Transformation of Aquatic Animal Biodiversity in the Aral Sea. It is not Dying, but Transforming in Accordance with Water Availability and its Salinity

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Abstract

The composition of free-living invertebrates and fishes in the Aral Sea has undergone significant changes during the second half of the 20th century and the beginning of the 21th century. Initially, these changes were small and resulted from both intentional and incidental introduction of invertebrate and fish species to the Aral Sea. Since the 1960s, the primary factor that influenced the composition of free-living invertebrates and other fauna was the increasing salinity of the Aral Sea due to the gradual withdrawal of inflowing river runoff. As a result, the total number of invertebrate and fish species has decreased significantly. Freshwater and brackish-water species have disappeared, and only euryhaline and marine species have survived. In the northern Small Aral Sea, construction of the Kokaral dam has led to the accumulation of runoff, which led to a significant increase in the size of the freshwater zone and the enlargement of the natural habitat for indigenous commercial fishes. Some highly valued fish populations grew to numbers that allowed their commercial catch possible once again.

Introduction

Located in the arid zone of Central Asia, the Aral Sea until the 2nd half of the 20th century existed as a single terminal water body (a huge closed lake) that received inflow from the Syr Dar’ya in the northeast and the

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Figure 1. Change of level and salinity of the Aral Sea.

Amu Dar'ya in the south. Both rivers originate in mountains, and because of the melting of glaciers and snow, their runoff volume varied significantly, reaching a peak in spring and early summer. Because of the natural loss of water in the plains and river deltas (e.g., evaporation and filtration) and irrevocable water withdrawal for the irrigation of cultivated crops, only a certain proportion of the waters of the Amu Dar'ya and Syr Dar'ya reached the Aral Sea. The source of the remaining water in the Aral Sea were atmospheric precipitation and underground waters, which contributed to an average of 56 km^3 of water per year during the 1st half of 20th century) (Bortnik and Chistyaeva 1990).

Kokaral Island divided the Aral Sea into 2 parts: Small Aral Sea in the north and Large Aral Sea in the south. These 2 parts were connected by 2 straits: the narrow and shallow Auzy-Kokaral strait (depth, up to 2 m) in the west and the wide and deep Berg's strait (depth, up to 13 m) in the east. In the Large Aral Sea, there were several islands, the largest being Barsakelmes and Vozrozhdeniya. In the southeast portion, there were many small islands of the Akpetkinsky (or Karabaili) archipelago, and several smaller islands existed in different parts of the Aral Sea depression. In the Small Aral Sea, there are no islands, but there are some bays. The largest and deepest of them are the Shevchenko, Butakov, and Bolshoy Sary-Cheganak bays. The Large Aral Sea is subdivided into the western deep-water region, extensive western basin, and the Tsche-Bas bay; the eastern region is rather shallow. Because of such geography, the Aral Sea divides further into separate water bodies as the water level falls.

Prior to its modern regression, the Aral Sea was the fourth largest continental water body in the world, with an area that reached 67,499 km^2 and a volume of 1089 km^3. The area and volume of the Small Sea were 6118 km^2 and 82 km^3, respectively, and those of the Large Sea were 61,381 km^2 and 1007 km^3. The maximal depth reached 69 m (in the western part of Large Aral Sea). The water level was about +53 m. The average salinity in most regions of the sea was 10 g/l, which corresponds to the first barrier salinity zone (8–13 g/l for the Aral Sea) or α-horohalinicum (Aladin and Plotnikov 2011). Thus, the Aral Sea was a brackish water body. The deltas of the Amu Dar'ya and Syr Dar'ya had wide zones with more freshwater influence. In the heart of the Akpetkinsky archipelago, in so-called "kultuks," intensive evaporation and limited water exchange caused salinity to increase (50 g/l or greater) (Husainova 1960).

For several centuries until the 1960s, the Aral Sea was in a quasi-stable state. For the entire period for which recorded observations are available (from the middle of the 19th century onward), the level of the Aral Sea fluctuated only slightly, and this was mainly due to natural climatic factors.

Native fauna

There was little diversity in the free-living invertebrate fauna of the Aral Sea. The available data indicate the presence of only 195 invertebrate species in the Aral Sea (Yablonskaya 1974), but it does not seem plausible that these data are complete, since some of the smaller groups of aquatic organisms, particularly the protozoa, may not have been studied in sufficient detail. In addition, the species that reside permanently in the strong freshwater zones at the mouths of the Amu Dar'ya and Syr Dar'ya rivers or those that migrated there with the runoff from these rivers are not always taken into account. Although these species had occupied wide areas of these waters, they were traditionally considered alien to Aral Sea fauna (Andreev 1989).

The native free-living invertebrate fauna of the Aral Sea were of heterogeneous origin. According to Yablonskaya (1974), 78% of the free-living invertebrate species were inhabitants of freshwater and brackish-water continental water bodies, 17% were Caspian species, and only 5% were Mediterranean-Atlantic species. Thus, species of freshwater origin were predominant in the Aral Sea fauna.

The native fish fauna of the Aral Sea consisted of only 20 species from 7 families (Table 1). Most species (12% or 60% of all fish fauna) belonged to the family Cyprinidae. The Percidae were represented by 3 species, and the Acipenseridae, Salmonidae, Siluridae, Esocidae, and Gasterosteidae, by only 1 species each. Eurybiontic species were the predominant original fish in the Aral Sea, accounting for about 95% of the fish fauna (Nikolsky 1940).

Only 3 of the 6 assemblages of native fish species in the Aral Sea were present in the basin (Nikolsky 1940):

1. Upper Quaternary fauna pike (*Esox*) and perch (*Perca*)
2. Aral-Caspian fauna: *Acipenser*, *Rutilus*, *Abramis*, *Aspius*, *Barbus*, and *Pungitius*, all of which lived in the sea and the lower reaches of the rivers. This assemblage was representative of Aral fish fauna and included 9 species, or 45% of all fish fauna.
3. Northern immigrants: 2 groups of northern (mainly Siberian) fish fauna
    a. Stenothermal psychrophilic fishes: Aral salmon *Salmo trutta aralensis*
    b. Eurythermal limnophilic fishes in the lower reaches of rivers and partially across the Aral Sea: silver crucian *Carassius auratus gibelio*, ide *Leuciscus idus oxianus*, and ruffe *Gymnocephalus cernuus* (= *Acerina cernua*).

No fish species were known to inhabit the deep-water zone, which testifies that the Aral Sea fish fauna originated from limnophilic fauna of the Amu Dar'ya basin (Nikolsky, 1940).

In addition, the Aral Sea had no native pelagic fish feeding on zooplankton and phytoplankton. However, some fish species, especially the sabrefish, shemaya, roach, and white-eye bream (Nikolsky 1940), partially fed on plankton in the pelagial and partially consumed benthos. The main food sources for fish in the pelagial were the pupae of insects, mostly those belonging to Chironomidae, that float on the water surface during mass emergence, and also their imagines and imagines of caddis flies. Zooplankton was not a significant food source for

Table 1. Species composition of the Aral Sea fish fauna.

Species	Years				Status
	1950	1960-1979	1980-1990	1991-2004	
	Acipenseridae				
Ship sturgeon *Acipenser nudiventris* Lovetsky	+	+	-	-	RB, I, AB
Stellate sturgeon *Acipenser stellatus* Pallas	-	+	-	-	I, AC
	Salmonidae				
Aral trout *Salmo trutta aralensis* Berg	+	+	-	-	RB, I, AB
	Clupeidae				
Baltic herring *Clupea harengus membras* (Linnaeus)	-	+	+	+	C-, AC
	Esocidae				
Pike *Esox lucius* Linnaeus	+	+	-	+	C-, AB
	Cyprinidae				
Aral roach *Rutilus rutilus aralensis* Berg	+	+	-	+	C, AB
Grass carp *Ctenopharyngodon idella* (Valenciennes)	-	+	-	+	C-, AC
Orfe *Leuciscus idus oxianus* (Kessler)	+	+	-	+	C-, AB
Zherekh *Aspius aspius iblioides* (Kessler)	+	+	-	+	C, AB
Rudd *Scardinius erythropthalmus* (Linnaeus)	+	+	-	+	C-, AB
Turkestan barbel *Barbus capito conocephalus* Kessler	+	+	-	-	RB, AB
Aral barbel *Barbus brachycephalus brachycephalus* Kessler	+	+	-	+	RB, AB
Bream *Abramis brama orientalis* Berg	+	+	-	+	C, AB
White-eye bream *Abramis sapa aralensis* Tjapkin	+	+	-	+	C-, AB
Aral shemaya *Chalcalburnus chalcoides aralensis* (Berg)	+	+	-	+	C-, AB
Sabrefish *Pelecus cultratus* (Linnaeus)	+	+	-	+	C-, AB
Crucian carp *Carassius carassius gibelio* Bloch	+	+	-	+	C-, AB
Carp *Cyprinus carpio aralensis* Spitshakow	+	+	-	+	C, AB
Silver carp *Hypophthalmichthys mobilitrix* (Valenci-ennes)	-	+	-	+	C-, AC
Spotted silver carp *Aristichthys nobilis* (Richardson)	-	+	-	+	C-,AC
	Siluridae				
Wels *Silurus glanis* Linnaeus	+	+	-	+	C-, AB

	Atherinidae				
Caspian big-scale sand smelt *Atherina boyeri caspia* (Eichwald)	-	+	+	+	I
	Gasterosteidae				
Nine-spined stickleback *Pungitius platygaster aralensis* (Kessler)	+	+	+	+	AB
	Percidae				
Pike perch, zander *Stizostedion lucioperca* (Linnaeus)	+	+	-	+	C, AB
Perch *Perca fluviatilis* Linnaeus	+	+	-	+	C-, AB
Ruff *Gymnocephalus cernuus* (Linnaeus)	+	+	-	-	AB
	Channidae				
Snakehead *Channa argus warpachowskii* Berg	-	+	-	+	C-, AC
	Gobiidae				
Bubyr goby, transcaucasian goby *Pomatoschistus caucasicus* Berg [= *Knipowitschia caucasica* (Berg)]	-	+	+	+	I
Sand goby *Neogobius fluviatilis pallasi* (Berg)	-	+	+	+	I
Tubenose goby *Proterorhinus marmoratus* (Pallas)	-	+	+	+	I
Round goby *Neogobius melanostomus affinis* (Eichwald)	-	+	+	+	I
Bighead goby *Neogobius kessleri gorlap* Iljin	-	+	+	+	I
Syrman goby *Neogobius syrman eurystomus* (Kessler)	-	+	+	+	I
	Pleuronectidae				
Black Sea flounder *Platichthys flesus luscus* (Pallas)	-	+	+	+	C, AC

Note: +, present; -, absent; C, commercial; C-, commercial but low stock; AB, original; AC, acclimatized; I, introduced; R, in Red Book; E, extinct.

fishes, and only stickle-back (*Pungitius platygaster aralensis*) fed mainly on zooplankton (Nikolsky 1940).

