Modern state of the Small (Northern) Aral Sea fauna

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Abstract

The Aral Sea is a terminal lake lying within the deserts of Central Asia in Kazakhstan and Uzbekistan, draining the Amu Darya and Syr Darya rivers. Before the 1960s, it was a large brackish water lake with an average salinity of 10.3 g L^{-1}. The anthropogenic regression and salinization of the Aral Sea at that time resulted from increasing water withdrawals from the Amu Darya and Syr Darya for irrigation purposes. The salinization resulted in the disappearance of most of its invertebrates and all freshwater fish. As a result of the water level decrease, the Aral Sea divided into a northern Small Aral and a southern Large Aral at the end of the 1980s, with the two having different hydrological regimes. After construction the first Kokaral Dam in 1992, the water level of the Small Aral Sea increased by >1 m, with a gradual decline in the salinity beginning. To date, the Small Aral has again become brackish. Its average salinity reached 5.3 g L^{-1} by April–May 2013, with the highest salinity of 9.9 g L^{-1} in Butakov Bay, whereas the salinity was very low at 1.2–2.0 g L^{-1} in the estuary zone of the Syr Darya. There is an ongoing process of restoration of the former biodiversity, with many fresh water and brackish water invertebrate species reappearing due to the decreasing salinity. Freshwater fish species (bream, roach, carp, asp, zander, wels, etc.) returned into the Small Aral from the Syr Darya River and lakes in its lower reaches where they survived. Fisheries are recovering and catches are growing. Continuing salinity decreases, however, may cause decreases in the numbers, or even disappearance, of marine and halophilic invertebrate species. This study summarizes the results of studies of the Small Aral zooplankton, zoobenthos and ichthyofauna carried out in the spring of 2013. An historical review of changes in the Aral Sea and its fauna also is presented.

Key words

Aral Sea, salinity, invertebrate fauna, fish fauna, fishery.

INTRODUCTION

The Aral Sea is a terminal or closed basin (endorheic) lake, lying amidst the vast deserts of Central Asia in Kazakhstan and Uzbekistan. Its catchment area encompasses more than 2 million km^2. As an endorheic lake, it has only water inflows, but no outflow. Thus, the balance between inflows from the Amu Darya and Syr Darya rivers, direct precipitation on the lake surface and evaporation fundamentally determine its water level. In the recent past, the Aral Sea was a unique, giant continental brackish water body. The hydrological regime of the Aral Sea was in reasonable balance from the 1600s to the 1960s, with a level variation of no >3–4 m. The average water level from 1900 to 1960 was about 53 m a.s.l. (above sea level, as measured on the Kronstadt gage near St. Petersburg, Russia). The average surface area of the sea was about 67–68 thousand km^2 and the water volume was around 1090 km^3. The average salinity was 10.3 g L^{-1}. The annual river inflow was 56 km^3, with the Amu Darya providing 42 km^3 and the Syr Darya 14 km^3 (Bortnik & Chistyaevaya 1990). The Aral Sea was distinguished into two main parts, including the smaller northern (Small Aral) and the larger southern (Large Aral), with extended in latitudinal direction along Kokaral Island between. The Auzy-Kokaral and Berg Straits connected them.

The water level and salinity of the Aral Sea, as for other water bodies in arid zones, depend closely on its water balance, which depends not only on climate

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change, but also on human factors, mostly water withdrawals for irrigation. The hydrological regime of the Aral Sea was originally controlled by local climatic factors influencing run-off of its influent rivers. The Aral Sea was almost stable between 1911 and 1961. Major deterioration of the Aral Sea began in 1961, resulting from an increasing diversion of water from the Syr Darya and Amu Darya for irrigated agriculture, thereby considerably reducing the inflows from these rivers to the Aral Sea. It averaged only about 5 km^3 yr^{-1} during 1981 to 1990 (Micklin 2014b). Thus, the dramatic increase in withdrawals from these rivers for irrigation seriously upset the equilibrium of the water balance, resulting in a rapid drop in the water level, a reded areal extent and increased salinity of the Aral Sea (Bortnik & Chistyaevaya 1990). The sea's hydrological and salinity changes since 1960 are summarized in Table 1.

This study discusses the results of new field studies carried out in the spring of 2013 of the Small Aral hydrology, zooplankton, zoobenthos and ichthyofauna. An historical review of changes in the Aral Sea and its fauna also is provided.

MATERIALS AND METHODS

Studies of the Small Aral Sea were carried out in April–May 2013. They included not only hydrobiological and ichthyological studies, but also hydrological and hydrochemical surveys. Materials were collected at 11 ichthyological, 20 hydrobiological and 20 hydrochemical stations (Fig. 1). For the analysis of hydrological regimes, data of the State Hydrometeorological Service were used. Electrochemical analyzer Consort C932 was employed in the field to measure water temperature, salinity, dissolved oxygen and pH. Levels of carbon dioxide and organic matter (permanganate index) were also measured analytically in the field. Hydrochemical parameters – concentration of main ions and nutrients – were determined analytically in the laboratory according to conventional methods and standards (Alekin 1959; Semenov 1977; Borisov *et al.* 2003).

Forty four hydrobiological samples from 21 sampling sites were collected in 2013 and fixed in 4% formaldehyde. Zooplankton was sampled using nets made from gauze sieve No. 61. This was carried out in shallow waters by filtering 100 L of water through an Apstein plankton net, and by pulling a Juday plankton net from

Table 1. Hydrological and salinity characteristics of Aral Sea, 1960–2013

Year and portion of sea	Level (m.a.s.l)	Area (km^2)	Per cent of 1960 area	Volume (km^3)	Per cent of 1960 volume	Average depth (m)	Average salinity (g L^{-1})	Per cent of 1960 salinity
1960 (all)	53.4	67 499	100	1089	100	16.1	10	100
Large	53.4	61 381	100	1007	100	16.4	10	100
Small	53.4	6118	100	82	100	13.4	10	100
1971 (all)	51.1	60 200	89	925	85	15.4	12	120
1976 (all)	48.3	55 700	83	763	70	13.7	14	140
1989 (all)	NA	39 734	59	364	33	9.2	NA	NA
Large	39.1	36 930	60	341	34	9.2	30	300
Small	40.2	2804	46	23	28	8.2	30	300
Sept 22, 2009 (all)	NA	7146	10.6	83	7.7	10.8	NA	NA
W. Basin Large	27	3588	ND	56	5.7	15.1	>100	>1000
E. Basin Large	27	516	NA	0.64	NA	0.7	>150	>1500
Tshche-Bas Gulf	28	292	ND	0.51	ND	~85	850	
Small	41.5	2750	45	27	33	9.8	10–13	100–130
Oct 19, 2013 (all)		7648	11.3	83	7.7	8.1	NA	NA
W. Basin Large	26.5	3279	ND	54	5.6	13.5	>100	>1000
E. Basin Large	26.2	770	NA	3.0	NA	1.3	>150	>1500
Tshche-bas Gulf	28.5	372	ND	0.72	ND	1.4	84	840
Small	42	3227	52.7	27.5	33.5	8.5	8–10	0.8–1

Sources: (1) Data for 1960–1989 from Micklin (2010); (2) data for 2009 and 2013: areas calculated from MODIS 250-m resolution natural colour images; volume data author estimates; salinity data for 2009 author estimates based on measurements from Aral Sea expedition in September 2007; 2008 salinity data provided by N. Aladin, Zoological Institute, Russian Academy of Sciences, St. Petersburg, Russia; 2013 salinity data based on measurements taken during Aral Sea expedition in August and September 2011.

