0.10)	0.22 ± 0.01	0.25-0.15 (0.10)	0.19 ± 0.01	0.25-0.15 (0.10)
Cysts, Dmin***, mm	0.21 ± 0.01	0.25-0.15 (0.10)	0.19 ± 0.01	0.30-0.15 (0.15)	0.19 ± 0.00	0.20-0.15 (0.10)	0.20 ± 0.01	0.25-0.15 (0,10)	0.20 ± 0.01	0.25-0.15 (0.10)	0.20 ± 0.01	0.25-0.15 (0.10)	0.17 ± 0.01	0.20-0.15 (0.10)
Cysts, S****, mm²	0.040 ± 0.008	0.059- 0.029 (0.030)	0.033 ± 0.012	0.071-0.018 (0.053)	0.030 ± 0.005	0.039-0.018 (0.021)	0.034 ± 0.008	0.049-0.018 (0.031)	0.034 ± 0.009	0.049-0.018 (0.031)	0.035 ± 0.010	0.049-0.018 (0.031)	0.026 ± 0.007	0.039-0.018 (0.021)
Nauplii, length, mm	0.40*****	0.40*****	0.36 ± 0.02	0.45-0.30 (0.15)	0.37 ± 0.01	0.55-0.30 (0.20)	–	–	0.40 ± 0.03	0.45-0.35 (0.10)	0.38 ± 0.03	0.40-0.35 (0.05)	0.30*****	0.30*****
Metanauplii, length, mm	1.29 ± 0.11	1.80-0.95 (0.85)	0.72 ± 0.02	1.05-0.50 (0.55)	0.68 ± 0.02	0.95-0.50 (0.45)	–	–	1.20 ± 0.04	1.65-0.55 (1.10)	1.00 ± 0.05	1.05-0.95 (0.10)	0.58 ± 0.08	0.65-0.50 (0.15)
Juvenile, length, mm	2.48 ± 0.13	3.70-1.50 (2.20)	1.67 ± 0.12	2.85-0.95 (1.90)	2.74 ± 0.18	3.40-1.80 (1.60)	–	–	2.18 ± 0.06	2.95-1.70 (1.25)	1.43 ± 0.06	1.85-1.15 (0.70)	1.43	1.45-1.40 (0.05)
Pre-adult, length, mm	4.38 ± 0.07	4.95-3.60 (1.35)	3.45 ± 0.20	4.55-2.45 (2.10)	4.54 ± 0.13	6.70-3.30 (3.40)	4.90 ± 0.13	6.15-3.70 (2.45)	3.47 ± 0.09	4.45-2.70 (1.75)	4.16 ±0.66	5.35-2.65 (2.70)	–	–
Females without ovisacs, length, mm	8.74 ± 0.27	11.70-5.40 (6.30)	9.26 ± 0.32	11.60-5.90 (5.70)	6.90*****	6.90*****	5.63 ± 0.26	6.10-5.20 (0.90)	6.50 ± 0.31	9.20-5.30 (3.90)	7.13 ± 0.27	9.10-5.60 (3.50)	7.88 ± 0.72	9.70-6.30 (3.40)
Females with ovisacs, length, mm	8.92 ± 0.24	11.10-6.40 (4.70)	10.22 ± 0.32	12.00-6.20 (5.80)	6.18 ± 0.21	7.30-5.10 (2.20)	5.90 ± 0.35	6.80-5.10 (1.70)	6.94 ± 0.19	8.90-5.40 (3.50)	7.90 ± 0.21	10.10-6.50 (3.60)	8.04 ± 0.24	9.60-6.60 (3.00)
Males, length, mm	4.73 ± 0.26	8.10-3.30 (4.80)	5.27 ± 0.36	8.10-3.10 (5.00)	10.66 ± 0.23	13.80-8.30 (5.50)	4.86 ± 0.12	6.30-4.10 (2.20)	6.11 ± 0.21	7.30-5.60 (1.70)	6.44 ± 0.19	8.20-4.70 (3.50)	6.10 ± 0.30	6.40-5.80 (0.60)

*M ± m – mean ± standard error of the mean; **D_{max} – large diameter (of ellipse); ***D_{min} – small diameter (of ellipse); ****S – surface area of cyst; *****only one specimen of this group in the sample.