The diversity of indigenous zooplankton species of the Aral Sea was highest in the strongly freshwater areas. The species composition in the zones with normal salinity became appreciably scantier.

The indigenous zooplankton of the Aral Sea could be divided into 3 groups depending on their tolerance to salinity: inhabitants of the open sea at its normal salinity (10.2 g/l), predominantly freshwater inhabitants that tolerate a small degree of salinization (29 species of Rotatoria, 8 species of Cladocera and 1 species of Copepoda), and predominantly riverine species that flow into the Aral Sea (Andreev 1989).

The first group of species formed the basis of the native zooplankton population of the Aral Sea. Twenty-one species of Rotatoria were widespread in fresh, brackish, and marine waters (Kutikova 1970); of the 7 Cladocera and 22 Copepoda species (Andreev 1980) that formed an assemblage, few were abundant. Four species of Cladocera – *Cercopagis pengoi aralensis* M.-Boltovskoi, *Evadne anonyx* G. Sars, *Podonevadne camptonyx* (G. Sars), and *P. angusta* (G. Sars) – are representative of the endemic Ponto-Caspian group, which was the most constant component of the original Cladocera fauna. The other 3 species of Cladocera – *Ceriodaphnia reticulata* (Jurine), *Alona rectangula* G. Sars, and *Moina mongolica* Daday – were not reported to be abundant, with some exceptions (Andreev 1989). *Arctodiaptomus salinus* (Daday) was previously the most dominant copepod, its extensive distribution being representative of fauna from continental saline waters (Lukonina 1960a). The endemic subspecies *Halicyclops rotundipes aralensis* Borutzky was distributed throughout the entire Aral Sea. Other copepods were freshwater euryhaline species of Cyclopoida, the most common among which was *Mesocyclops leuckarti* (Claus), and 15 brackish water and marine species of Harpacticoida, among which *Schizopera aralensis* Borutzky, *S. reducta* Borutzky, and *Enhydrosoma birsteini* Borutzky were considered endemic to the Aral Sea (Borutzky 1974). The most abundant in summer zooplankton of the Aral Sea were the larvae of bivalves belonging to the genera *Dreissena* and *Hypanis* (Lukonina 1960a; Kortunova 1975).

The most common original benthic fauna of the Aral Sea consisted of freshwater and Caspian species. The macrozoobenthos consisted mainly of 12 species and 1 mollusk subspecies, 6 species of Oligochaeta, 5 species of Crustacea, and larvae of over 25 species of Chironomidae (Dengina 1959; Belyanina and Konstantinov 1974). However, only the following were abundant: among Aral-Caspian bivalve mollusks, *Dreissena polymorpha aralensis* (Andrusov), *D. p. obtusecarinata* (Andrusov), *D. caspia pallasi* (Andrusov), *Hypanis minima minima* (Ostroumoff), and *H. m. sidorovi* Starobogatov; among oligochaetes, *Nais elingius* Müller and *Paranais simplex* Hrabe; among ostracods, *Cyprideis torosa* (Jones); among amphipods, *Dikerogammarus aralensis* (Uljanin); among chironomids, larvae of the genus *Chironomus* (*C. behningi* Goetghebuer being the most abundant); and among trichopterans, larvae of the genus *Oecetis intima* MacLachlan.

Mollusks of marine origin, namely, *Cerastoderma* spp. and salt-tolerant *Caspiohydrobia* spp., were plentiful only in the salinized bays on the eastern coast (Husainova 1958; Dengina 1959; Yablonskaya 1960a, 1960b). The gastropod *Theodoxus pallasi* Lindholm was present, but in much lower numbers than the bivalves belonging to the genera *Dreissena* and *Hypanis* (Yablonskaya 1960a; Yablonskaya et al. 1973). Mollusks comprised 63% of zoobenthos biomass, and larvae of chironomids, 33% (Karpevich 1974). The faunal species composition of benthic communities depended largely on the sediment and composition of the benthic vegetation, with the bivalve *Dreissena* being the predominant organism (Zenkevich 1963).

The native fish fauna of the Aral Sea were represented primarily by species of freshwater origin. The suitable conditions for natural reproduction were the main factor that influenced the fluctuation in fauna abundance (Bervald 1964; Nikolsky 1940). These native fish typically reproduced in freshwater, where they migrated. They spawned most successfully in freshwater bays near deltas, deltaic lakes, and rivers. The role of marine spawning areas has remained unclear. The main commercial fishes such as bream, carp, and roach have been observed to spawn in areas varying widely in salinity – from freshwater through fully saline water. However, this does not imply that embryonic development is normal at high salinity levels. There are no reliable data on the upper range of acceptable salinity at which the development of roe and larvae is normal. For example, roach were reported to tolerate much higher salinity (10.5–11.6 g/l) than carp or bream, whereas Bervald (1950) found that the normal breeding populations of roach, bream, and carp were located far from deltaic areas at a salinity range of 10.5–11.6 g/l (also pointed out by Gosteeva [1956,1957, 1959]).

The rate of endemism was very low despite the Aral Sea's geographical isolation. This is explained often by the relatively young age of this water body (Aladin and Plotnikov 1995; Boomer et al. 2000). Only 3 species of Harpacticoidea (Borutzky 1974) and no fish were endemic to the Aral Sea. The fish fauna were representative mainly of the limnophilic group of Pleistocene fishes from the Amu Dar'ya (Nikolsky, 1940).

Until the 20th century, the Aral Sea seemed to be rather stable with respect to its geographical, physical, chemical, and biological condition. However, anthropogenic introduction of fish and invertebrate species changed the biological conditions. This change occurred even more rapidly with changes in the hydrological system, which had led to even more salinization and desiccation.

Introduction of new species before salinization

One cannot completely exclude the possibility that some free-living invertebrate species (now considered endemic) could have been introduced passively into the Aral Sea from other water bodies by ancient people. It is assumed that about 5000 years ago, Neolithic tribes wandered along the banks of the Uzboy River and Sarykamysh Lake between the Aral and Caspian Seas and introduced a food source, namely, the Mediterranean-Atlantic bivalve mollusk *Cerastoderma rhomboides rhomboides* (Lamarck), from the Caspian Sea to the Aral Sea.

By the end of the 1920s, the efforts for increasing the efficiency of fisheries led to the introduction of the shad *Alosa caspia* (Eichwald) and stellate sturgeon *Acipenser stellatus* (Pallas) from the Caspian Sea. Both of these attempts were unsuccessful (Behning 1934, 1935, 1936).

To increase the production of fish as a food source, scientists discussed the introduction of a wide variety of invertebrate species. The proposal was to introduce—in addition to the bivalve mollusks *Syndosmya segmentum* Recluz a.k.a. *Abra ovata* (Philippi) and *Mytilaster lineatus* (Gmelin) (Zenkevich and Birshtein 1934) – amphipods, shrimp, and crab species from the Caspian Sea, and mysids and some other brackish-water species from the Azov-Black Sea basin, Baltic, and the Far East seas (Behning 1936; Averintsev 1936; Zenkevich and Birshtein 1934, 1937; Zenkevich 1947; Ilyin 1954). Karpevich evaluated these proposals in several papers (1947, 1948, 1953, 1960a, 1960b, 1975, 1986).

The Aral Sea's low production of zooplankton could not sustain a large number of planktivorous fishes (Yablonskaya and Lukonina 1962). For example, the calanoid copepod *Arctodiaptomus salinus* has low fertility (1 generation per year), but comprised 70% of the spring zooplankton bloom (Kortunova 1975, Lukonina 1960a). During summer, the total zooplankton levels decreased and the rotifers (abundant in the deltaic areas) were present in small numbers in the open sea (Karpevich 1975). Because of these factors as well as the low diversity of endemic species in the Aral Sea, all food resources could not be used effectively. Further, some resources were removed from the system, for example, wind drove adult chironomids into the desert, thus substantially diminishing the organic matter mass in the sea (Karpevich 1960a, 1975).