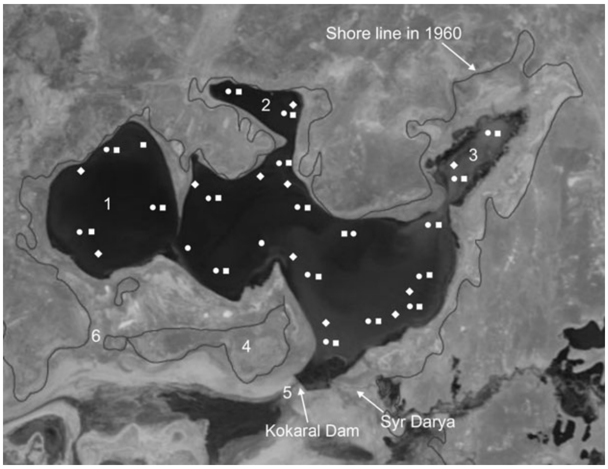

Fig. 1. Small Aral Sea, 19 August 2014 (MODIS 250 m, true colour images, bands 1-4-3; 1, Saryshiganak Bay; 2, Butakov Bay; 3, Shevchenko Bay; 4, Kokaral Island; 5, Berg Strait; 6, Auzy-Kokaral Strait; Sampling sites: ♦, ichthyological; ●, hydrobiological; ■, hydrochemical).

the bottom to the surface for depths greater than 2 m. Zoobenthos was collected with a Petersen sampler ($S = 0.025\ m^2$), followed by washing the collected materials through a gauze (No. 36) and No. 50 sieve. Microbenthos and a part of meiobenthos (e.g. protozoans, turbellarians, nematodes, ostracods), as well as vage macrobenthos (i.e. actively moving malacostracan crustaceans such as mysids and shrimp), were not collected by these techniques (being obtained in samples only by chance) because they needed special sampling. Samples were analysed in the laboratory using conventional methods (Winberg & Lavrenteva 1984; Sharapova & Falomeeva 2006). Taxonomic composition of samples was determined, identifying mainly to species or, in some cases, to genera. Zooplankton was examined in a Bogorov chamber with microscopes MBS-10 and MS-300. Planktonic and benthic invertebrates were identified and counted. Quantitative analysis (abundance and biomass) was performed according to species and groups of invertebrates. Biomasses of planktonic invertebrates were calculated by their standard weights. Biomasses of benthic organisms were determined with a torsion balance.

Ichthyological material was examined in the field, using research catches from 10 sampling sites, also using commercial catches. The material was analysed with conventional methods (Chugunova 1950; Pravdin 1965). Fixed nets were used for fish, with more than 1900 specimens of 14 fish species being used for biological analysis, and another 4845 individuals used for different measurements.

Archive data of aquatic invertebrates and fish faunas were used for analysing the long-term data on hydrology and chemical conditions.

RESULTS

Historical review

By 1988–1989, when the Aral Sea water level declined from +53 m to +40 m a.s.l., the Berg Strait dried up (Auzy-Kokaral Strait had dried up earlier). The total area of the sea at that time was reduced from 67 500 km^2 in 1960 to 40 000 km^2, the volume from 1089 to 333 km^3 and the average salinity in both the Small and Large Aral increased from 10 to 30 g L^{-1} (Table 1). As a result, the Aral Sea separated into two lakes, namely the southern Large Sea and the northern Small Sea. However, a channel (earlier dredged in the bottom for navigation in the shoaling Berg Strait) continued to connect them. The flow of the Syr Darya into the Small Sea stabilized its level, and even gave it a somewhat positive water balance with surplus water flowing from the higher-level Small Sea towards the lower-level Large Sea through this channel on the dried bottom of Berg Strait (Aladin & Plotnikov 2008; Micklin 2014b).

After the division of the Aral Sea into a smaller northern sea and smaller southern sea, changes in the hydrological–hydrochemical regimes of these two lakes occurred independently. Since its separation, the Small Aral Sea has exhibited a positive water balance and its level has stabilized. The salinity increase has not only stopped, but substantially declined. In contrast, the water balance of the Large Aral Sea remained negative, with the drying of the lake and a continuing salinity increase (Table 1) attributable to the greatly diminished inflow of the Amu Darya to the sea (Micklin 2014b). As a result, the biota between the two seas began to differ (Aladin & Plotnikov 2008).

A low earthen Kokaral Dam was built in the dried-up Berg Strait in 1992, in order to prevent the outflow of water from the Small Aral to the Large Aral, as well as to increase and stabilize the water level and to decrease the salinity. The level of the Small Aral increased >1 m, and the salinity declined (Aladin *et al.* 1995). This dam was not durably constructed, however, and had no spillway. Accordingly, it was breached every time during the spring level rise and after it was rebuilt. It was finally destroyed by a storm in the spring of 1999 (Micklin 2014a).

In 2004, construction of an engineeringly sound Kokaral Dam in Berg Strait began. It was the implementation of the project, 'Regulation of Syr Darya River bed and the northern part of the Aral Sea', within the framework of the programme, 'Concrete actions for the improvement of the ecological situation in the Aral Sea basin'. The work was completed in autumn 2005, and the new dam had a spillway for the discharge of excess water and for maintaining the level of the regulated Small Sea at a safe level. After closing the gates, the water level of the Small Aral reached the design height of +42 m a.s.l. by spring 2006 because of a large winter flow on the Syr Darya (Micklin 2014a).

The level of the regulated Small Aral Sea is determined by the water regime of its main influent, the Syr Darya, which is very irregular in its annual inflows. The Small Aral seasonally fluctuates by 0.5 m. Its maximum level of about +42.5 m a.s.l. occurs in mid-April because of large winter releases from the Syr Darya, with the minimum (about +42.0 m a.s.l.) occurring in the winter.

The Small Sea has again become a brackish water body. The average salinity of the Small Sea in April–May 2011 was 9.9 g L^{-1}. In the highly isolated Butakov Bay, which exhibits a weak water exchange with the main part of the Small Aral, the salinity was higher at 11 g L^{-1}. The lowest salinity value of 6.3 g L^{-1} was typical of the area located at the mouth of the Syr Darya and near the Kokaral Dam (Table 13.1; Micklin *et al.* 2014). These both are influenced by low-salinity river discharges. The salinity continued decreasing, reaching an average value of 5.3 g L^{-1} by April–May 2013, lower than it was before the beginning of the recent deterioration and salinization of the Aral Sea. As before, the highest salinity value of 9.9 g L^{-1} was recorded in Butakov Bay. The salinity in the estuary zone was very low at 1.2–2.0 g L^{-1} due to the inflow of fresh riverine water.

Unlike the water balance of the Small Aral Sea, the water balance of the Large Aral remains negative. Water from the Amu Darya reaches it irregularly, and the water level continues to decline and the salinity to increase. The Large Sea had turned into a hyperhaline water body by the end of the 1990s (Aladin & Plotnikov 2008).

The invertebrate fauna of the Aral Sea exhibited a low species diversity. Earlier there were at least 180 free-living species, excluding Protozoa. Species originating from fresh water, brackish water and saline continental water bodies predominated in the fauna. The remainder represented Ponto-Caspian and marine Mediterranean–Atlantic faunas. The fauna endemism was very low. Only three species each of Harpacticoida and of Turbellaria are considered endemic. There also were some endemic subspecies of Mollusca and Crustacea (Mordukhai-Boltovskoi 1974).

