

Structural variables of macrozoobenthos during stabilization and increase of the Small Aral Sea's level (1996-2008).

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Abstract

The purpose of this work was to study the macrozoobenthos of the Small Aral Sea in the period from 1996 to 2008, which was characterized by stabilization and then by a steady increase in the water level and decrease in water salinity. Samples of macrozoobenthos were taken in the Small Aral Sea using a grid of 20 stations. During the study period, the average salinity of water varied from 6.3‰ to 19.0‰. 10 taxa were identified in the benthic community. The average annual abundance of macrozoobenthos was 1962 species/m², with its biomass at 83.3 g/m². Quantitative variables of the community were primarily formed by polychaete *Hediste diversicolor*, mollusks *Abra ovata*, *Caspihydrobia* sp. and *Cerastoderma isthmicum*. During the period of study, abundance and biomass of macrozoobenthos decreased by an order of magnitude from 4274 to 641 species/m² and from 206.0 to 20.6 g/m², respectively. The average values of the Shannon index - 1.20 bits/specimen and 0.92 bits/mg, were characteristic of a low diversity of benthic cenosis. Evidently, the water salinity had a positive effect on the long-term dynamics of macrozoobenthos biomass. The observed decrease in the quantitative variables of macrozoobenthos during desalination of the Small Aral Sea is not only due to the deterioration of hydrochemical conditions for marine and halophilic species, but also to the increased pressure on the benthic fauna caused by fish.

Keywords: Small Aral Sea, benthic invertebrates, hydrological regime, sea level, salinity, Kazakhstan, dynamics.

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Introduction

The Aral Sea is an inland water body with no connection to the ocean [1]. It is characterized by shallow water and strong desalination due to the pronounced influence of atmospheric processes and river runoff. These features cause a great variability of hydrological, hydrochemical and biological variables of the Aral Sea under the influence of external conditions.

Until 1961, during the quasi-stable period, the water level of the Aral Sea varied within relatively small limits. At the level of 53.4 m Baltic System (BS), surface area was 68 900 km², the volume of water was 78.2 thousand km³, with the maximum depth of 18.0 m and an average depth of 8.7 m [2]. The average salinity of water during this period changed marginally from 9.7 to 10.2. In the following decades, due to disruption of water balance, the sea level decreased from 53.4 to 39.0 m BS, and salinity increased to 58.0 [3]. In 1988-1989, the sea was divided into two isolated parts - the Small and Large Aral. In 2005, in order to restore the northern part of the sea, a dam was built in the Berg's Strait, preventing the flow of the Syrdarya River to the Great Aral Sea. This led to an increase in the level of the Small Aral to 42.5 m and a decrease in the average salinity of water to 12.9‰ [4]. The salinity of the Big Aral, which by 2010 was divided into several isolated hypersaline water bodies, continued to grow and exceeded 150‰ by the end of the 1990s [5].

In the period of the natural hydrological regime, the benthic

fauna was studied throughout the entire floor of the Aral Sea [6-10]. After the division of the sea, mainly the northern part of the sea, the Small Aral was under constant observation [11-15]. The above-listed works provide information on the species composition and quantitative parameters of benthic invertebrates in the quasi-stable and subsequent period of degradation of the Aral Sea. The dramatic consequences of salinization of the marine ecosystem, that caused the extinction of a number of freshwater and brackish-water species from various systematic groups, are shown. There is data of the structure of benthic cenoses in the subsequent period of stabilization of the level of the Small Aral [16-18], which was due to favorable weather conditions of 1988-1994.

The purpose of this work was to study the macrozoobenthos of the Small Aral Sea in the period from 1996 to 2008, which was characterized by stabilization and then by a steady increase in the water level and decrease in water salinity.

Description of the Study Area

The Aral Sea is located in the arid climatic zone, with an average annual precipitation of up to 100-115 mm and a temperature gradient from -36°C to +43°C [19]. Until the second half of the 20th century, the Aral Sea was the largest brackish water body in Central Asia. The complex of anthropogenic and natural factors caused a significant reduction in the water surface area and the division of a single water area into two

isolated parts, the Small and the Large Aral [18]. Starting from 1988-1989, the succession of the northern and southern parts of the sea occurs independently of each other.