With the prospective drastic changes in hydrology and irrigation intensity in the run-off from both tributaries to the Aral Sea (Syr Dar'ya and Amu Dar'ya), it was foreseen that the salinity would rise and original fauna and flora would adapt accordingly or die. To minimize these negative effects, plans were made to alter the sea's diversity and thus retain its value for fisheries (Karpevich 1953). Thus, it was proposed that euryhaline species would be introduced while taking care not to introduce unwanted elements into the Aral Sea. Scientists advised that species belonging to the lower trophic levels be introduced first, beginning with phytoplankton, followed by zooplankton and zoobenthos, and finally fish. Among the various fish species, the benthophages and predators could be introduced readily, whereas planktophage species could be introduced only after increasing their food reserve (high-producing planktonic invertebrate species) (Karpevich 1960a, 1975).

On the basis of an analysis of the Aral Sea ecosystem and preliminary surveys, it was proposed that many species of planktonic algae, planktonic and benthic invertebrates, and fishes would be introduced. The following benthic invertebrates were recommended: polychaete worms *Hediste* (= *Nereis*) *diversicolor* (O.F. Müller) and *Nephtys hombergii* Savigny in Lamarck, bivalve mollusks *Monodacna colorata* (Eichwald) and *Syndosmya segmentum*, cumaceans *Schizorhamphus bilamellatus* (Sars) and *Pterocuma pectinata* (Sowinsky), amphipods *Corophium nobile* (Sars), *C. curvispinum* (Sars), and several other species. To strengthen the second pelagic trophic link – planktonic invertebrates – the introduction of the following species was proposed: the highly productive brackish-water and marine crustaceans *Calanipeda aquaedulcis* Kritchagin, *Heterocope caspia* Sars, *Acartia clausi* Giesbrecht, *A. latisetosa* (Kritchagin), *Acanthocyclops vernalis* (Fischer), *Halicyclops sarsi* Akatova, *Centropages kroeyeri* Giesbrecht, and rotifers of the genus *Synchaeta*. (Karpevich 1960a, 1975).

However, when in the mid-1950s, aquatic invertebrates and fishes began to be introduced to the Aral Sea, scientifically derived recommendations were neglected. The potential negative consequences were not considered. The adaptation was initiated by introducing fish species, but without any preliminary strengthening of the lower levels of the trophic chain (Karpevich 1947, 1948, 1953, 1960a, 1975).

Incidentally, valuable commercial fish were introduced to the Aral Sea together with invertebrate and non-commercial fish species that were not only unplanned, but simply undesirable. From the 6 species of gobies from the Ponto-Caspian area, 3 species: bubyr *Knipowitschia caucasicus* (Berg), monkey goby *Neogobius fluviatilis* (Pallas), and round goby *N. melanostomus* (Pallas) were successfully naturalized. In the mid-1960s, the steep increase in goby numbers (1958–1963) led to significant reduction in the numbers of benthic invertebrates (Doroshev 1968; Markova 1972; Karpevich 1975; Yablonskaya et al. 1973). During an unsuccessful attempt in 1954–1956 to introduce the Caspian mullets *Liza auratus* (Risso) and *L. saliens* (Risso), shrimp species were introduced to the Aral Sea (Husainova 1958). Initially, it was believed that 2 species of shrimp (*Palaemon elegans* Rathke and *P. adspersus* Rathke [Karpevich 1960c]) were introduced, but it was later confirmed that *P. elegans* (Malinovskaya 1961) alone was distributed throughout the entire sea (Gavrilov 1970; Karpevich 1975). In addition, the plankton-eating atherine *Atherina boyeri caspia* Eichwald was naturalized along with the mullets (Karpevich 1975).

In the 1954–1956 time frame, the Baltic herring *Clupea harengus membras* (Linnaeus) was introduced. It naturalized rapidly (Konovalov et al. 1958) and became common in the entire Aral Sea by 1960. With the introduction of Baltic herring, atherine, and gobies, there was a sharp increase in the use of low-productivity zooplankton as a food source. Since their food sources had not been reinforced (Karpevich 1960b), the Baltic herring together with the atherine species rapidly exhausted their food reserves (Karpevich 1975; Yablonskaya and Lukonina 1962; Kortunova 1975). There was a considerable decrease in the numbers of the large planktonic crustaceans *Cercopagis pengoi aralensis*, *Moina mongolica*, *Ceriodaphnia reticulate*, and cyclopoids. In particular, the availability of the copepod *Arctodiaptomus salinus*, the most important Aral Sea planktonic species, had decreased immensely. Therefore, since 1961, the larvae of bivalve mollusks accounted for the largest proportion of summer zooplankton (Lukonina 1960a; Yablonskaya and Lukonina 1962; Kortunova and Lukonina 1970; Kortunova 1975), and the number of minute rotifers increased. The undersupply of available zooplankton resulted in mass extinction of the Baltic herring and atherine (Bykov 1964; Kortunova and Lukonina 1970; Kortunova 1975). The introduction of plankton-eaters had also influenced the abundance of zoobenthos species (planktonic larvae of bivalves and also larval chironomids and trichopterans) as significant components of the Aral Sea zooplankton population (Lukonina 1960a; Husainova 1968, 1971).

The mysids *Paramysis (Serrapalpisis) lacustris* (Czerniavsky), *P. (Mesomysis) intermedia* (Czerniavsky), *P. (Metamysis) ullskyi* Czerniavsky, and *Paramysis (Paramysis) baeri* Czerniavsky were the first invertebrates to be introduced intentionally to the Aral Sea (1958–1960). In 1958, the invertebrates were released into the Bolshoy Sary-Cheganak bay, but they did not survive because of high salinity. In 1960, *P. lacustris* and *P. intermedia* were introduced successfully in the freshwater bay Karateren. By 1964, the invertebrates had spread to the entire near-deltaic area of Syr Dar’ya. In addition, *P. intermedia* was introduced successfully to the more freshwater bay Abbas in southern Aral Sea. In 1964, mysids from the mouth of Syr Dar’ya were transported to the mouth of Amu Dar’ya (Bekmurzaev 1974; Husainova 1971). In 1965, *P. ullskyi* was found in the southern areas of the sea, having likely immigrated from the Amu Dar’ya water reservoirs. Near the end of the 1960s, mysids had spread all across the Aral Sea up to depths of 5–7 m, except in the Akpetkinsky archipelago, which exhibited higher salinity. Initially, the predominant species was *P. lacustris*, but later *P. intermedia* became the most abundant mysid species (accounting for about 90% of their number) (Karpevich and Bokova 1970; Kortunova 1970; Karpevich 1975).

By the beginning of the 1960s, 3 new species of invertebrates were introduced intentionally, and 1 accidentally, to the Aral Sea. From 1927 to 1963, 17 new fish species appeared in the Aral Sea, which increased fish diversity considerably from 20 to 34 species. Nevertheless, the commercial fish species composition changed little (Table 1). Overall, the negative activities outweighed the positive effects.

Fauna of the salinized Aral Sea

Since 1960, anthropogenic activity along with increase in potential new irrigation areas enormously affected the withdrawal of freshwater biota in the Aral Sea.

Although the reduced river run-off volume that reached the Aral Sea remained small through 1974, the water shifted to a negative balance permanently (with 1969 as the unique exception). To minimize the effects on fisheries, researchers addressed the steady fall in Aral Sea levels and the increase in its salinity primarily by introducing euryhaline species.

Introduction of new species

In the early 1960s, the euryhaline polychaete worm *Hediste diversicolor* was introduced successfully to the Aral Sea. This worm was present in the entire sea until the middle of 1970 (Fig. 2) (Kortunova 1970; Karpevich 1975).

The second invertebrate species that was naturalized successfully was the Mediterranean-Atlantic euryhaline bivalve mollusk *Syndosmya segmentum*. After the first and unsuccessful attempt to introduce this mollusk in 1960, it was released twice (1961 and 1963) in the Bolshoy Sary-Cheganak bay, and the naturalization was successful. In 1967, this mollusk was observed in zoobenthos samples for this first time and was distributed across the Aral Sea until the mid-1970s (Fig. 3) (Kortunova 1970; Karpevich 1975).

Both *Hediste diversicolor* and *Syndosmya segmentum* became the main components of the Aral Sea benthic fauna, and owing to the high euryhalinity of these species, they survived the additional salinization even though they were introduced artificially.

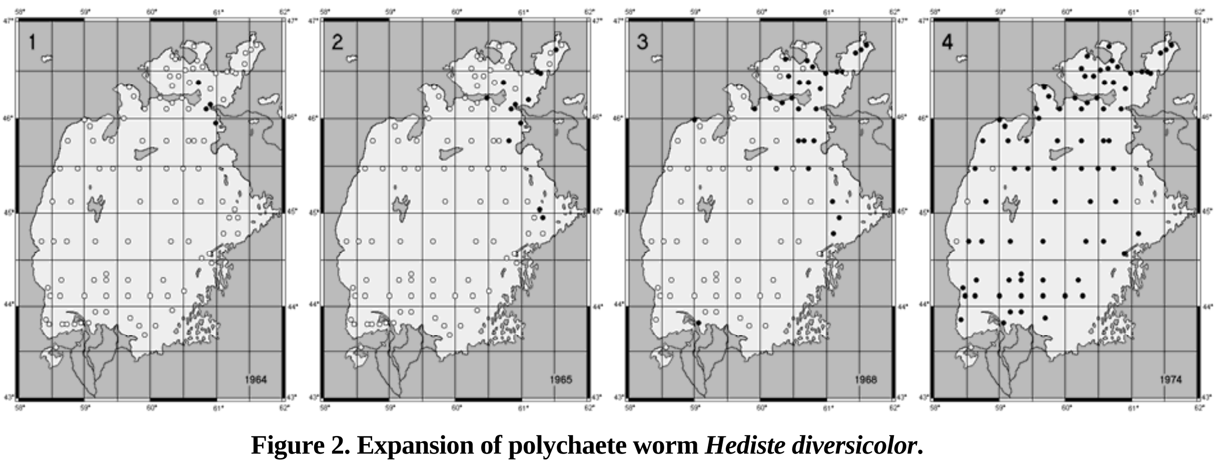

Figure 2. Expansion of polychaete worm *Hediste diversicolor*.