When comparing the size of brine shrimp at certain stages of development in ponds 1 and 2 (Fig. 8), according to the dates of selection, at first glance, a chaotic dynamic is observed.

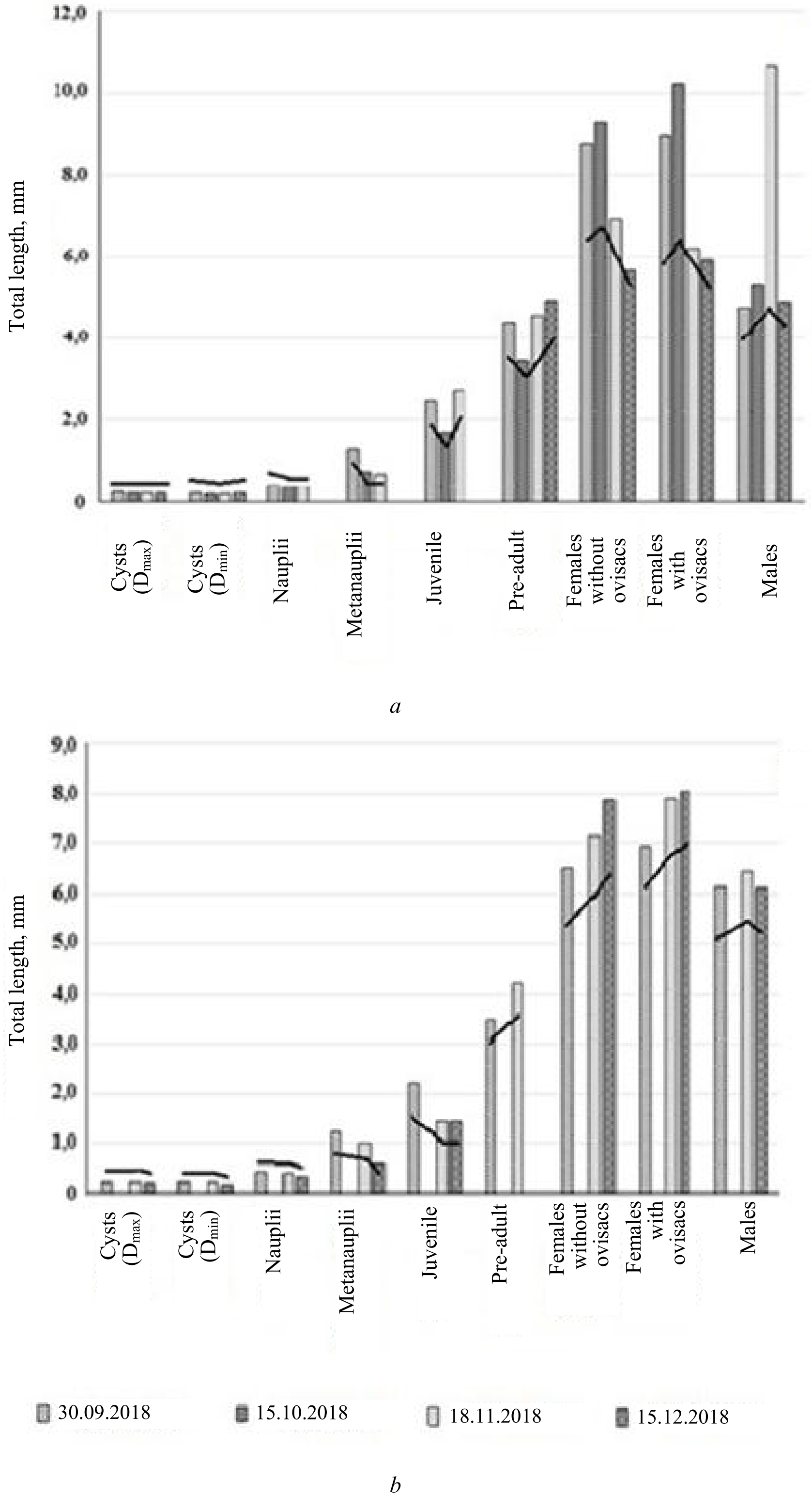

Fig. 8. Change in the average length of the *Artemia* sp. by groups:
a – in the cooling pond; *b* – in the natural part of Lake Aktashskoe