Invertebrate species were introduced in the Aral Sea in 1954–1970. It was already clear in the 1940s that the planned hydroconstruction and development of irrigation in the Aral Sea Basin inevitably would lead to a reduced river flow and, as a result, related increases in the Aral salinity. As a result of the prevalence of mainly freshwater or brackish water species, many were expected to become extinct due to salinization. Thus, it was necessary to create more euryhaline and salinity-resistant fauna by acclimatization of suitable brackish water and marine species (Karpevich 1975; Aladin *et al.* 2004).

The first free-living invertebrate introduced was the shrimp *Palaemon elegans* Rathke. It was incidentally brought from the Caspian Sea in 1954–1956 during the unsuccessful acclimatization of mullets, resulting in the disappearance of the native amphipod *Dikerogammarus aralensis* Uljanin (Karpevich 1975; Micklin 2014b).

The intentional acclimatization of invertebrates as food for fishes to the Aral Sea started in 1958 (Karpevich 1975; Aladin *et al.* 2004). The first invertebrates introduced in 1958–1960 were relict Ponto-Caspian mysids *Paramysis lacustris* (Czerniavsky), *P. intermedia* (Czerniavsky) and *P. ullskyi* (Czerniavsky) (Kortunova 1970; Karpevich 1975). In 1960–1961, the Mediterranean–Atlantic, euryhaline polychaete worm *Hediste diversicolor* (Müller) and, in 1960–1963, the Mediterranean–Atlantic bivalve mollusc *Syndosmya segmentum* Récluz also were introduced from the Sea of Azov. The highly productive marine planktonic crustacean *Calanipeda aquaedulcis* Kritschagin was successfully introduced from the Sea of Azov in 1960–1965 (Karpevich 1975). The introduced marine euryhaline species of invertebrates in the 1960s not only expanded the food base for fish, but also generally replaced the native species in the 1970s that were first reduced in numbers and then disappeared (Plotnikov 2013; Plotnikov *et al.* 2014).

The free-living invertebrate fauna of the Aral Sea was completely changed from the 1960s to 1980s, and the species diversity decreased in this period, mainly because of an increased salinity. Predation by, and competition from, some of the introduced invertebrates and fishes also played a role in the loss of native species. The result was that the free-living invertebrates *Arctodiaptomus salinus* (Daday), *Moina mongolica* Daday, *Dikerogammarus aralensis* (Uljanin) disappeared, although not because of salinity increases (Plotnikov 2013; Plotnikov *et al.* 2014).

The first to disappear because of salinity were the highly diverse freshwater invertebrate species. The next to disappear were Ponto-Caspian brackish water species. By the time the Aral Sea separated into two seas, only marine fauna and fauna of the continental saline waters persisted. Most rotifer species, Copepoda and Ostracoda, all species of Cladocera, all species of Oligochaeta, larval Chironomidae, all molluscs (*Dreissena* spp., *Hypanis* spp., *Theodoxus pallasi* Lindholm) and all species of mysids died out (Plotnikov 2013; Plotnikov *et al.* 2014).

Of the free-living invertebrate species, only rotifers *Synchaeta* spp. and a few species of copepods *Calanipeda aquaedulcis*, *Halicyclops rotundipes aralensis* Borutzky, and several species of harpacticoids, nematodes, bivalves *Cerastoderma isthmicum* Issel and *Syndosmya segmentum*, gastropods *Caspiohydrobia* spp., ostracods *Cyprideis torosa* (Jones), polychaete worm *Hediste diversicolor* and the shrimp *Palaemon elegans* still persisted in the Small Aral Sea. In the heavily depleted fauna of free-living invertebrates, the euryhaline species of marine origin and euryhaline halophiles of continental waters chiefly survived (Plotnikov 2013; Plotnikov *et al.* 2014).

The continued rapid salinity increase in the Large Aral resulted in rapid changes in the composition of all its biota. The lake became hyperhaline by the end of the 1990s, with most species disappearing. A number of invertebrates from other saline water bodies colonized the lake by natural means (Aladin & Plotnikov 2008; Plotnikov *et al.* 2014).

Soon after the separation of the Aral Sea into two parts, when the salinity decrease in the Small Aral began (but before construction of the first dam regulating flow between the two parts), *Podonevadne camptonyx* (Sars), a crustacean that had gone extinct in the 1980s, reappeared apparently from its still-dormant eggs. The benthos larval Chironomidae were again found in 1999, having not been encountered for 25 years since 1974 (Aladin *et al.* 2000; Plotnikov 2013; Plotnikov *et al.* 2014).

The decreased salinity of the Small Aral and its restoration as a brackish water body, as well as the appearance of a large strongly freshened zone, created conditions in it for the return of invertebrate species that had previously disappeared because of salinization. As a result, an ongoing process of natural reintroduction of the invertebrates from the rivers, upstream lakes, and by bird dispersal of eggs, began in the 1990s. Recovery of some species can occur because of their dormant stages of development, which can sustain viability until environmental conditions again become favourable (Plotnikov 2013; Plotnikov *et al.* 2014).

Zooplankton

Just as in the early 1990s, zooplankton in the Small Aral Sea was represented in the spring of 2013 by the euryhaline rotifers *Synchaeta* spp., *Keratella quadrata* (Gosse), *K. cochlearis* (Gosse), *Brachionus quadridentatus* Hermann, *B. plicatilis* Müller, *Notholca acuminata* Ehrenberg, *Hexarthra oxyuris* (Zernov), and the cladoceran *Podonevadne camptonyx* and the copepod *Calanipeda aquaedulcis* (Table 2). As a result of a significantly decreased average salinity, and the appearance of an extensive freshwater zone in the north-eastern part, an increase in biodiversity of planktonic invertebrates was initiated by natural reintroduction of some species that had gone extinct because of salinization. Such freshwater species as rotifers *Filinia longiseta* (Ehrenberg), *Asplanchna priodonta* Gosse and *Brachionus calyciflorus* Pallas reappeared.

The planktonic crustacean biodiversity has increased significantly to the present time. As a result of natural reintroduction into the Small Aral, freshwater crustaceans that have reappeared include *Bosmina longirostris*

Table 2. Taxonomic composition and frequency of occurrence of Small Aral Sea zooplankton in 2011–2013

Taxon	Occurrence (%)		
	2011	2012	2013
Rotifera			
Asplanchna priodonta Gosse	–	5	5
Synchaeta spp.	50	60	74
Keratella quadrata (Gosse)	68	77	74
Keratella cochlearis (Gosse)	–	–	5
Brachionus quadridentatus Hermann	41	40	26
B. calyciflorus Pallas	–	9	26
B. plicatilis Müller	23	40	68
Notholca acuminata Ehrenberg	5	5	5
Filinia longiseta (Ehrenberg)	23	27	–
Hexarthra oxyuris (Zernov)	5	36	37
Cladocera			
Bosmina longirostris (Müller)	10	18	21
Chydorus sphaericus (Müller)	15	23	26
Moina mongolica Daday	10	9	–
Ceriodaphnia reticulata (Jurine)	15	36	21
Diaphanosoma brachyurum (Lievin)	–	–	5
Podonevadne angusta (Sars)	5	5	–
P. camptonyx (Sars)	10	5	37
Evadne anonyx Sars	73	73	79
Copepoda			
Phyllodiaptomus blanci (Guerne et Richard)	14	14	11
Calanipeda aquaedulcis Kritschagin	100	100	100
Cyclops vicinus Uljanin	60	86	79
Mesocyclops leuckarti (Claus)	20	23	26
Acanthocyclops viridis (Jurine)	28	36	32
Harpacticoida gen. sp.	25	14	26