○ – stations where this species was not found; ● – stations where this species was found.

Other attempts to introduce the bivalve mollusk *Monodacna colorata* in 1964 and 1965 did not yield any results (Husainova, 1971; Karpevich 1975).

Planktonic crustaceans were introduced to the middle of the Aral Sea for recovering the planktonic community destroyed by the illogical introduction of plankton-eaters. On the basis of the earlier recommendations for euryhaline copepods, 2 copepod species—*Calanipeda aquaedulcis* and *Heterocope caspia*—were chosen (Gun'ko and Aldakimova1963; Bondarenko 1974; Karpevich 1975) to be introduced at the end of the 1960s and beginning of the 1970s. *C. aquaedulcis* rapidly increased in number, and by 1971, was the predominant species of the Aral Sea zooplankton population (Fig. 4) (Daribaev 1967; Kazahbaev 1972, 1974; Andreev 1978, 1980,

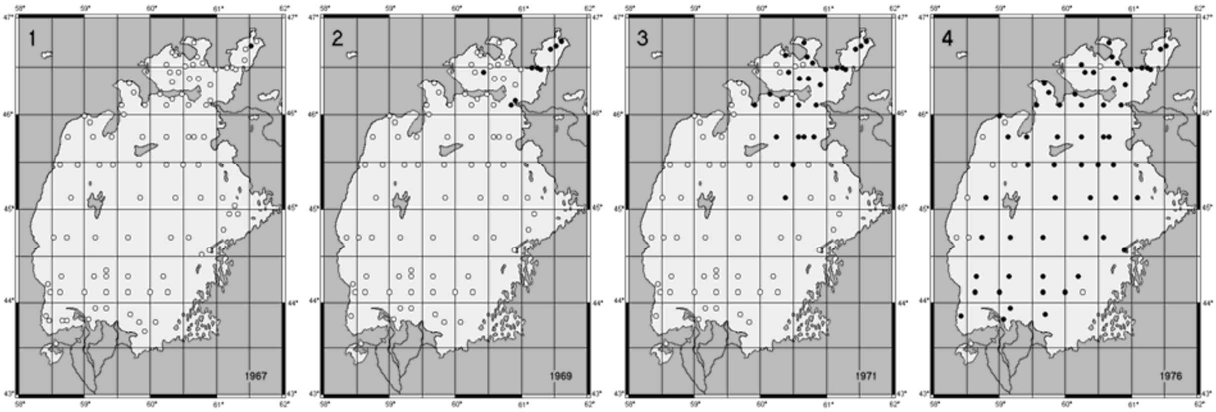

Figure 3. Expansion of bivalve mollusk *Syndosmya segmentum*.
○ – stations where this species was not found; ● – stations where this species was found.

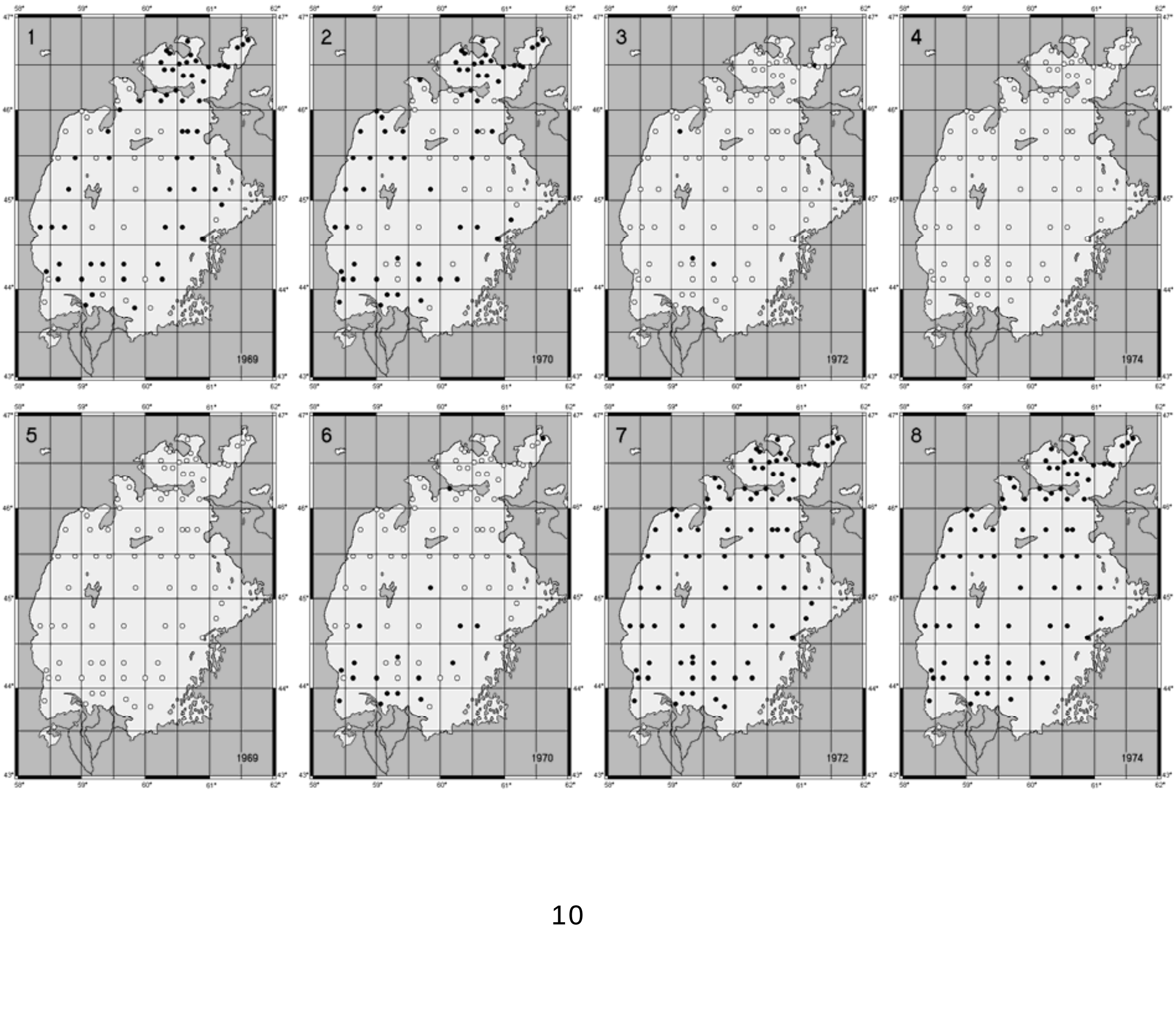

Figure 4. Dynamics of spreading of the copepods *Arctodiaptomus salinus* (*1–4*) and *Calanipeda aquaedulcis* (*5–8*). ○ – stations where this species was not found; ● – stations where this species was found.

1989). However, the attempt to introduce *H. caspia* was unsuccessful. By 1974, *C. aquaedulcis* had replaced the former predominant species—*Arctodiaptomus salinus*—which decreased in number probably because of predation by the introduced planktophages (Fig. 4). The same is true for the highly euryhaline (salinity > 80 g/l) (Aladin 1996) cladoceran *Moina mongolica* (Fig. 5).

The larvae of the crab *Rhithropanopeus harrisii tridentata* (Maitland) also was accidentally introduced during this activity (Morduhai-Boltovskoi 1972). Since 1976, this crab was observed in the Large Aral Sea only (Andreev and Andreeva 1988). The current in Berg's strait that flowed from the Small Aral Sea to the Large Aral Sea most likely hindered the crab's distribution into the Small Aral Sea.

Since 1964, the amphipod *Dikerogammarus aralensis* decreased in number and disappeared by 1973 from the Aral Sea (Fig. 6) (Andreeva 1989). Its disappearance was probably not due to the increasing salinity (it can survive at salinity levels as high as 50 g/l) (Husainova 1960; Dengina 1959), but due to biotic factors such as predatory fish or competing invaders (Aladin and Kotov 1989). Some scientists believe that this amphipod became extinct due to the competing presence of the shrimp *Palaemon elegans* (Morduhai-Boltovskoi 1972; Andreeva 1989; Aladin and Potts 1992).

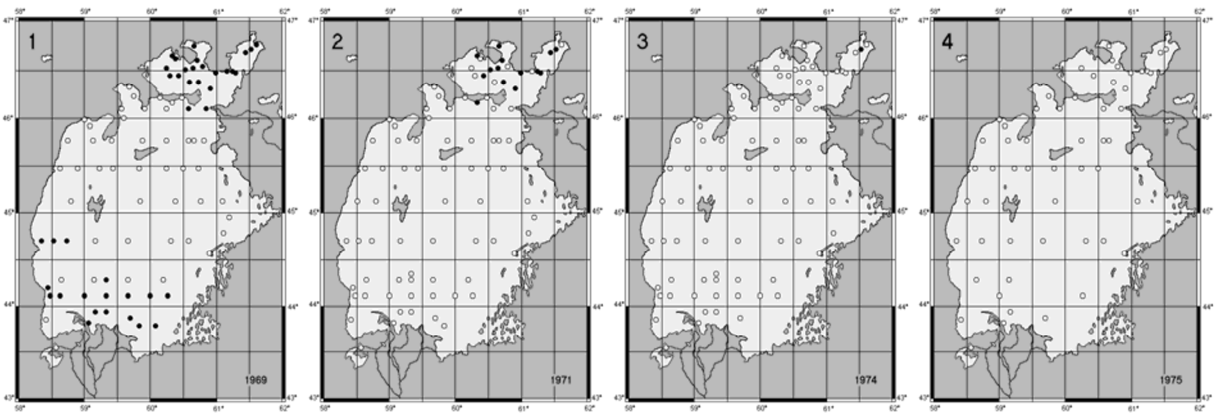

Figure 5. Dynamics of cladoceran *Moina mongolica* disappearance.
○ – stations where this species was not found; ● – stations where this species was found.