However, it is possible to identify a number of specific trends. The younger age groups (nauplius – metanauplius, and at pond 2, juveniles) become smaller. *Artemia* sp. during the pre-adult stage grows faster up to the end of the season. In the cooling pond (No. 1) adult females get smaller in size when temperature decreases, while in the natural part of the lake (pond No. 2), on the contrary, they become larger. The sizes of males in both ponds practically do not change throughout the entire observation period (without taking into account the values for November in pond No. 1).

In general, the size of the *Artemia* sp. in terms of stages of development in both ponds is relatively equal. The only thing that requires explanation is the fact of a sharp difference in the size of males in reservoirs No. 1 (4.73-5.25 mm) and No. 2 (6.10-6.44 mm). The issue of changes in the size of females during the period of deterioration of the living conditions of the population remains debatable. What is its cause: accelerates (or slows down) their differentiation by sex and their participation in reproduction; slows down (or accelerates) their growth (food supply, etc.)?

When comparing the average values for groups in September (the period of relative well-being of the population) and November (the beginning of mass production of cysts and depression of the population) for ponds (Fig. 9), the following was established.

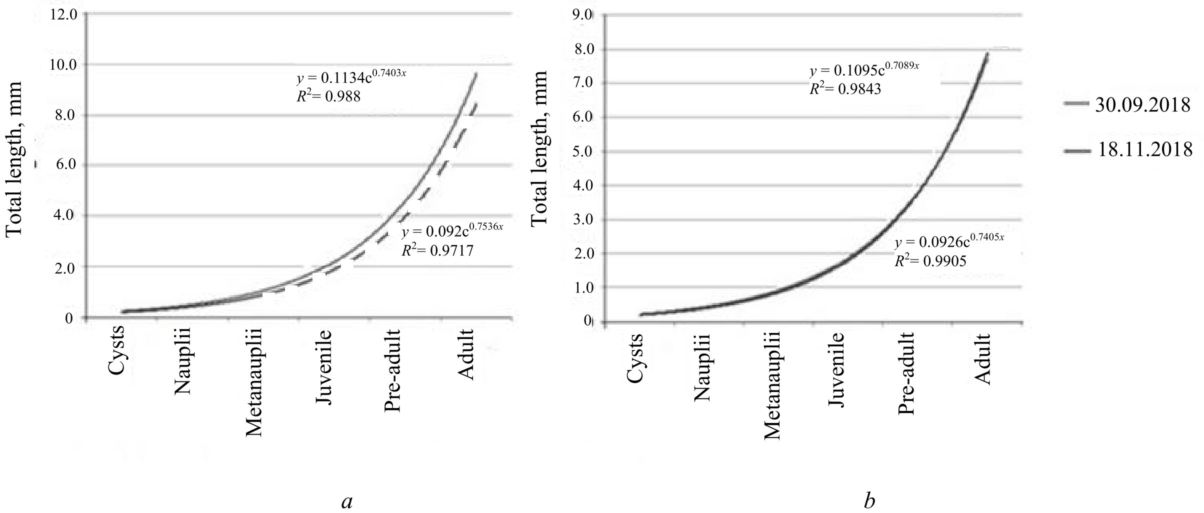

Fig. 9. Change in the average size of the brine shrimp in groups as it grows in September and November 2018: *a* – at the cooling pond; *b* – at the natural part of Lake Aktashskoe

In the cooling pond (No. 1) under conditions of a sharp temperature drop, the length of the *Artemia* sp. specimens decreases in all groups. In the natural part (No. 2), on the contrary, there are no significant changes in the values of the average body length in any of the groups.