(Müller), *Chydorus sphaericus* (Müller), *Diaphanosoma brachyurum* (Lievin), *Ceriodaphnia reticulata* (Jurine), *Podonevadne angusta* (Sars), *Evadne anonyx* (Sars) and copepods *Phyllodiaptomus blanci* (Guerne et Richard), *Cyclops vicinus* Uljanin, *Mesocyclops leuckarti* (Claus) and *Acanthocyclops viridis* (Jurine). The cladoceran *Moina mongolica* that was lost in the early 1970s because of biotic reasons rather than by increased salinity was also again found. It reappeared in a natural way by the end of the 1990s. The marine copepod *Halicyclops rotundipes aralensis* was not found. It never was numerous, however, even when the salinity was high. As a result of low salinity, this species numbers have either currently decreased or this crustacean has even disappeared.

The most common planktonic invertebrate species in the Small Aral now are the rotifers *Synchaeta* spp., *Keratella quadrata*, *Brachionus quadridentatus*, *B. plicatilis*; cladoceran *Evadne anonyx*; and the copepods *Calanipeda aquaedulcis* and *Cyclops vicinus* (Table 2). As before, copepods dominate the zooplankton in the Small Aral, accounting for 76% and 91% of abundance and biomass, respectively, in the spring of 2013. Among the copepods, *Calanipeda aquaedulcis* remains dominant, accounting for >50% of both zooplankton abundance and biomass. A subdominant group is rotifers. In the spring and summer, bivalve larvae currently remain a major permanent component of the Small Aral meroplankton (i.e. temporary pelagic larvae of benthic invertebrates). These are mainly the larvae of *Syndosmya segmentum,* and some of *Cerastoderma isthmicum*. Larvae of the polychaete worm *Hediste diversicolor* are also encountered. Meroplankton comprised about 10% of the abundance and 4% of biomass of zooplankton in the spring of 2013.

Zooplankton distribution in the Small Aral Sea is uneven (Figs 2, 3). The zooplankton density was minimum in Shevchenko Bay, and in the central and north-eastern parts of the sea. Zooplankton abundance and biomass in Butakov and Saryshiganak bays were high. Butakov Bay also exhibited high values of abundance and biomass of larval bivalves, which formed the basis of meroplankton. Cladoceran densities were high in Butakov Bay, and near the mouth of the Syr Darya.

Zoobenthos

As in the early 1900s, the benthic fauna of the Small Aral Sea (Table 3) in 2013 included the polychaete worm *Hediste diversicolor*, bivalves *Syndosmya segmentum* and *Cerastoderma isthmicum*, gastropods *Caspiohydrobia* spp., and shrimp *Palaemon elegans*. The decreased average salinity of the Small Aral Sea, and the forming of an extensive freshwater zone, created favourable conditions for a higher zoobenthos biodiversity attributable to the natural reintroduction of species that had disappeared due to increased salinity, but which has persisted in nearby water bodies.

Mysids have returned to the Small Aral from the lower reaches of the Syr Darya. Thus far, however, only one species (*Paramysis intermedia*), located in Shevchenko Bay, has been identified. Reintroduction of the bivalve mollusc *Dreissena polymorpha aralensis* (Andrusov) has occurred in the strongly freshened area of the sea. The increase in species diversity of larval chironomids was most significant, with there now being at least eight species of them (Table 3), although these lists are only tentative as the low abundance in the number of species may have resulted in their underestimation.

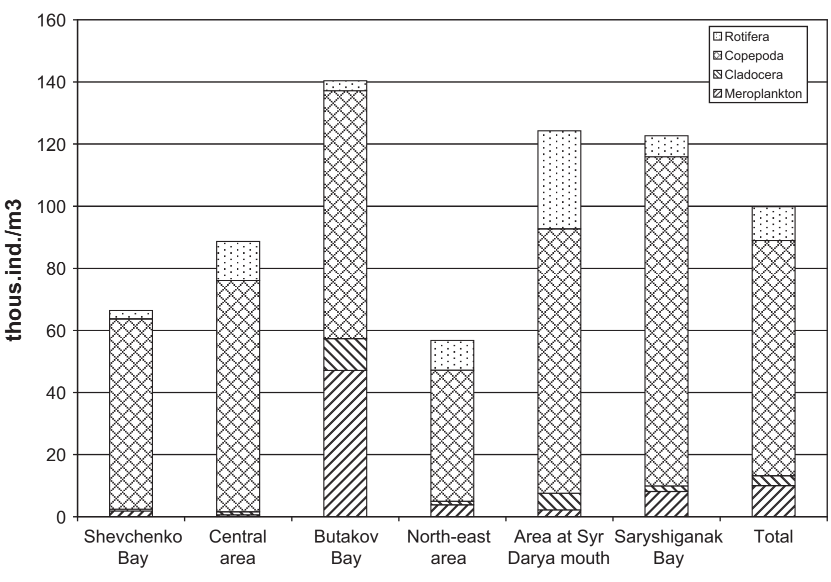

Fig. 2. Numbers of Small Aral Sea zooplankton in 2013.

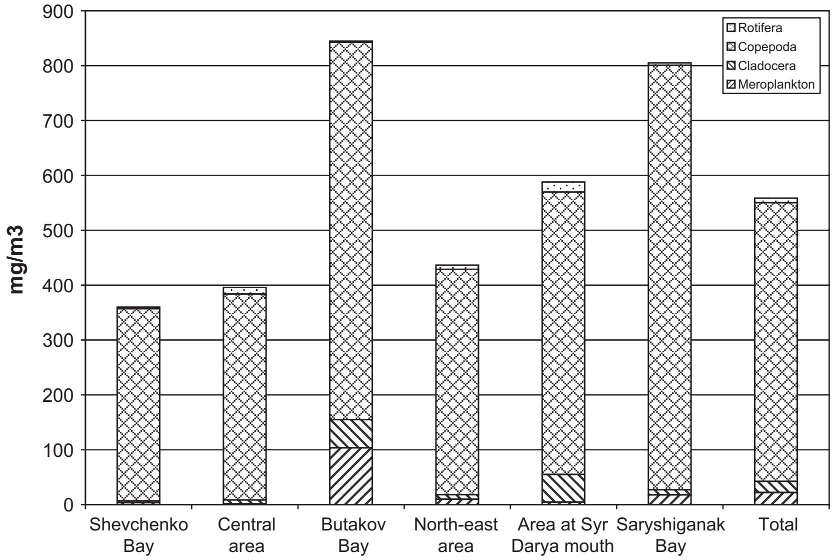

Fig. 3. Biomass of Small Aral Sea zooplankton in 2013.