The Small Aral Sea has a highly dissected coastline forming three large bays - Shevchenko in the west, Butakova in the north and Saryshyanak in the northeast (Figure 1). The main feeding artery of the Small Aral is the Syrdarya River. It is formed at the confluence of Naryn and Karadarya rivers in the eastern part of the Fergana Valley in Uzbekistan. The river is predominantly fed by snow, to a lesser extent, by glacier and rain water [20]. The river is controlled by five large reservoirs, including the Shardara Reservoir on the territory of Kazakhstan. The flow of the Syrdarya River is determined by the climatic conditions of the year, the regime of filling and draining the Shardara Reservoir, as well as the amount of water taken in for crop irrigation.

The Syrdarya River's flow volume, along with natural factors, causes changes in the morphometric and hydrochemical parameters of the Small Aral Sea. During quasi-stable period (1930-1960s), the surface area of the Small Aral Sea reached 3300 km² [21]. The Syrdarya River's flow volume during these years was estimated at 9.9-21.3 km³ [3]. The intensive intake of river water for irrigation of agricultural crops led to the shallowing of the sea in subsequent years [21,22]. The most catastrophic decrease in the flow of the Syrdarya River - 0.2-0.3 km³ was observed in 1973-1977. In 1987-2010, the volume of water in the Small Aral Sea varied from 2.0 to 17.9 km³ [3].

In the study period of 1996-2008, the water level of the Small

Aral Sea varied from 39.0 to 42.1 m BS. The average depth of the sea reached 5.0 m. Shevchenko Bay, as well as the central and northeastern parts of the water area, were characterized by the greatest depths and transparency of the water (Table 1). The values of these parameters, as well as the water temperature, were minimal in the zone of influence of the Syrdarya River. The predominant types of soil were dark gray silt and sand.

Materials and Methods

Samples of macrozoobenthos were taken by a small Petersen grab in the summer of 1996-2008, in the spring of 2002-2004 and in the autumn of 2006, according to a standard grid of 20 stations covering the entire water area of the Small Aral Sea (Figure 1). A total of 160 macrozoobenthos samples were processed. At each station, the depth, transparency, water temperature, predominant type of soil were determined. To determine the chemical composition and total dissolved salts, water samples were taken into plastic containers with a volume of 1 L.

Conventional methods of chemical analysis of water were used [23]. Water samples were analyzed in three-four replications. The error of estimate for major ions in the water was 0.5%-5.0%, depending on the analysis. Macrozoobenthos samples were processed according to generally accepted methods [24] using determinants for corresponding groups [25-28]. The average values with a standard error were calculated for all variables in Excel. The Shannon Index values (Shannon Ab, Shannon Bi), characterizing the diversity of biological communities [29], were calculated in Primer 5 program. To

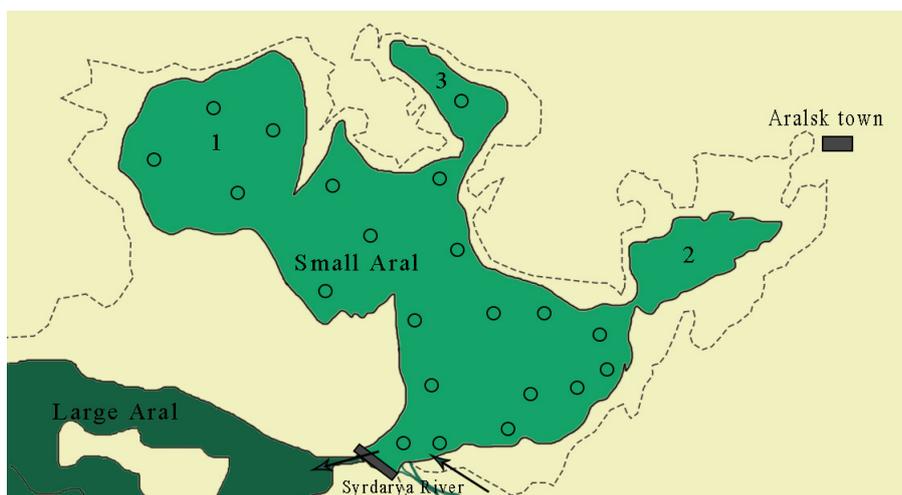


Figure 1. Map of macrozoobenthos sampling in the Small Aral Sea
The dashed line indicates the outline of the Small Aral during the quasi-stable state of the level.
Circles - macrozoobenthos sampling stations. Arrows - the direction of movement of water masses.
The numbers indicate the bays: 1. Shevchenko, 2. Saryshyanak, 3. Butakova