Other species of invertebrates in hyperhaline ponds of the aquatic complex – Lake Aktashskoe

In the samples of zooplankton from the cooling pond (No. 1) at a salinity of 186-200‰, in addition to brine shrimp, a few individuals of one species of copepods were found: October 15, 2018 – 5 ind./m^3; December 15, 2018 – 3 ind./m^3.

In the natural part (No. 2) of Lake Aktashskoe the biological diversity of other invertebrate species was significantly higher. Seven species of invertebrates were recorded here, including 5 species of larvae of near-aquatic insects, one species of beetles (imago) and 1 species of copepods. The numbers in species are given in Table 5.

Table 5

Composition and dynamics of other species of invertebrates in the plankton of the natural part (No. 2) of Lake Aktashskoe during the study period

Aquatic arthropods, juveniles and adults	Number, ind./m^3		
	30.09.2018 (salinity 140‰)	18.11.2018 (salinity 112‰)	15.12.2018 (salinity 76‰)
Chironomidae larvae	611	119	95
Larvae of other Diptera	7	0	32
Coleoptera	14	0	0
Copepoda	197	375	2 874

In addition, in September-November, the presence of green filamentous algae was noted in the plankton of the pond (No. 2), while their number decreased from the beginning of the study period to its end (there were no algae in December).

Conclusion

Sex and age structure of populations of the branchiopod crustacean *Artemia* sp. in the autumn-winter period, it has a complex structure, which is due both to environmental conditions and too much greater adaptive abilities of this species than is commonly believed. The nature of the impact on brine shrimp of the accepted triggering factors of the natural environment (threshold values of water temperature and salinity), which predetermine the decline in population size during the transition from parthenogenetic reproduction of offsprings to sexual reproduction or, on the contrary, rapid increase of brine shrimp caused by the release of nauplii from wintering cysts, does not can always be unambiguously used in practice.

In both ponds (No. 1 – cooling pond, No. 2 – natural part of Lake Aktashskoe), at different salinity at water temperatures below 10-8°C, an increase in the number of cysts takes place. At the same time, the difference in salinity in water bodies is almost 100‰. Apparently, this indicator in brine shrimp has a much wider range of optimum.

The *Artemia* sp. population in the cooling pond (No. 1), due to its larger volume of water and depth, develops gradually, without sharp changes in numbers and short-term disappearance of certain age groups. At the same time, the productivity of this population is somewhat lower than in the second pond, which is probably due to increased salinity and food shortage, etc. On the contrary, the population in the natural part (No. 2) of the lake, which has a smaller volume and depth, develops explosively, but the biomass of the *Artemia* sp. at the peak of its development is much higher. Under conditions of a sharp decrease in temperature, the nature of changes in the sex, age and size structure in water bodies with different salinity is different.

The nature of regulation of the *Artemia* sp. population, its sex and size-age structure are probably much more complicated than it was previously thought. At the same time, it is necessary to take into account a larger list of environmental factors, as well as the nature of their joint influence, which requires additional research involving more analytical material in terms of chronology (duration of observation) and geography.

References

1. Balushkina V. E., Golubkov S. M., Golubkov M. S., Litvinchuk L. F. Strukturno-funktsional'nye kharakteristiki ekosistem malykh solenykh ozer Kryma [Structural and functional characteristics of ecosystems of small saline lakes of Crimea]. *Biology of inland waters*, 2007, no. 2, pp. 11-19.

2. Balushkina V. E., Golubkov S. M., Golubkov M. S., Litvinchuk L. F., Shadrin N. V. Vliianie abioticheskikh i bioticheskikh faktorov na strukturno-funktsional'nuiu organizatsiiu ekosistem solenykh ozer Kryma [Influence of abiotic and biotic factors on the structural and functional organization of ecosystems of saline lakes of the Crimea]. *Zhurnal obshchei biologii*, 2009, no. 6, pp. 504-514.