Table 3. Taxonomic composition and frequency of occurrence of Small Aral Sea zoobenthos in 2012–2013

Taxon	Occurrence (%) 2012	2013
Polychaeta		
Hediste diversicolor (Müller)	86	80
Insecta: Diptera		
Chironomus behningi (Goetghebuer)	25	18
Chironomus sp.	–	36
Ch. plumosus (Linne)	50	50
Glyptotendipes gripekoveni (Kieffer)	–	10
Cryptochironomus sp.	30	5
Cladotanytarsus sp.	–	8
Tanypus villipennis (Kieffer)	–	8
Tanytarsus sp.	17	8
Ceratopogonidae gen. sp.	–	18
Mollusca: Bivalvia		
Syndosmya segmentum Récluz	60	46
Dreissena polymorpha aralensis (Andrusov)	5	4
Cerastoderma isthmicum Issel	25	4
Mollusca: Gastropoda		
Caspiohydrobia spp.	5	–
Crustasea		
Paramysis intermedia (Czerniavsky)	–	4
Palaemon elegans Rathke	5	–

Despite the decreased salinity, there are presently no oligochaetes in the Small Aral. These worms had already completely disappeared from the lake in the mid-1970s, due possibility to both an increased salinity and the appearance of the polyhaete *Hediste diversicolor*. This worm presumably can eat oligochaetes, as it does larval chironomids (Micklin 2014b). If so, the presence of polyhaetes can prevent reintroduction of oligochaetes.

The main components of zoobenthos are currently, as in the early 1990s, the polychaete worm *Hediste diversicolor* and bivalve molluscs. The larvae of chironomids have also been added to this number (Figs 4, 5).

The *H. diversicolor* was dominant in the spring of 2013, based on the frequency of its occurrence. The bivalve mollusc *Syndosmya segmentum* (46%) and chironomid larvae (55%) (Table 3) were subdominant. Larval chironomids dominated the zoobenthos, being 44% of the total. The bivalve mollusc *S. segmentum* dominated the biomass, being about 60% of the total. Both the larval chironomid density and biomass doubled from 2012 to 2013. The mean macrozoobenthos density and biomass in 2013 were 751 ind m^{-2} and 32 g m^{-2}, respectively.

A significant decrease in the numbers of common benthic invertebrates was noted, namely the marine bivalve *Cerastoderma isthmicum*, and especially the gastropods *Caspiohydrobia*, representing the continental saline waters' fauna. These changes can be associated with freshening of the Small Aral Sea below the salinity considered normal before the recent manmade impacts.

There is a non-uniform distribution of zoobenthos density and biomass over the Small Aral Sea (Figs 4, 5). The maximum densities occur in Butakov Bay, with the polychaete worm *Hediste diversicolor* being dominant, whereas the bivalve mollusc *Syndosmya segmentum* accounts mainly for the total zoobenthos biomass. Low levels of zoobenthos in the Syr Darya estuary zone are likely attributable to both abiotic and biotic factors,

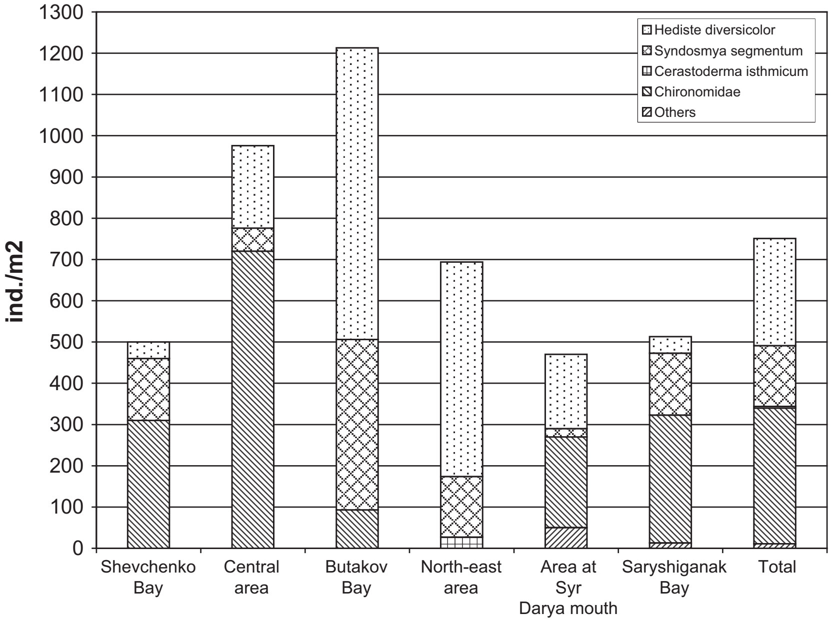

Fig. 4. Numbers of Small Aral Sea zoobenthos in 2013.

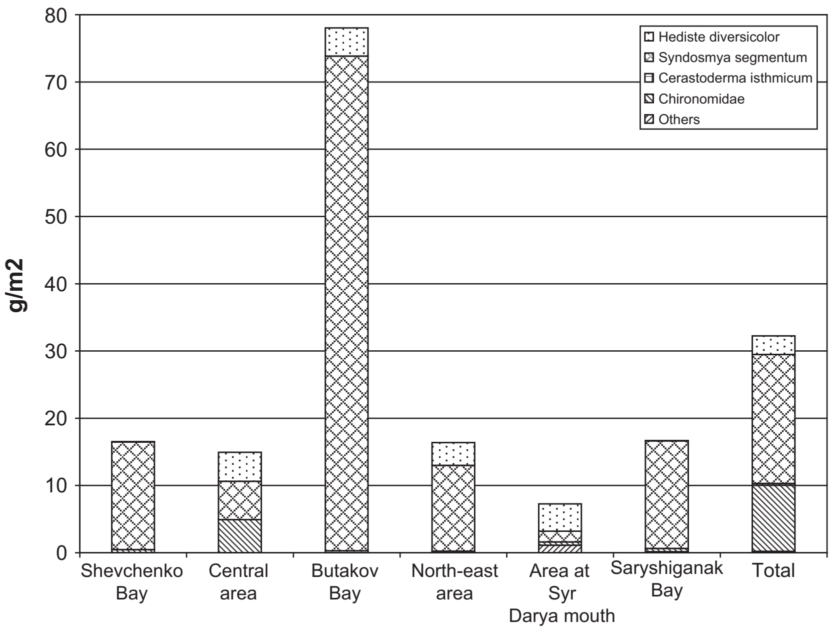

Fig. 5. Biomass of Small Aral Sea zoobenthos.

including a decreased salinity, bottom instability in the zone of mixing of saline and fresh water and predation by fishes.

Ichthyofauna

The indigenous ichthyofauna of the Aral Sea included 20 species from seven families (Acipenseridae, Salmonidae, Esocidae, Cyprinidae, Siluridae, Percidae and Gasterostidae), with the family Cyprinidae being richest in species. Endemic fish genera or species (endemism) are only known on the subspecies level (Nikolsky 1940). The modern ichthyofauna of the Small Aral Sea consists of 32 species, both native and introduced.

The original ichthyofauna of the Aral Sea is represented by freshwater species. Their reproduction typically occurs in fresh water, although they can also spawn in brackish water. All the native fishes in the Aral Sea migrated into the coastal zone or into the rivers for their reproduction. Two species were anadromous, namely the Aral salmon *Salmo trutta aralensis* Berg and the ship sturgeon *Acipenser nudiventris* Lovetzky. Most indigenous fishes were benthophages, with only some being piscivorous predators (pike, zander, wels, asp, salmon). The only aboriginal fish, whose main diet is zooplankton, is the nine-spined stickleback *Pungitius platygaster aralensis* (Kessler). Almost all the Aral Sea autochthonous fish, except ruff *Gymnocephalus cernuus* (Linnaeus) and stickleback, have commercial value. The main objects of the fishery were bream, carp, roach and zander. The perch *Perca fluviatilis* Linnaeus is present in small numbers, with its fishery value being very low. Only 18 species of local fish remain in the Aral, with the anadromous aral salmon and ship sturgeon now being extinct.