Table 1. Hydrophysical variables and the predominant types of soil of the Small Aral Sea

Part of the sea	Hydrophysical variables			Types of soil
	Depth, m	Transparency, m	Water temperature, °C	
Shevchenko Bay	11.5	1.7	17.7	Dark gray and Gray silt, sand
Butakova Bay	4.4	1.8	21.8	Sand, Dark gray
Centre	7.8	1.6	22.4	Dark gray and Black silt, Sand
North-eastern	6.9	1.5	21.5	Sand, Gray and Dark gray silt
Near the mouth of the Syrdarya	2.6	0.8	17.5	Gray and Light brown silt

assess the effect of water salinity on the quantitative variables of macrozoobenthos, Spearman's rank correlation coefficients were calculated in Statistica 10.

Results

Hydrochemical characteristics of the Small Aral Sea

Fluctuations of the sea level caused significant changes in salinity and chemical composition of waters (Table 2). The maximum values of the variable were observed at the beginning of the analyzed period. After the construction of a permanent dam in the Berg's Strait in 2005, the average salinity of sea water decreased. Generally, water salinity in summer was higher than in the spring. Regarding the chemical composition, water belongs to the chloride or sulphate class, the sodium group. The ratio of chloride and sulfate ions varied in different years, but was not directly related to the salinity of water. So, at similar values of salinity, in 2005 sulfate ions prevailed, while in 2008 there were more chloride ions. Similar instability of chemical composition of water was recorded during other periods of observation.

Macrozoobenthos of the Small Aral Sea

10 taxa of macrozoobenthos were identified (Table 3). Only three species were encountered constantly - the polychaete *Hediste diversicolor*, mollusks *Abra ovata* and *Cerastoderma isthmicum*. In 2007, polychaete was distributed throughout

the entire water area, including the zone near the river mouth and almost completely dry Saryshyanak Bay. Until 2005, mollusk *A. ovata* was found throughout the water area. In 2006-2007, with a decrease in salinity of sea waters, this species became rare in the estuarine zone, although it was still widely distributed throughout the rest of the water area. In certain years, the bivalve mollusk *C. isthmicum* was recorded in all areas of the sea, excluding the desalinated zone. In 2004, gastropod *Caspihydrobia sp.* disappeared from of the benthic community of the desalinated estuarine area. In 2007-2008, this species was found only in the western part of the sea. Other species of benthic invertebrates were rare. Oligochaetes, leeches, chironomids *Procladius ferrugineus*, *Chironomus behningi*, mollusk *Theodoxus pallasi*, prawn *Palaemon elegans*, mysid *Paramysis (Mesomysis) lacustris* were found sporadically in the desalinated areas of the sea.

With relatively stable species composition, the quantitative variables of macrozoobenthos varied significantly from year to year (Table 4). The maximum values of abundance and biomass of the benthic community were recorded at the beginning of the analyzed period (1996-2002), with their subsequent decrease against the background of desalination. Statistical analysis of the available data showed that the salinity of water had a statistically significant effect on the biomass of the benthic community, with the Spearman correlation coefficient $R=0.75$

Table 2. Salinity and chemical composition of the water of the Small Aral Sea

Year, month	Salinity, %	Ion concentration, g/dm ³					
		Ca ²⁺	Mg ²⁺	Na ⁺ K ⁺	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻
1996, June	20.4	-	-	-	-	-	-
1997, June	19.0	-	-	-	-	-	-
1998, June	14.5	-	-	-	-	-	-
2001, June	18.6	0.7	1.1	4.3	0.2	5.4	6.2
2002, June	15.1	0.4	0.7	3.7	0.2	4.7	4.7
2004, August	13.9	0.1	0.1	4.8	0.3	4.6	3.5
2005, May-June	10.8	0.4	0.7	2.3	0.2	3.7	3.1
2006, May-June	8.9	-	-	-	-	-	-
2006, July-September	11.2	-	-	-	-	-	-
2007, May-June	6.3	0.4	0.5	1.0	0.2	1.6	2.4
2007, August-September	10.5	-	-	-	-	-	-
2008, June-July	11.8	0.5	0.6	3.0	0.9	3.3	3.5