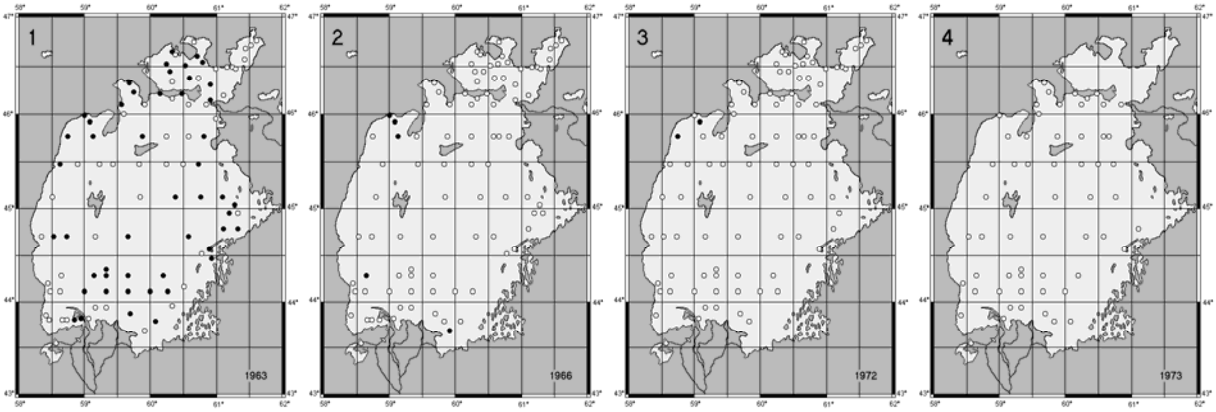

Figure 6. Dynamics of amphipod *Dikerogammarus aralensis* disappearance.

○ – stations where this species was not found; ● – stations where this species was found.

Fauna before the Aral Sea division

The drop in the water level of the Aral Sea and increase in salinity remained slow from 1961 to 1970. By 1971, the level had fallen by 1.7 m and the salinity had increased by 1.5 g/l (reached 11.5 g/l) (Fig. 1). At that time, the faunal composition changed mainly because of the introduction of new species and not because of the increasing salinity, which first become evident by the diminishing numbers of chironomid larvae (Fig. 7). The most sensitive chironomid larvae are *Procladius* spp., *Pelopia vilipennis* Kieffer, *Corynoneura* sp., *Limnochironomus nervosus* Staeger, *Glyptotendipes gripekoveni* Kieffer, and *Glyptotendipes glaucus* Meigen.

However, the reduction in the numbers of chironomids and oligochaetes in the Aral Sea may have been caused by the invasion of *Hediste diversicolor*.

Unfortunately, no concrete data were collected regarding the dynamic changes in Ostracoda fauna and its distribution in the Aral Sea during the initial salinization period. According to Schornikov (1974) and Aladin (1996), the freshwater species *Candona marchica* Hartwig and *Plesiocypris newtoni* (Brady et Robertson) began to disappear first.

The zebra mussel *Dreissena polymorpha* sharply decreased in number after 1964 (Fig. 8). In 1967, these mollusks decreased 40 times in number (Andreeva 1989).

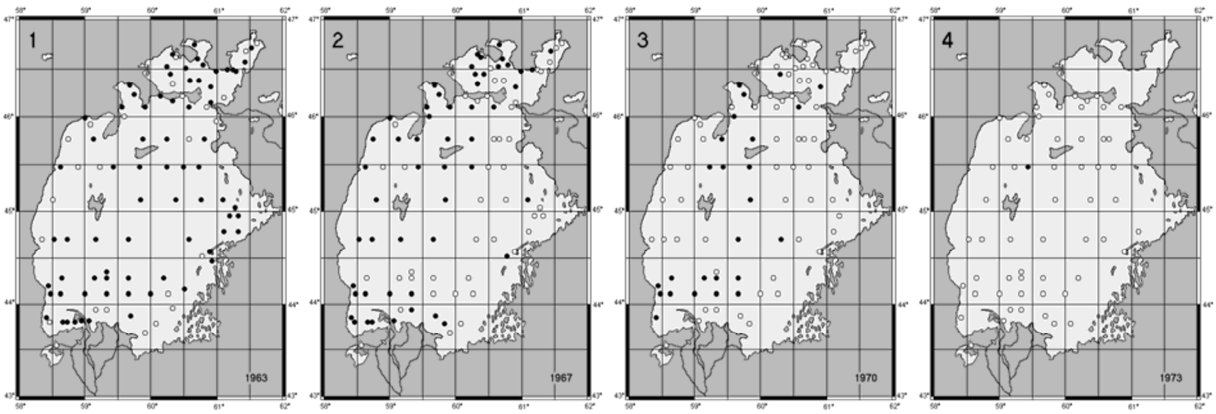

Figure 7. Spreading of Chironomidae larvae.
○ – stations where this species was not found; ● – stations where this species was found.

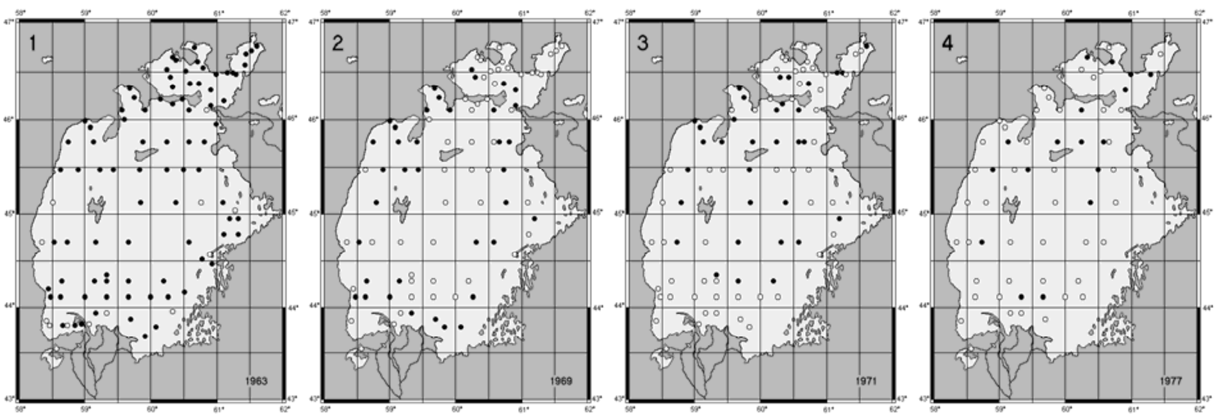

Figure 8. Dynamics of bivalve mollusk *Dreissena* spp. disappearance.
○ – stations where this species was not found; ● – stations where this species was found.

Cerastoderma rhomboides rhomboides and *C. isthmicum* Issel (earlier identified as *Cardium edule* Linnaeus) are 2 species of bivalve mollusks found in the Aral Sea. They tolerate salinity to different degrees (Starobogatov 1974; Andreeva 1989). *C. r. rhomboides* prefers areas with more freshwater, and *C. isthmicum* inhabits areas with salinity levels of up to 24–28 g/l (Dengina 1959). In 1964–1968, a simultaneous reduction in the inhabited area and increase in abundance occurred (Fig. 9). After the high floods of 1969, the *C. r. rhomboides* population was never recovered and the total settlement area for both species was strongly reduced (Andreeva 1989).

During the 1970s, the Aral Sea level fell considerably and salinization increased further (Fig. 1). Since 1974, the flow of the Amu Dar'ya and Syr Dar'ya rivers has decreased sharply, resulting in an incremental water balance deficit and accelerated regression.

Prior to 1971, the changes that occurred in the free-living invertebrate fauna of the Aral Sea were a consequence of planned and incidental introductions of new invertebrate and fish species. At present, the major factor affecting fauna is the constant rise in water salinity.

In 1971–1976, the Aral Sea ecosystem endured its first crisis caused by the increase in salinization (about 12–13 g/l and higher). For the Aral Sea, in which salinization occurs because of the evaporation of freshwater, this degree of salinity was the upper limit of the α-horohalinicum, where most freshwater animals can no longer live and only a few of the marine species can survive (Aladin 1981, 1983, 1989: Andreev and Andreeva 1981; Andreev 1989; Aladin and Plotnikov 2011); this is a minimum-species zone.

In 1976, only 8 of the 21 rotifers species occupying the open areas of the Aral Sea remained. Of these 8 species, *Synchaeta vorax* Rousselet, *S. cecilia* Rousselet, and *S. gyrina* Hood was observed to undergo mass development throughout the sea. Other species of rotifers existed locally or were sparsely distributed. Only *Brachionus plicatilis* Müller, *B. caliciflorus* Pallas, and *Notholca squamula* (Müller) (Andreev 1983, 1989) were collected at times.