3. Bambeeva V. I. Biologiia zhabronoga artemiia v Bol'shom Iashaltinskom ozere Kalmykii [Biology of Artemia branchiod in Lake Big Yashalta of Kalmykia]. *Problemy sokhraneniia i ratsional'nogo ispol'zovaniia bioraznoobraziia Prikaspiia i sopredel'nykh regionov: materialy 3-i Mezhdunarodnoi zaochnoi nauchnoi konferentsii*. Elista, Izd-vo KGU, 2005. Pp. 81-83.

4. Vesnina L. V., Mitrofanova E. Iu., Lisitsina T. O. Plankton solenykh ozer territorii zamknutogo stoka (iug Zapadnoi Sibiri, Rossiia) [Plankton of saline lakes on closed runoff area (south of Western Siberia, Russia)]. *Sibirskii ekologicheskii zhurnal*, 2005, no. 2, pp. 221-233.

5. Vesnina L. V., Permiakova G. V. Dinamika chislennosti i osobennosti raspredeleniia raznovozrastnykh osobei zhabronogogo rachka roda *Artemia* v glubokovodnom ozere Bol'shoe Iarovoe Altaiskogo kraia [Dynamics of number and distribution of different-aged individuals of branchiopod Artemia in deep-water Lake Bolshoye Yarovoe, Altai Territory]. *Vestnik Tomskogo gosudarstvennogo universiteta*, 2013, no. 1 (21), pp. 89-102.

6. Vizer L. S., Rostovtsev A. A. Monitoring *Artemia* sp. v gipergalinnom ozere Karachi [Monitoring *Artemia* sp. in hypersaline Lake Karachi]. *Vestnik Novosibirskogo gosudarstvennogo agrarnogo universiteta*, 2016, no. 2 (39), pp. 65-70.

7. Voronov P. M. Vliianie temperatury na rost i sozrevanie *Artemia salina* [Effect of temperature on growth and maturation of *Artemia salina*]. *Zoologicheskii zhurnal*, 1982, vol. 61, iss. 10, pp. 1594-1596.

8. Voronov P. M. Rost i sozrevanie artemii (*Artemia salina*) v solenykh ozerakh Kryma [Growth and maturation of shrimp (*Artemia salina*) in salt lakes of Crimea]. *Trudy VNIRO*, 1975, no. 109, pp. 152-158.

9. Voronov P. M. Sezonnaia chislennost' i biomassa artemii i ee iaits v solenykh ozerakh Kryma [Seasonal abundance and biomass of brine shrimp and its eggs in salt lakes of Crimea]. *Trudy VNIRO*, 1973, no. 94, pp. 170-178.

10. Voronov P. M. Solevoi sostav i izmenchivost' *Artemia salina* (L.) [Salt composition and variability of *Artemia salina* (L.)]. *Zoologicheskii zhurnal*, 1979, vol. 58, iss. 2, pp. 175-178.

11. Zagorodniaia Iu. A., Batogova E. A., Shadrin N. V. Mnogoletnie transformatsii planktona v gipergalinnom Bakal'skom ozere (Krym) pri kolebaniiakh solenosti [Long-term transformations of plankton in hypersaline Lake Bakkal (Crimea) with salinity fluctuations]. *Mors'kii ekologichnii zhurnal*, 2008, no. 4, vol. VII, pp. 41-50.

12. Ivanova V. I., Konieva G. N., Baktasheva N. M. Vliianie ekologicheskikh faktorov na rost i produktivnost' artemii v gipergalinnykh vodoemakh Kalmykii [Influence of environmental factors on growth and productivity of Artemia in hypersaline reservoirs of Kalmykia]. *Problemy regional'noi ekologii i prirodopol'zovaniia. Estestvennye nauki*, 2012, no. 3 (40), pp. 51-55.

13. Karnaukhov G. I., Skliarov V. Ia., Zlotnikov A. S. Produktivnost' nekotorykh solenykh ozer Stavropol'skogo kraia [Productivity of saline lakes in Stavropol Territory].

Trudy Kubanskogo gosudarstvennogo agrarnogo universiteta, 2015, no. 53, pp. 63-77.