Table 3. Taxonomic composition and frequency of occurrence of benthic invertebrates of the Small Aral Sea

Taxon Name	Frequency of Occurrence, %							
	2001	2002	2003	2004	2005	2006	2007	2008
Phylum Annelides								
Oligochaeta gen. sp.	15	-	-	-	-	-	-	-
<i>Hediste diversicolor</i> Muller	80	90	100	85	86	80	55	75
Phylum Arthropoda, Subphylum Crustacea								
<i>Dikerogammarus aralensis</i> Uljanin	-	-	5	-	-	-	-	-
<i>Paramysis lacustris</i> Czerniavsky	-	-	-	-	5	-	-	-
<i>Palaemon elegans</i> Rathke	-	-	-	5	-	-	-	-
Subphylum Tracheata, Superclass Insecta								
<i>Chironomus behningi</i> Goetghebuer	-	5	25	-	5	35	9	25
Phylum Mollusca								
<i>Cerastoderma isthmicum</i> Issel	50	50	40	45	43	15	9	45
<i>Abra ovata</i> Philippi	70	65	55	70	52	50	59	70
<i>Caspihydrobia sp.</i>	35	55	80	20	5	-	5	5
<i>Theodoxus pallasi</i> Lindholm	30	5	-	10	-	-	-	-
Bcero:	6	6	6	6	6	4	5	5

Table 4. The long-term dynamics of the abundance and biomass of the dominant species and the whole macrozoobenthos of the Small Aral Sea.

Year	<i>H. diversicolor</i>	<i>A. ovata</i>	<i>C. isthmicum</i>	<i>Caspiohydrobia</i> sp.	Others	Total
	Abundance, spec./m ²					
2001	578 ± 172	3174 ± 1031	180 ± 63	294 ± 89	46 ± 19	4274 ± 1229
2002	1342 ± 261	2606 ± 888	264 ± 114	324 ± 140	4 ± 2	4540 ± 1084
2003	770 ± 105	1094 ± 650	105 ± 47	1302 ± 913	50 ± 21	3321 ± 1600
2004	292 ± 104	544 ± 182	154 ± 56	18 ± 10	6 ± 4	1014 ± 307
2005	339 ± 94	366 ± 194	70 ± 33	2 ± 2	4 ± 3	781 ± 210
2006	167 ± 51	359 ± 208	96 ± 82	0 ± 0	59 ± 24	681 ± 261
2007	194 ± 55	230 ± 71	4 ± 3	2 ± 2	12 ± 8	442 ± 73
2008	170 ± 28	318 ± 87	89 ± 35	22 ± 18	42 ± 21	641 ± 140
Average	482 ± 144	1086 ± 408	120 ± 28	246 ± 158	28 ± 8	1962 ± 624
Biomass, g/m ²						
1996	8.1 ± 1.6	90.0 ± 27.5	70.4 ± 22.8	1.1 ± 0.3	0.06 ± 0.02	169.7 ± 43.9
1997	6.6 ± 1.2	80.8 ± 30.2	37.3 ± 18.0	0.5 ± 0.2	0.02 ± 0.01	125.2 ± 40.7
1998	8.8 ± 1.6	101.8 ± 36.4	22.4 ± 12.6	1.1 ± 0.6	0.08 ± 0.04	134.2 ± 40.0
2000	3.9 ± 0.9	130.4 ± 25.6	53.9 ± 35.3	1.5 ± 0.6	0.0 ± 0.0	189.7 ± 41.9
2001	5.8 ± 2.2	138.0 ± 36.8	18.6 ± 15.7	1.2 ± 0.4	0.3 ± 0.2	206.7 ± 48.7
2002	7.8 ± 2.0	135.0 ± 39.7	47.8 ± 15.4	1.4 ± 0.6	0.04 ± 0.2	192.1 ± 53.8
2003	4.1 ± 0.7	50.8 ± 24.5	14.0 ± 7.3	25.4 ± 24.6	0.4 ± 0.2	94.7 ± 50.2
2004	1.3 ± 0.4	33.6 ± 14.7	15.3 ± 6.7	0.1 ± 0.04	0.2 ± 0.2	50.4 ± 18.6
2005	2.6 ± 0.6	19.5 ± 9.8	18.5 ± 8.7	0.01 ± 0.01	0.04 ± 0.2	40.7 ± 17.0
2006	1.1 ± 0.3	19.5 ± 8.0	17.5 ± 11.2	0 ± 0	0.5 ± 0.2	38.6 ± 15.0
2007	3.4 ± 1.2	18.4 ± 5.3	0.5 ± 0.4	0.01 ± 0.01	0.01 ± 0.1	22.3 ± 5.1
2008	4.2 ± 0.7	12.0 ± 3.5	4.0 ± 1.7	0.2 ± 0.2	0.02 ± 0.2	20.6 ± 4.9
Average	3.8 ± 0.8	53.4 ± 18.6	17.0 ± 5.0	3.5 ± 3.1	0.2 ± 0.1	83.3 ± 26.6