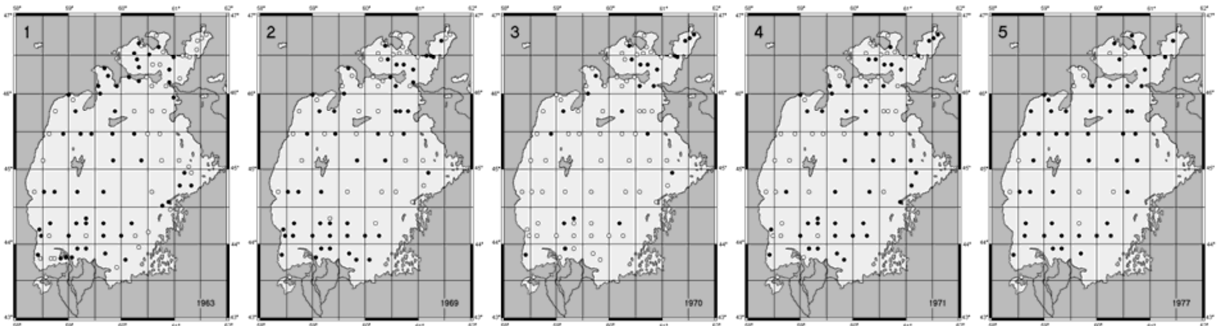

Figure 9. Dynamics of bivalve mollusk *Cerastoderma* spp. distribution.
○ – stations where this species was not found; ● – stations where this species was found.

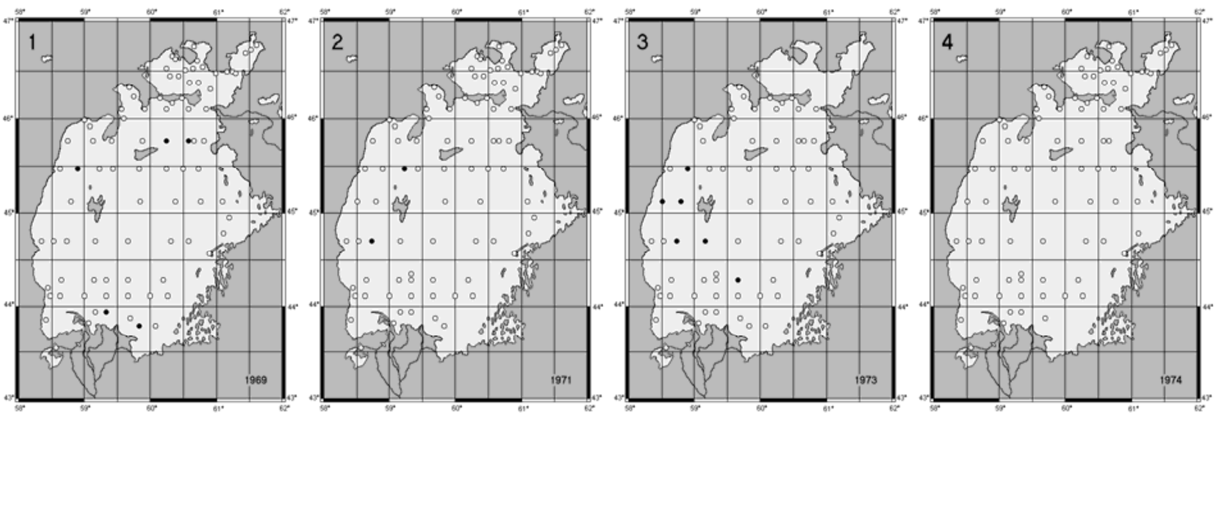

Figure 10. Disappearance of freshwater Cladocera.

○ – stations where this species was not found; ● – stations where this species was found.

The Aral Sea freshwater cladocerans *Alona rectangula* and *Ceriodaphnia reticulata* survived the introduction of planktivorous fish, but disappeared in 1974 when water salinity exceeded 12 g/l (Fig. 10). By 1975, from among the 7 species of Cladocera that formerly inhabited the Aral Sea, there remained only 4 representatives of the Pont-Caspian fauna: *Evadne anonyx*, *Podonevadne camptonyx*, *P. angusta*, and *Cercopagis pengoi aralensis*. The number of copepods also decreased sharply in 1973. The freshwater *Mesocyclops leuckarti* was replaced by the euryhaline *Halicyclops rotundipes aralensis*. Decreases in the total number of Harpacticoida (Fig. 11) were observed as well.

From 1971 to 1976, the first animals began to disappear from the zooplankton of the Aral Sea, beginning with organisms that flowed in with the rivers, followed by those that normally lived in conditions of very low salinity, and finally the main faunal components (Andreev 1989).

The rising salinity affected various species of *Dreissena* differently. Although both subspecies of *D. polymorpha* (Pallas) (*D. p. aralensis* and *D. p. obtusecarinata*) decreased in number, the number of the more halophilous *D. caspia pallasi* increased, and this species was able to tolerate salinity up to 17–20 g/l (Dengina 1959; Andreeva 1989). Because of this change and the decreasing number of other bivalve mollusks from the genus *Hypanis* Eichwald, some stabilization of areal and zebra mussels was observed in 1974–1976 (Fig. 12) (Andreev and Andreeva, 1987; Andreeva 1989).

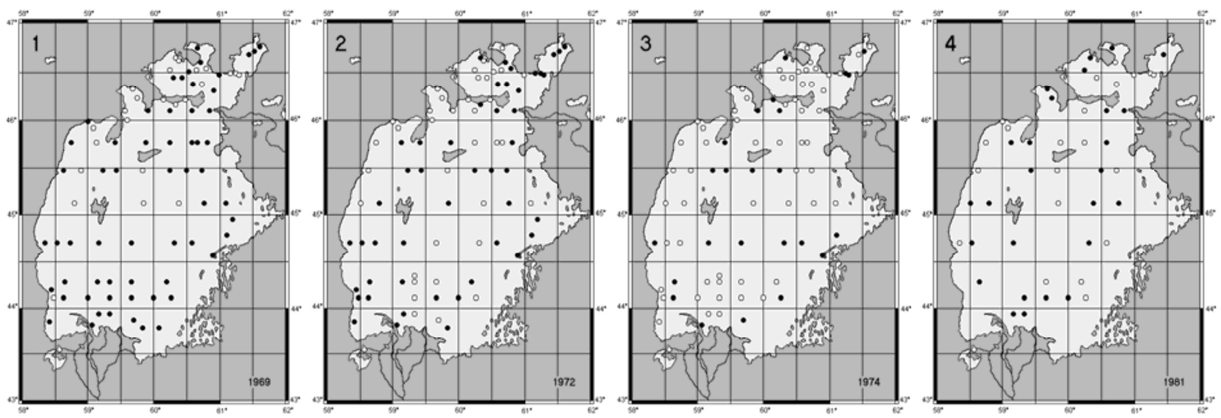

Figure 11. Distribution of Harpacticoida.

○ – stations where this species was not found; ● – stations where this species was found.

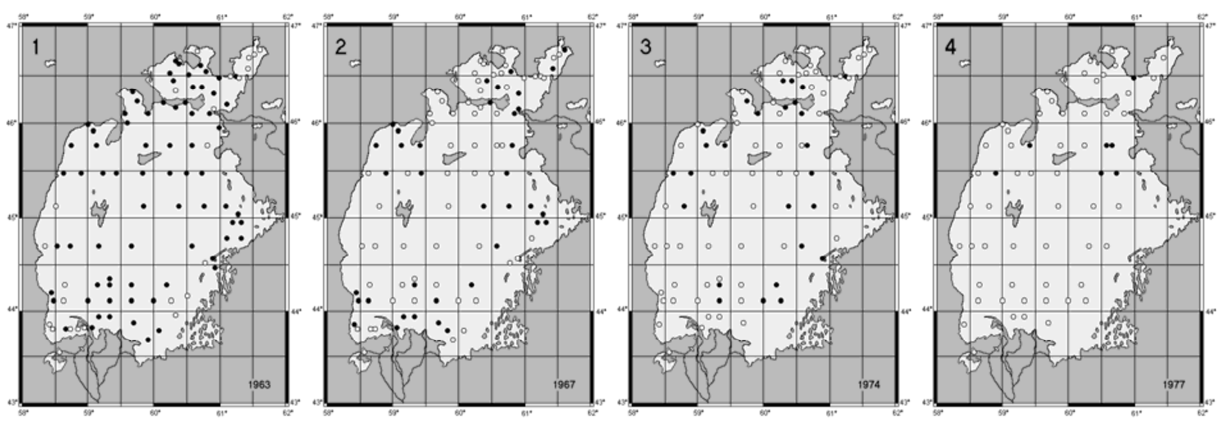

Figure 12. Distribution of bivalve mollusk Hypanis spp.

○ – stations where this species was not found; ● – stations where this species was found.

Since 1971, the euryhaline native mollusk *Cerastoderma isthmicum* expanded its habitat in the entire Aral Sea (Fig. 9) (Dengina 1959). In contrast, the abundance of and area inhabited by *C. rhomboides rhomboides* continued to decrease, and since 1978, when the sea's salinity reached 15 g/l (Fig. 1), the species was no longer observable (Andreev and Andreeva, 1987; Andreeva 1989).

The rising salinity was also favorable for the earlier introduced euryhaline bivalve mollusk *Syndosmya segmentum* (Andreev and Andreeva 1983). Living on all types of sediment – in contrast to *C. isthmicum*, which lives only on solid ground – it colonized the entire lake by 1976 and provided more than 50% of the zoobenthic biomass (Andreeva 1989; Andreev and Andreeva 1987).

The same changes occurred within the gastropods; for example, *Theodoxus pallasi* was found frequently in the Aral Sea (Andreeva 1978), but by the late 1960s, the area it inhabited and its and abundance were decreasing (Fig. 13) and the halophilous gastropods *Caspiohydrobia* spp. became dominant (Andreeva 1989).