14. Litvinenko L. I., Litvinenko A. I., Boiko E. G. *Artemiia v ozerakh Zapadnoi Sibiri* [Artemia in lakes of Western Siberia]. Novosibirsk, Nauka Publ., 2009. 304 p.

15. Litvinenko L. I., Litvinenko A. I., Boiko E. G., Kutsanov K. V. Vliianie faktorov vneshnei sredy na strukturu i funktsionirovanie biotsenozov gipergalinnykh vodoemov iuga Zapadnoi Sibiri [Influence of environmental factors on structure and functioning of biocenoses of hyperhaline reservoirs in south of Western Siberia]. *Sibirskii ekologicheskii zhurnal*, 2013, no. 3, pp. 321-332.

16. Solovov V. P., Studenikina T. L. Osobennosti dinamiki chislennosti populiatsii zhabronogogo rachka *Artemia salina* (L.) v ozerakh iuga Zapadnoi Sibiri i perspektivy ispol'zovaniia ego resursov [Peculiarities of population dynamics of branchiopod *Artemia salina* (L.) in lakes of south of Western Siberia and prospects for using its resources]. *Gidrobiologicheskii zhurnal*, 1992, vol. 28, no. 2, pp. 33-41.

17. Solovov V. P., Studenikina T. L. *Rachok artemiia v ozerakh Zapadnoi Sibiri: morfologiia, ekologiia, perspektivy khoziaistvennogo ispol'zovaniia* [Artemia crustaceanin lakes of Western Siberia: morphology, ecology, prospects for economic use]. Novosibirsk, Nauka Publ., 1990. 81 p.

18. Iasiuchenia T. L. Khoziaistvennoe ispol'zovanie resursa rachka artemiia v ozere Bol'shoe Iarovoe: itogi i perspektivy [Economic use of Artemia crustacean resource in Lake Bolshoye Yarovoye: results and perspectives]. *Bioraznoobrazie artemii v stranakh SNG: sovremennoe sostoianie ee zapasov i ikh ispol'zovanie: sbornik dokladov mezhdunarodnogo nauchno-issledovatel'skogo seminara.* Tiumen', Izd-vo FGUP «Gosrybtsentr», 2004. Pp. 70-78.

19. *Metodicheskie rekomendatsii po otsenke zapasa i prognozirovaniiu rekomendovannogo ob"ema dobychi (vylova) artemii* [Guidelines for stock assessment and forecasting recommended volume of extraction (catch) of Artemia]. Moscow, Izd-vo VNIRO, 2019. 50 p.

20. Semik A. M. Produktsionnye pokazateli lichinok khironomid (*Chironomus salinatius*) v Aktashskom ozere [Production parameters of larvae of chironomids (*Chironomus salinatius*) in Lake Aktash]. *Osnovnye rezul'taty kompleksnykh issledovanii v Azovo-Chernomorskom basseine i Mirovom okeane.* Kerch', Izd-vo IugNIRO, 2013. Pp. 53-57.

Список источников

1. *Балушкина В. Е., Голубков С. М., Голубков М. С., Литвинчук Л. Ф.* Структурно-функциональные характеристики экосистем малых соленых озер Крыма // Биология внутренних вод. 2007. № 2. С. 11–19.

2. *Балушкина В. Е., Голубков С. М., Голубков М. С., Литвинчук Л. Ф., Шадрин Н. В.* Влияние абиотических и биотических факторов на структурно-функциональную организацию экосистем соленых озер Крыма // Журн. общей биологии. 2009. № 6. С. 504–514.

3. *Бамбеева В. И.* Биология жабронога артемия в Большом Яшалтинском озере Калмыкии // Проблемы сохранения и рационального использования биоразнообразия Прикаспия и сопредельных регионов: материалы 3-й Междунар. заоч. науч. конф. Элиста: Изд-во КГУ, 2005. С. 81–83.