and $p < 0.05$.

The main part of quantitative variables of the community was formed by the background species listed above. The absolute leader during the observation period, except for 2003, was the bivalve *A. ovata*. It accounted for 46-60% of the abundance and 54-83% of the macrozoobenthos biomass. *H. diversicolor* and *C. isthmicum* were on the second place. In the perennial dynamics, there was a declining trend of the mollusk *C. isthmicum* in the total abundance (from 15% to 1%) and biomass (from 25% to 2%) of the benthic community.

To define the diversity of benthic community, the Shannon index was calculated. The average values of the diversity index, calculated by the share of species in the total abundance (Shannon

Ab) and the biomass of the community (Shannon Bi), over a number of years changed synchronously (Figure 2). The maximum values of both indices occurred in 2008, the minimum in 2007. According to the average perennial values of the Shannon index (1.20 ± 0.05 bits/specimen and 0.92 ± 0.07 bits/mg) the diversity of macrozoobenthos in the analyzed period was very low.

Discussion

The fauna of any water body is determined primarily by the salinity of water [30,31]. During our studies, with an average salinity of 6.3%-19.0%, the macrozoobenthos of the Small Aral Sea was represented by 10 taxa. This is significantly less than in the quasi-stable period, when macrozoobenthos included 39 species at an average salinity of 10.0% [10]. The background

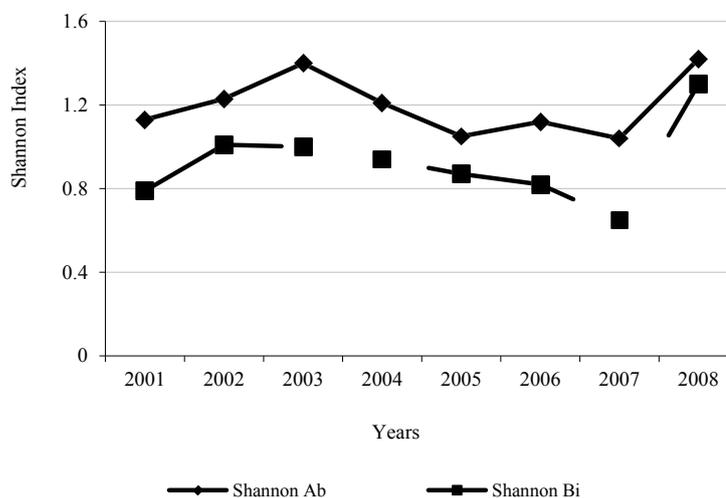


Figure 2. The long-term dynamics of the diversity of macrozoobenthos of the Small Aral Sea according to the Shannon index.

Table 5. Changes in the average values of macrozoobenthos biomass of the Aral Sea in different periods of its existence.