Some attempts were made to introduce new commercially important fish species into the Aral Sea between 1927 and 1963, with not all being successful. Moreover, together with the commercial fishes (grass carp, silver carp, bighead carp and snakehead), non-commercial fish species were accidentally introduced, including Caspian atherine (*Atherina boyeri caspia* Eichwald from the family Atherinidae); bubyr goby or transcaucasian goby (*Pomatoschistus caucasicus* Berg), sand goby (*Neogobius fluviatilis pallasi* (Berg)), round goby (*Neogobius melanostomus affinis* (Eichwald)), syrman goby (*Neogobius syrman eurystomus* (Kessler)), tubenose goby (*Proterorchinus marmoratus* (Pallas)) and bighead goby (*Neogobius kessleri gorlap* Iljin) from the family Gobiidae. All these non-commercial fish are undesirable exotic species. Baltic herring (*Clupea harengus membras* (Linnaeus)) was introduced in 1954–1959 as a commercial fish, although this planktophage did not become an object for the fishery (Karpevich 1975). Thus, 14 new fish species naturalized in the Aral Sea.

Declining Aral Sea water levels, increased salinity and drying of the deltas significantly altered the living conditions of the fishes, especially for their reproduction. It also impacted the state of the commercial fishery, with the spawning conditions for semi-anadromous fishes worsening significantly during the late 1960s. Signs of the negative effects of salinity on adult fishes first appeared in 1971. By the mid-1970s, when the average salinity of the sea exceeded 14 g L^{-1}, the natural reproduction of Aral fishes came to a standstill, with recruitment of many fish species being nearly absent, and commercial fish catches across the Aral Sea decreasing to less than one-fourth of their predesiccation level. By 1981, when the salinity exceeded 18 g L^{-1}, the Aral Sea had completely lost its commercial fishery. The ichthyofauna consisted of native stickleback and alien gobies, atherine and Baltic herring. Native commercial fish survived only in the Syr Darya and Amu Darya rivers and in the floodplain deltaic lakes (Ermakhanov *et al.* 2012).

Flounder-gloss (*Platichthys flesus* (Linnaeus)) from the Sea of Azov was successfully acclimatized to the Aral Sea during 1979–1987 to preserve its fishery (Lim 1986), remaining the only commercial fish in the Aral Sea from 1991 to 2000. By the end of the 1990s, the salinity of the Large Aral reached 60–70 g L^{-1}, resulting in the complete loss of all fish in that part of the Aral Sea (Ermakhanov *et al.* 2012).

After construction of the Kokaral Dam, and resulting stabilization of the Small Aral hydrological regime, decreasing salinity and appearance of a freshened zone in front of the new Syr Darya Delta, the freshwater commercial fish began returning little by little from the Syr Darya and its lacustrine systems. Over time, the freshwater fish fauna increased its spawning and feeding zones, promoting the numbers of commercial fish, including such food fish species (Fig. 5) as carps, bream, zander and asp (Ermakhanov *et al.* 2012).

Commercial ichthyofauna of the Small Aral Sea is now represented by 22 species, including pike, bream, white-eye bream, asp, common carp, grass carp, silver carp, sabrefish, Aral roach, rudd, wels, pike, snakehead and flounder. These species are briefly described below.

Pike (*Esox lucius* Linnaeus) is a piscivorous predator, but is not numerous. The age structure in 2013 was represented by eight generations from 1 to 8 years, with age groups 5 and 6 dominating. The population is in a dynamic state and normal range, indicating a satisfactory condition. In experimental catches in 2013, the body length ranged from 25 to 65 cm, with an average of 44 cm. The weight was from 130 to 2520 g, with an average of 886 g.

Bream (*Abramis brama orientalis* Berg). The high adaptive abilities of this species, especially to changing environmental conditions, provide its sustainable economic importance. While bream is a typical benthophage, it can eat plants and plankton. The temperature regime of the sea and the presence of reeds and underwater vegetation are favourable for intensive spawning of bream. The age structure in 2013 was represented by 10 generations ranging from 1 to 10 years, with the ages from 5 to 7 predominating. Bream spawns on vegetation in brackish areas of the sea, in deltaic water bodies, and even in marine spawning grounds where there is no inflow of fresh water. Bream arrives at its spawning grounds in late April and May. The 2013 catches indicated the body length ranged from 13 to 42 cm, with an average length 28 cm. The weight varied from 38 to 1470 g, with an average of 479 g.

White-eye bream (*Abramis sapa aralensis* Tjapkin), a benthophage, is not numerous. The age structure in 2013 was represented by five generations ranging from 1 to 6 years, with the ages 4 and 5 years predominating. The 2013 catches indicated the body length ranging from 17 to 26 cm, with an average of 21 cm. The weight ranged from 80 to 225 g, averaging 163 g.

Asp, zherekh (*Aspius aspius iblioides* (Kessler)) is a predator, with fish fry and crustaceans dominating its diet. This semi-anadromous fish feeds in the sea and spawns in the Syr Darya River into which it migrates up to the Kyzylorda Dam in October–November for reproduction. Asp lays eggs in stony places and between roots of plants. Spawning occurs immediately after the start of ice cover melting, with the spawners then migrating back to the sea. Due to the freshening of the Small Aral in recent years, the habitat area of asp has significantly changed. Although asp was found only in the mouth area of the Syr Darya in 2001–2004, its habitat area had spread almost all over the lake in 2005, except for Butakov Bay, where it appeared in 2008. The 2013 fish catch showed six generations representing 2- to 7- year-old classes, with the 4-year-old fish being predominant in the catches. The body length of the fish ranged from 30 to 53 cm, with an average length of 40 cm. Its body weight ranged from 365 to 2105 g, averaging 965 g per fish.

Common carp (*Cyprinus carpio aralensis* Spitshakow) is a benthophage, with a diet including bivalves, worms and insect larvae, as well as vegetation and detritus. The fish spawns (peak value) in mid-May, although it continues from April to July. *Cyprinus* lays eggs in underwater vegetation, with the presence of reeds and underwater vegetation almost over the entire Small Aral being favourable for its spawning. The 2013 age structure revealed nine generations varying from 1- to 9-year classes, with the age groups from 2 to 5 predominating. Experimental catches in 2013 showed a body length ranging from 18 to 56 cm, with an average length of 32 cm. The weight per individual fish varied from 135 to 3925 g, averaging 980 g.

Grass carp (*Ctenopharyngodon idella* (Valenciennes)) were introduced into the Aral Sea in 1960–1961. Its stocks are currently small, being concentrated in the sea near the mouth of the Syr Darya. The fish is herbivorous, feeding on higher aquatic plants, submerged terrestrial vegetation, and on detritus, insects and other invertebrates. The age structure of fish in the 2013 catch showed six generations ranging from 3 to 8 years, with the age group 7 predominating. Based on 2013 fish catches, the body length ranged from 29 to 70 cm, averaging 52 cm. The weights ranged from 800 to 7160 g, averaging 3600 g.