In the 1970s, another group of crustaceans, the Mysidacea, disappeared (Andreev and Andreeva 1981). In 1973, Oligochaeta were no longer observed. In addition, the ostracod *Loxoconchissa (Loxocaspia) immodulata* (Stepanaitys) was no longer encountered. The larvae of the majority of chironomid species disappeared from the main water area by 1974 (Fig. 7). *Chironomus salinarius* (Kieffer) and *Ch. halophilus* Kieffer remained only in the salinized bays on the eastern coast (Andreeva 1989), and it was there that these halophilous chironomids endured salinity levels greater than 36 g/l (Dengina 1959).

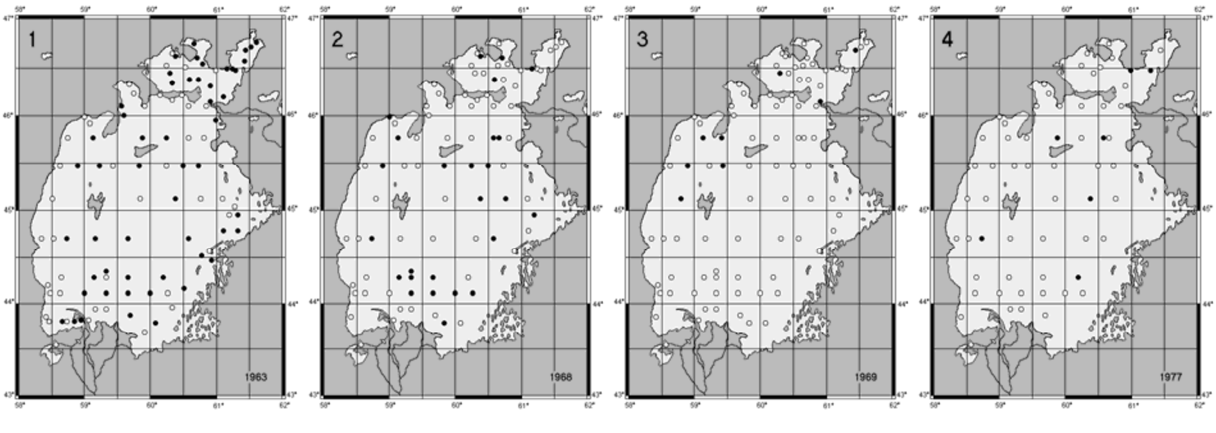

Figure 13. Distribution of gastropod mollusk Theodoxus pallasi.
○ – stations where this species was not found; ● – stations where this species was found.

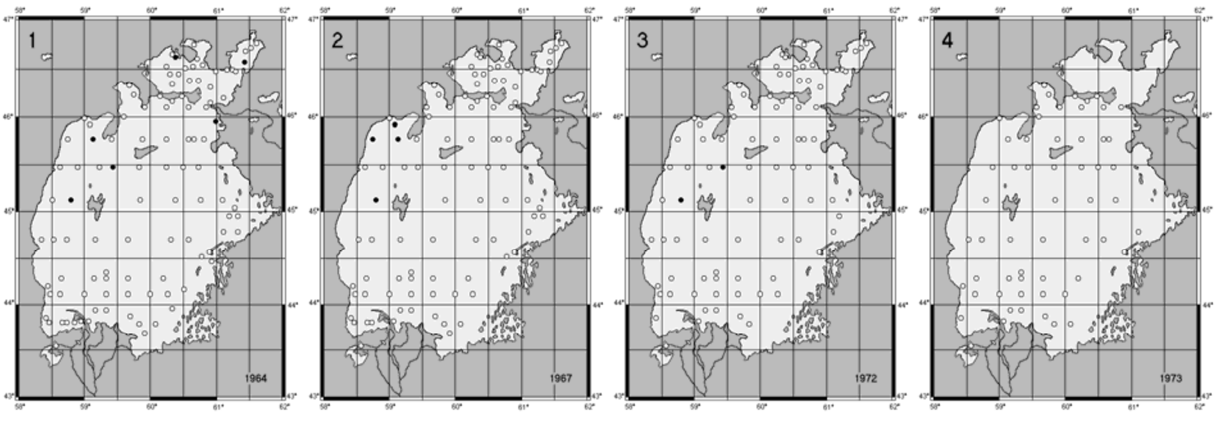

Figure 14. Distribution of Oligochaeta.

○ – stations where this species was not found; ● – stations where this species was found.

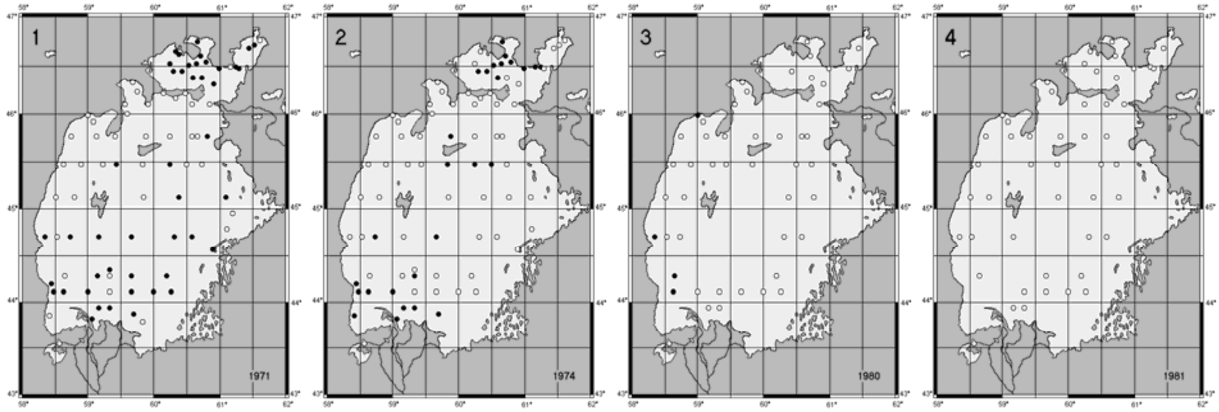

Figure 15. Dynamics of Cercopagis pengoi aralensis disappearance.
○ – stations where this species was not found; ● – stations where this species was found.

By 1974, *Hediste diversicolor* had colonized all of the Aral Sea areas and became one of the main constituents of the benthic fauna (Andreeva 1989). By 1980, the leading forms of zoobenthos became euryhaline Mediterranean-Atlantic species such as *Syndosmya segmentum*, *Cerastoderma isthmicum*, *H. diversicolor*, and halophilous gastropods from continental waters (*Caspiohydrobia* spp.) (Proskurina 1979; Andreeva 1983, 1989; Andreev and Andreeva 1987).

A strong alteration in faunal composition took place during the transition from freshwater to brackish water. Euryhaline Caspian and Mediterranean-Atlantic species replaced the more stenohaline freshwater species (Andreev and Semakina 1978; Andreev 1989). From 1976 to 1985, the progressive rise in salinity (Fig. 1) caused small changes to the Aral Sea ecosystem; it was a period of relative stabilization.

The cladoceran *Podonevadne trigona* (Sars) was identified for the first time in 1981. Most likely, it was imported incidentally to the Aral Sea (Aladin and Andreev 1981, 1984; Andreev 1989). In 1976–1979, *P. camptonyx* became the most abundant species of Cladocera and *Evadne anonyx* was encountered less frequently and in smaller numbers. The cladoceran *Cercopagis pengoi aralensis* was the most sensitive to the increased salinization of the Aral Sea (Fig. 15); it inhabited the least salinized water areas until 1980 (Balymbetov 1972).

Out of the 22 Copepoda species observed in 1976–1982, the most abundant was *Calanipeda aquaedulcis*. The euryhaline and halophilous *Halicyclops rotundipes aralensis* were distributed throughout the entire Aral Sea, but only in small numbers. The cyclopoid *Acanthocyclops bisetosus* (Rehberg) was detected rarely.

By 1977, 3 endemic subspecies of bivalve mollusks from the genus *Hypanis*: *H. vitrea bergi*, *H. minima minima*, and *H. m. sidorovi* had disappeared.

By 1984, the salinity rose to 21 g/l, and the ostracods *Darwinula stevensoni* (Brady et Robertson), *Tyrrhenocythere amnicola donetziensis* (Dubowsky), *Plesiocypris newtoni* (Brady et Robertson), *Limnocythere (Limnocythere) inopinata* (Baird), *Amnicythere cymbula* (Livental), and *Limnocythere (Galolimnocythere) aralensis* Schornikov disappeared from the benthic fauna; the widely euryhaline (Aladin 1996) *Cyprideis torosa* (Jones) is the only ostracod that remains today.

By 1987, a reduction in the number of free-living invertebrate species in the Aral Sea was observed again. By then, the salinity of the sea water had increased to 27 g/l (Fig. 1), which corresponds to the second barrier salinity (27–32 g/l) or β-horohalinicum for this water body (Aladin and Plotnikov 2011). Caspian species have started to disappear, and the ecosystem has entered its second crisis period (Plotnikov et al. 1991).

From the original fauna populations, only the rotifer *Synchaeta* spp., cyclopoid copepod *Halicyclops rotundipes aralensis*, some harpacticoid species *Nitocra lacustris* (Schmankewitsch), *Cletocamptus retrogressus*

Schmankewitsch, *C. confluens* (Schmeil), and possibly *Enchydrosoma birsteini* Borutzky, and the cladocerans *Evadne anonyx* and *Podonevadne camptonyx* survived. Of the introduced species, only the calanoid copepod from *Calanipeda aquaedulcis* survived the second crisis. Based on information gathered in the Sea of Azov, the prediction that *C. aquaedulcis* would disappear when salinization reaches 20 g/l since it stops reproducing at 15 g/l (Andreev 1978; Andreev and Semakina 1978) proved to be incorrect.