Period	Years	Salinity, %		Macrozoobenthos Biomass, g/m ²	
		Average	Min-Max	Average	Min-Max
Quasi-stable	1933-1964 [39]	10.1 ± 0.2	9.0-10.9	22.8 ± 1.5	17.9-40.6
Salinization	1961-1991 [10,39]	17.9 ± 2.4	11.5-33.8	124.0 ± 14.9	33.1-372.5
Stabilization	1992-2002[10]	19.6 ± 1.4	14.5-28.7	192.0 ± 14.9	125.3-246.0
Desalination	2003-2008	10.7 ± 0.8	6.3-12.9	42.1 ± 10.0	19.2-94.4

Note: 1933, 1986-2009 - Data is of Small Aral Sea only; Other years - Data is of entire water area of the sea.

species were polychaeta *Hediste diversicolor* Muller, amphipod *Dikerogammarus aralensis* Uljanin, Chironomidae larvae, mollusks of the genera *Dreissena*, *Cerastoderma*, *Caspihydrobia*, *Abra*, *Hypanis*, *Theodoxus*. Primary depletion in species composition of benthic invertebrates occurred at a salinity of 11.6%-13.7% [18,32,33]. Upon further salinization of the sea to 25%-28%, only species of marine origin - *Hediste diversicolor*, *Abra ovata*, *Cerastoderma isthmicum*, *Palaemon elegans*, *Rhitropanopeus harrisi* and halophilic representatives of the genus *Caspihydrobia* sp. remained in macrozoobenthos.

On average for 1996-2008, the abundance of macrozoobenthos was 1962 species/m², with a biomass of 83.3 g/m². Polychaete *H. diversicolor*, mollusks *A. ovata* and *C. isthmicum*, in some years together with *Caspihydrobia* sp. were dominant. Against the background of desalination of the Small Aral Sea from beginning to end of the observation period, the values of both parameters decreased by an order of magnitude from 4274 to 641 species/m² and from 206.0 to 20.6 g/m², respectively. When analyzing both our own and literature data (Table 5), we observed the positive effect of water salinity on the long-term dynamics of macrozoobenthos biomass. This is due to the dominance of the above-mentioned marine and euryhaline species in the benthic community. The polychaete *H. diversicolor* and the mollusk *A. ovata* were introduced into the Aral Sea in the 1960s and soon became one of the widespread species of benthic invertebrates [10]. For these introduced species, as well as for the aboriginal mollusk *C. isthmicum*, the increase in salinity, which began in the late 1960s - early 70s, turned out to be extremely favorable [34,35]. The decrease in the quantitative variables of macrozoobenthos during the desalination of the Small Aral Sea is explained not only by the deterioration of hydrochemical conditions for marine and halophilic species, but also by the increased pressure of fish on the benthic fauna [36].

It is likely that the observed decrease in the number and biomass of macrozoobenthos is only one of the stages of changing of the community structure. If the planned increase in the crest of Dike Kokaral by 6-8 m is done, a further decrease in the average salinity of the northern part of the sea will occur. As the level rises, the area of the desalinated water area will significantly expand, which will be a negative factor for marine and euryhaline species. Desalination will contribute to the emergence of the generative freshwater and brackish-water species in the benthic community of the Small Aral Sea, which currently remain in the delta of Syrdarya and its floodplain lakes [37,38].

Conclusion

In 1996-2008, the macrozoobenthos of the Small Aral Sea was represented by 10 taxa. The long-term average annual abundance of benthic invertebrates was 1962 species/m², with a biomass of 83.3 g/m². Marine and euryhaline species were prevalent - polychaete *H. diversicolor*, mollusks *A. ovata* and *C. isthmicum*, in some years together with *Caspihydrobia* sp. Against the background of desalination of the Small Aral Sea from 18.6-20.4% to 6.3%-11.8%, the quantitative variables of the community decreased by an order of magnitude from 4274 to 641 species/m² and from 206.0 to 20.6 g/m². According to the values of the Shannon index - 1.20 bits/specimen and 0.92 bits/mg - the diversity of macrozoobenthos in the analyzed period was very low. The positive relationship between the long-term variability of water salinity and quantitative variables of macrozoobenthos was due to the dominance of species of marine origin in its composition. The observed decrease in the quantitative variables of macrozoobenthos during the desalination of the Small Aral Sea is explained not only by the deterioration of hydrochemical conditions for marine and halophilic species, but also by the increased pressure of fish on the benthic fauna.

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