Silver carp (*Hypophtalmichthys molitrix* (Valenciennes)) was introduced into the Aral Sea in 1960–1961. It is a filter feeder, consuming phytoplankton, zooplankton and detritus. The fish are concentrated in the sea near the Syr Darya mouth, with only small stocks. The 2013 age structure comprised six generations ranging from 1- to 6-year classes, with the age groups 1 and 2 predominating. The 2013 catches had body lengths ranging from 30 to 76 cm, with an average fish length of 52 cm. The fish weights ranged from 450 to 7250 g per fish, with the population average fish weight being 2878 g.

Bighead carp, spotted silver carp (*Aristichtys nobilis* (Richardson)) was introduced into the Aral Sea in 1960–1961. It is a filter feeder, consuming phytoplankton, zooplankton and detritus. It is rare in the Aral Sea, with its stocks being rather small for body length and weight estimations.

Sabrefish (*Pelecus cultratus* (Linnaeus)) is an adaptable euryphage, feeding mainly on planktonic crustaceans, larvae and imagoes of Diptera, mysids, amphipods and fish fry. Most of the sabrefish in the Small Aral spawn along the sea coast at 2 to 6 m depths. Spawning occurs between late May and early June, and the eggs are bathypelagic. Its age structure showed six generations ranging from 1 to 7, with ages 4, 5 and 6 predominating. The 2013 fish catches showed body lengths ranging between 26 and 36 cm, with an average of 31 cm. The weights ranged from 87 to 422 g, averaging 276 g.

Aral roach (*Rutilus rutilus aralensis* Berg) is found over the entire Small Aral, but is more plentiful near the Syr Darya mouth. The basis of the roach diet is chironomid larvae, although it also consumes molluscs, vegetation and detritus. Roach was found only in the mouth area of the Syr Darya during 2001–2003. By 2005, however, its habitat had expanded to almost the entire water body, except in Butakov Bay where it appeared in 2008. The fish spawns mainly in the second half of April, usually laying its eggs on submerged vegetation. In 2013, there were six generations ranging from 1 to 7 years, with age groups 4 and 5 years dominating. Body lengths in the population ranged between 14 and 29 cm, averaging 21 cm. The fish weights ranged from 47 to 447 g, with an average of 205 g. An increased number of roach numbers is undesirable, however, since the fish competes for food and spawning areas with the commercially valuable common carp.

Rudd (*Scardinius erythropthalmus* (Linnaeus)). The age series in 2013 comprised generations from 1 to 6, with age groups 4 and 5 years predominating. The body length in 2013 ranged from 13 to 27 cm, averaging

21 cm. The corresponding weights ranged from 45 to 523 g, averaging 224 g per fish. The rudd population is in a satisfactory state.

Ide, orfe (*Leuciscus idus oxianus* (Kessler)). Its stocks are very small in the Aral. Ide is omnivorous, with its diet including insects, crustaceans, molluscs and small fish.

Aral shemaya (*Chalcalburnus chalcoides aralensis* (Berg)) is a semi-anadromous fish living in the Small Aral, lakes of the lower Syr Darya and in the river itself. It produced about 6% of the total fish production in the Aral Sea in the past, mainly (70%) in its northern part. Its numbers have recently decreased sharply and it is now rare. It had six generations in the 2013 catch, with age groups 4 and 5 predominating.

Aral barbel (*Barbus brachycephalus brachycephalus* Kessler) is a benthophage, with the main part of its diet being bivalve molluscs. The fish was common in the Aral Sea Basin in the past, with great commercial value. Regulation of inflowing rivers and large water withdrawals resulted in a sea level decrease that subsequently led to a serious collapse of fish reproduction, including fingerlings mortality in irrigation channels, etc. The fish numbers are now low, with the fish being rare and considered an endangered species (Red Book of Kazakhstan 2010). A small population survives in the lower reaches of the Syr Darya. As a result of the partial restoration of the Small Aral Sea, barbel is beginning to be found at the mouth of the Syr Darya and later also in the north-eastern part of the sea.

Turkestan barbel (*Barbus capito conocephalus* Kessler) is endangered, and considered a very rare species in the Aral (Red Book of Kazakhstan 2010). Its small self-reproducing populations survived in the lower reaches of the Syr Darya.

Wels (*Silurus glanis* Linnaeus) is a piscivorous predator, which prefers to spawn on vegetation. It was represented in 2013 by generations 4 to 8 years, with age group 7 predominating. The body length of the fish ranged from 65 to 92 cm, averaging 81 cm. It weights ranged between 2300 and 7628 g, averaging 4723 g per fish. The state of the wels population is stable.

Pike perch, zander (*Stizostedion lucioperca* (Linnaeus)) is mostly a piscivorous predator. Zander lived only near the Syr Darya mouth in 2001–2003. As a result of the Small Sea freshening, its habitat area then increased, being found everywhere in 2005, except for Butakov Bay. It has more recently been encountered in all parts of the sea. Zander is a phytophilic fish, with spawners migrating into the Syr Darya from late September until March–April, when they mainly spawn. There are seven generations (1–7 years), with age groups 4 and 5 dominating. The body length of the fish ranged from 21 to 62 cm, with an average length of 39 cm. The fish weights ranged from 105 to 2800 g, averaging 787 g per fish.

Snakehead (*Channa argus warpachowskii* Berg) was accidentally introduced into the Aral Sea in 1960–1961. It is primarily piscivorous, but also consumes crustaceans, other invertebrates and amphibians. The fish is found near the mouth of the Syr Darya. Its catch is small. It has six generations ranging 2 to 7 years, with age 4 predominating. Its body length in 2013 ranged from 30 to 64 cm, averaging 43 cm. The weights exhibited a wide range from 320 to 2875 g, with an average of 1018 g per fish.

Flounder (*Platichthys flesus* (Linnaeus)). This marine fish currently only lives in Butakov Bay and adjacent areas exhibiting higher salinities. Flounder is benthophage, eating mainly molluscs. They start spawning at temperatures close to 0 °C in February–March, with the main spawning taking place from mid-March to early April. As a result of the freshening in the eastern and north-eastern parts of the sea, flounder have spawned only in Shevchenko and Butakov bays since 2004–2005 where the salinity is relatively high. The flounder in 2013 had seven generations in the age groups ranging from 2 to 8 years, with the age groups 4 and 5 predominating. The body length of the groups ranged between 18 and 30 cm, averaging 23 cm. The weights ranged from 80 to 483 g, averaging 193 g per fish. The decreased salinity in the Aral Sea, and increases in the number of native freshwater fish, has worsened the food base and environmental conditions for natural reproduction. Accordingly, the area inhabited by flounder is shrinking and its stocks are dropping.

Fisheries are recovering, and the fishery catch in the Small Sea changed substantially during 2006–2013. Commercial catches have grown from 650 tons in 1996 to 4190 tons in 2012 (Fig. 6). The flounder contribution decreased from 52% to 28% of the total, the roach increased from 18% to 30% and the bream increased from 8% to 26%. The contribution of zander increased from 4% to 10% and asp from 0.4% to 2.7%. The share of carp during the study period declined from 26% to 2.0%, while the sabrefish increased from 1.9% to 2.3%.