4. *Веснина Л. В., Митрофанова Е. Ю., Лисицина Т. О.* Планктон соленых озер территории замкнутого стока (юг Западной Сибири, Россия) // Сиб. экол. журн. 2005. № 2. С. 221–233.

5. *Веснина Л. В., Пермякова Г. В.* Динамика численности и особенности распределения разновозрастных особей жаброногого рачка рода *Artemia* в глубоководном озере Большое Яровое Алтайского края // Вестн. Том. гос. ун-та. 2013. № 1 (21). С. 89–102.

6. *Визер Л. С., Ростовцев А. А.* Мониторинг *Artemia* sp. в гипергалинном озере Карачи // Вестн. Новосиб. гос. аграр. ун-та. 2016. № 2 (39). С. 65–70.

7. *Воронов П. М.* Влияние температуры на рост и созревание *Artemia salina* // Зоолог. журн. 1982. Т. 61. Вып. 10. С. 1594–1596.

8. *Воронов П. М.* Рост и созревание артемии (*Artemia salina*) в соленых озерах Крыма // Тр. ВНИРО. 1975. № 109. С. 152–158.

9. *Воронов П. М.* Сезонная численность и биомасса артемии и ее яиц в соленых озерах Крыма // Тр. ВНИРО. 1973. № 94. С. 170–178.

10. *Воронов П. М.* Солевой состав и изменчивость *Artemia salina* (L.) // Зоол. журн. 1979. Т. 58. Вып. 2. С. 175–178.

11. *Загородняя Ю. А., Батогова Е. А., Шадрин Н. В.* Многолетние трансформации планктона в гипергалинном Бакальском озере (Крым) при колебаниях солености // Морський екологічний журнал. 2008. № 4. Т. VII. С. 41–50.

12. *Иванова В. И., Кониева Г. Н., Бакташева Н. М.* Влияние экологических факторов на рост и продуктивность артемии в гипергалинных водоемах Калмыкии // Проблемы региональной экологии и природопользования. Естественные науки. 2012. № 3 (40). С. 51–55.

13. *Карнаухов Г. И., Скляров В. Я., Злотников А. С.* Продуктивность некоторых соленых озер Ставропольского края // Тр. Кубан. гос. аграр. ун-та. 2015. № 53. С. 63–77.

14. *Литвиненко Л. И., Литвиненко А. И., Бойко Е. Г.* Артемия в озерах Западной Сибири. Новосибирск: Наука, 2009. 304 с.

15. *Литвиненко Л. И., Литвиненко А. И., Бойко Е. Г., Куцанов К. В.* Влияние факторов внешней среды на структуру и функционирование биоценозов гипергалинных водоемов юга Западной Сибири // Сиб. эколог. журн. 2013. № 3. С. 321–332.

16. *Соловов В. П., Студеникина Т. Л.* Особенности динамики численности популяции жаброногого рачка *Artemia salina* (L.) в озерах юга Западной Сибири и перспективы использования его ресурсов // Гидробиол. журн. 1992. Т. 28. № 2. С. 33–41.

17. *Соловов В. П., Студеникина Т. Л.* Рачок артемия в озерах Западной Сибири: морфология, экология, перспективы хозяйственного использования. Новосибирск: Наука, 1990. 81 с.

18. *Ясюченя Т. Л.* Хозяйственное использование ресурса рачка артемия в озере Большое Яровое: итоги и перспективы // Биоразнообразие артемии в странах СНГ: современное состояние ее запасов и их использование: сб. докл. междунар. науч.-исслед. семинара / под ред. А. И. Литвиненко. Тюмень: Изд-во ФГУП «Госрыбцентр», 2004. С. 70–78.

19. *Методические* рекомендации по оценке запаса и прогнозированию рекомендованного объема добычи (вылова) артемии. М.: Изд-во ВНИРО, 2019. 50 с.

20. *Сёмик А. М.* Продукционные показатели личинок хирономид (*Chironomus salinatius*) в Акташском озере // Основные результаты комплексных исследований в Азово-Черноморском бассейне и Мировом океане. Керчь: Изд-во ЮгНИРО, 2013. С. 53–57.

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