DISCUSSION

Although the list of invertebrate species found in the Small Aral Sea during the present study is not long, it does not mean it is exhaustive. Many species can remain undiscovered, including those there are rare species or those whose numbers are small in the spring time,

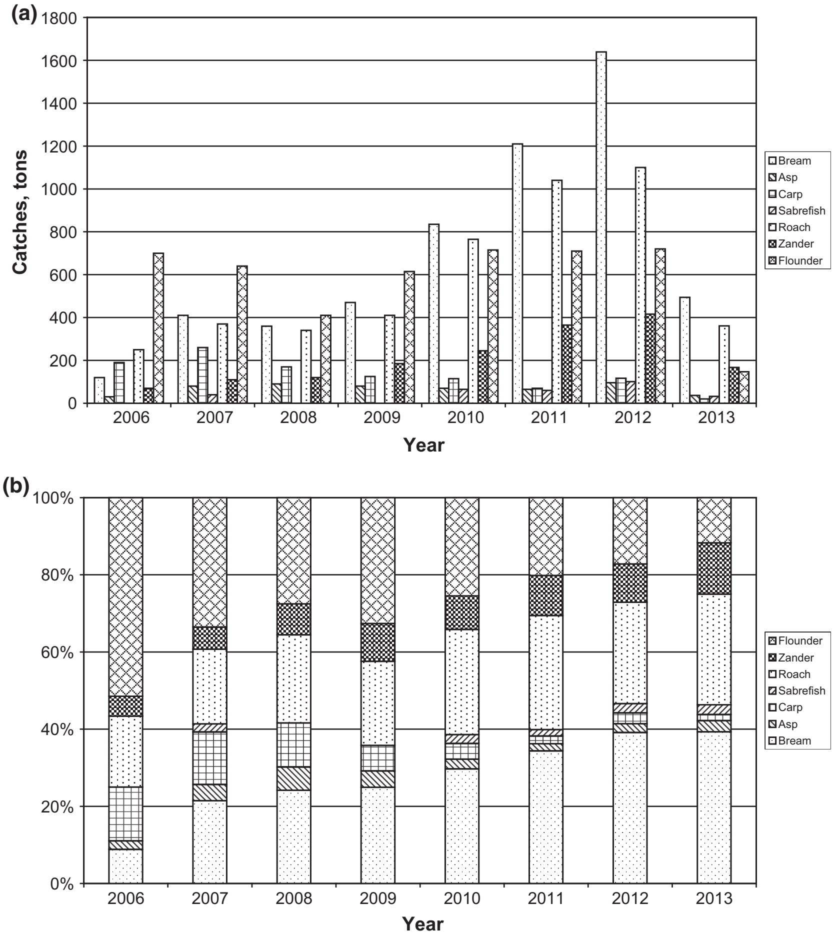

Fig. 6. Dynamics of Small Aral Sea fish catches (2013 data for only 9 months), (a) composition of catches, tons and (b) portion of fish species in the catches.

meaning the species that exhibit higher numbers in the summer were not found. The fauna of shoals with aquatic vegetation where a number of invertebrates only lived in the past still remain unexplored.

There are no studies on the current species composition of the Small Aral nematode fauna. It is only known that nematodes did not disappear with increasing salinity (Filippov *et al.* 1993). Even today in the hyperhaline Large Aral, the species diversity of the nematodes is high and their fauna, known from studies in the 1920–1930s, survived (Mokievsky & Miliutina 2011). Thus, there are good reasons to believe the former diversity of nematodes has been preserved in the Small Aral.

The recent species composition of ostracods in the Small Aral remains unknown because of a lack of focused studies. Nevertheless, their number should include the widely euryhaline *Cyprideis torosa* (Jones), which can survive in both high salinity and fresh water. In view of the decreased salinity in the Small Sea, a natural reintroduction of at least part of the ostracod species, which had disappeared by the end of the 1980s because of salinization, is quite likely.

It should be noted that a small number of invertebrate species either were endemic, or only lived in the Aral Basin. For this reason, the source of their natural reintroduction does not exist, and they are extinct. Examples among them include marine bivalve molluscs *Cerastoderma rhomboides rhomboides* (Lamarck), endemics of the Aral Sea, cladoceran subspecies *Cercopagis pengoi aralensis* M.-Boltovskoi, bivalve molluscs subspecies *Dreissena polymorpha obtusecarinata* (Andrusov), *D. caspia pallasi* (Andrusov), *Hypanis minima minima* (Ostroumoff), *H. m. minima* sidorovi Starobogatov and *H. vitrea bergi* Starobogatov (Plotnikov & Aladin 2014).

CONCLUSIONS AND MANAGEMENT ADVICE

The Small Aral Sea fauna experienced significant changes since the late-1950s because of human activities. Desiccation and salinization resulted in decreasing biodiversity attributable to the disappearance initially of freshwater and later brackish water species. Introduction of new exotic species, on the one hand, increased the fauna biodiversity and, on the other hand, caused the disappearance, and even extinction, of some species.

The damming of the northern part of the Aral Sea resulted in decreased salinity and the subsequent formation of an extensive more freshwater zone in that location. This created conditions for increasing biodiversity of all fauna attributable to the natural reintroduction of invertebrate species, and the migration back of fish that had disappeared because of the increased salinization, but which remained in the nearby water bodies.

Some components of modern invertebrate fauna of the Small Aral are still unexplored or else insufficiently explored. Most importantly among these are micro- and meiobenthos, microzooplankton and fauna of shoals with vegetation. New studies are necessary to address this topic.

Continuing salinity decreases, however, will cause decreased numbers, or even disappearance, of marine and invertebrate species inhabiting continental waters, including *Brachionus plicatilis*, *Hediste diversicolor*, *Halicyclops rotundipes aralensis*, *Cerastoderma isthmicum*, *Caspiohydrobia* spp. If the salinity in more saline parts of the Small Aral became insufficient for reproduction of the flounder *Platichthys flesus*, this fish will disappear, although they will not necessarily disappear completely, but rather remain in the more saline Butakov Bay. What ultimately occurs will depend on how low the salinity will become before it ceases and stabilizes, which is currently difficult to estimate because of the potential influence of climate change in diminishing the flow of the Syr Darya.

The relative stabilization of the hydrological regime and, more importantly, the decreased salinity of the Small Aral Sea contributed to valuable freshwater fish species reaching commercial numbers. The native ichthyofauna has expanded its spawning and feeding to encompass almost the entire area of the Small Aral Sea. Fish abundance and commercial stocks are increasing.

There is a water body on the channel of the bottom of former Berg Strait below the Kokaral Dam. During the spring period of high Syr Darya flows, the water flows through the gates in the dam into this water body and then in the direction of the Large Aral. During the summer, when this outflow is absent, the salinity in this shallow water body increases because of evaporation and transpiration from the extensive reed beds growing here. Many valuable fish, mainly common carp, gathering here before spawning migration are carried from the Small Aral via this discharge. These fish cannot get back into the Small Aral and subsequently perish because of increasing salinity and a deficit of food. Several measures are needed to resolve this problem. It is desirable to replace the primitive fish protection device in the body of the Kokaral Dam that keeps fish from being transported out of the Small Aral with an electrical fish-protecting device. Regular commercial fishing in the shallow lakes downstream of the dam is also needed. When developing a water discharge schedule from the Small Aral Sea, it is necessary to consider the main discharge must occur in autumn and winter.

It is also desirable to explore the possibility of reintroduction of some species of invertebrates, which are a valuable food for fish, into the Small Aral from lakes located in the lower reaches of the Syr Darya. These are species that have not returned naturally or, if they have, their current numbers are still very low, examples being the zebra mussel and mysids. It also is possible to explore the possibility and expediency of introducing new invertebrate species into the Aral Sea fauna. Furthermore, it may be appropriate to reintroduce rare and endangered fish species, examples being Aral barbell and ship sturgeon.

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