In 1988, the salinity reached 28 g/l and the cladoceran *Evadne anonyx* disappeared. By 1990, cladocerans in the Aral Sea zooplankton became fully extinct. At this level of salinity, *Calanipeda aquaedulcis* and larvae of the bivalves *Syndosmya segmentum* and *Cerastoderma isthmicum* were the dominant species.

After the second crisis, the only original species that remained were the bivalve *Cerastoderma isthmicum*, gastropod *Caspiohydrobia* spp., and ostracod *Cyprideis torosa*. The only introduced species that survived were the polychaete worm *Hediste diversicolor*, bivalve mollusk *Syndosmya segmentum*, shrimp *Palaemon elegans*, and crab *Rhithropanopeus harrisii tridentata*. The common elements of the benthic fauna were the mollusks *S. segmentum* and *C. isthmicum*.

After the Aral Sea's second crisis, a sharply reduced faunal population reached a second period of relative stability. Only marine and euryhaline species of marine origin and euryhaline halophytes from continental waters remained.

The last attempts to introduce invertebrates to the Aral Sea took place in the mid-1980s. The euryhaline bivalve mollusks *Mytilus galloprovincialis* Lamarck and *Mya arenaria* Linnaeus were introduced from the Sea of Azov; both introductions were unsuccessful. In the first case, the absence of a firm substrate to which the larvae could attach was the obvious reason. The second species, *M. arenaria*, was released on shoals that completely dried up within several months after the introduction of mollusks. Otherwise, the introduction may have been successful.

The copepod *Acartia clausi* Giesbrecht was also introduced, but in this case, the environmental niche it needed was occupied already by the earlier introduced *C. aquaedulcis.*

The history of planned and accidental acclimatization in the Aral Sea came to an end by the end of the 1980s.

The Aral Sea's dropping levels, drying deltas, and increasing salinity significantly altered the historical living conditions of Aral fish, especially their reproductive conditions. For semi-anadromous fish, the dropping water levels, the drying up of the spawning grounds in the deltaic regions, and for anadromous fish, the disappearance of migration routes to places of natural reproduction were disastrous.

In the early 1960s, the fresh-water deltaic bays and lakes still were considered the best places for spawning (Bervald 1964) and were the location in which 65–70% of the main commercial fish reproduced. The falling sea levels in the mid-1960s caused a nearly 5-fold decrease in the spawning area, and the reproduction of bream, zander, roach, and shemaya – the main fish species – decreased accordingly. In mass, the northern Aral fishes began to spawn in places that earlier were considered unsuitable. During the years when the Syr Dar'ya exhibited heavy or average flow and was connected to the lakes, fish reproduced in the lakes and juvenile fish migrated to the sea. In low-water years, such as 1974–1975, the connection of the river to the lakes was interrupted, and the spawning occurred directly in the river. In this case, the survival of larvae as they migrated to the sea was poor because of the sharp salinity shift in the mouth of the Syr Dar'ya.

In the late 1970s and early 1980s, the Syr Dar'ya was blocked by a dam that lacked discharge gates near the settlement Aklak (20 km from the mouth), and the discharge of freshwater to the sea ceased and freshwater bays disappeared. The most important of these bays were separated from the sea and remained dry until their recent restoration as separate lakes (Karashalan and Karateren).

Since 1975, marine spawning areas are less common because of the drop in sea level. Studies on the fish fauna in the coastal zone showed that juvenile yields in 1971–1975 were comprised of silverside, gobies, and sometimes noncommercial nine-spined stickle-back.

In addition, the catastrophic deterioration of natural reproductive conditions sharply influenced commercial fish populations. The fish catch in the entire Aral Sea over the 1961–1976 period decreased more than 4 times (Table 2). The first signs of the salinization's negative impacts on the Aral Sea fish fauna were observed in the mid-1960s when the salinity reached 12–14 g/l. The salinity increased faster in shallow spawning areas than in the open sea, and by 1965–1967, it exceeded 14 g/l, which negatively affected the development of roe in fish of freshwater origin. In the late 1960s, the conditions of spawning areas for semi-anadromous fish worsened in particular.

Table 2. Fish catch dynamics in the Aral Sea from 1961 to 1980 in metric tons (pre-separation of the Small and Large Aral Seas).

Fish	Year										
	1961	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Bream	8920	600	640	790	1100	1608	1975	1381	528.9	66.8	6
Carp	9940	1390	1000	990	1050	1346	328	219.5	100.9	-	373.5
Roach	6950	2360	1350	1380	1980	2277	1423	418.6	213.9	242.8	68.6
Shemaya	440	10	11	2	5	-	-	-	-	-	-
Barbel	1220	330	344	260	316	361.2	306	134.6	27.8	0.4	-
Zander	2740	8290	12	10680	6630	5351	4474	3500	2696	1689	2479
Pike	650	120	10	40	360	128.8	30	9.5	44.9	-	-
Wells	920	430	110	320	450	248.5	61	20.6	30.1	-	2.2
Asp	900	1010	1000	1460	2740	554.3	207	195.4	7.9	-	-
Snakehead	-	-	50	180	500	72.5	38	34.8	158.8	-	-
Grass carp	-	40	10	20	50	306.9	101	58.8	148.1	-	-
Silver carp	-	10	13	-	10	485.8	14	29.1	48.6	-	-
Others	1480	370	200	850	210	422.9	68	4	39	9.3	5.5
Total	34160	14960	16730	16970	15500	13462	9027	6007	4045	2009	2935

Beginning in 1971, the average water salinity in the open sea was 12 g/l, and the first signs of its negative effects were observed on adult fish populations. For many fish species, the rate of growth slowed and their numbers sharply fell.

By the mid-1970s, the average salinity of the sea exceeded 14 g/l and Aral fish completely ceased to reproduce naturally. As a result, many fish populations shrank considerably.

By 1981, the salinity exceeded 18 g/l and the Aral Sea completely lost its fishery potential. From the original species, only the nine-spined stickle-back and gobies remain in the Aral Sea, and from the introduced and acclimatized species, only silverside and Baltic herring remain. The only commercial fishery existed in the mouths of the Syr Dar'ya and Amu Dar'ya.

Since the mid-1970s, researchers of the Aral branch of KazNIIRKH carried out a selection of euryhaline and halophilic fish species based on the hydrological and hydrochemical forecasts in the Aral Sea.

They conducted experiments with Caspian sturgeon, Kura salmon, Far East coho salmon, Azov-Black Sea flounder-gloss, and flounder-turbot. The most promising experiments were on flounder-gloss, which are characterized by remarkably large ecological flexibility and an ability to reproduce at salinities ranging from 17 to 60 g/l.

In order to preserve the fishery under conditions of increasing salinization in the Aral Sea and according to the developed biological concept, 14,280 flounder-gloss from the Sea of Azov were resettled in the Aral Sea from 1979 to 1987 (Lim 1986), and they have acclimatized successfully. In the early 1990s, the species was distributed across the entire sea and provided a commercially useful population in water with a salinity ranging from 15 to 50 g/l. The acclimatized flounder-gloss represents the only commercial species in the Aral Sea from 1991 to 2000 (Table 3).

Table 3. Dynamics of flounder-gloss catch in the Small Aral Sea from 1991 to 2004 in metric tons (period between separation of the Small and Large Aral Seas and construction of the Kokaral Dam).

Years											
1991	1992	1993	1996	1997	1998	1999	2000	2001	2002	2003	2004
50	100	85	650	720	945	1050	1155	1225	1260	1350	1230

Fauna after the Aral Sea division

The drop in Aral Sea levels by 2–2.5 m in 1968–1969 caused the Auzy-Kokaral strait to dry up. By 1988–1989, the level dropped to the +40 m mark (Fig. 1) and Berg’s strait dried up as well. The total area of the Aral Sea by this time had declined by nearly 40,000 km^2 (60% of its size in 1960), the volume had decreased by 333 km^3 (33% of the 1960 volume), and the average salinity reached 30 g/l (Fig. 1). The former brackish-water Aral Sea had split into 2 polyhaline water bodies — the Small and Large Aral Seas, and its transformation into a complex network of residual water bodies with different evolutionary prospects has begun (Aladin and Plotnikov 2011).

The Small Aral Sea

With the collapse of the USSR, the withdrawal of Syr Dar’ya water for irrigation purposes had decreased, and since the 1990s, the runoff from the Syr Dar’ya into the Small Aral Sea has increased. As water inflow to the Small Sea exceeded evaporation from the surface, the surplus began to run off through the dried up Berg’s strait to the Large Aral, and a slow decrease in the salinity of the Small Sea was initiated. One result of increasing Small Aral Sea levels was an increased effluent through Berg’s strait into the Large Aral Sea. This presented the risk for further deepening of this watercourse, gradual destruction of the natural barrier between the Large and Small Aral Sea, and the renewal of falling Small Sea levels. Furthermore, this channel was able to reach the mouth of Syr Dar’ya, from which the runoff would be routed directly to the Large Aral Sea, posing a threat of total desiccation to the Small Sea. To prevent such a possibility and to preserve the Small Aral Sea, the former Berg’s strait was closed by a low dam in 1992. The Small Aral Sea levels began to rise and the salinity continued to decrease gradually. The southern part of the separate and dried up Bolshoy Sary-Cheganak bay was filled with water again, and the separation of Butakov and Shevchenko Bays was prevented. On the other hand, the damming of runoff through Berg's strait has accelerated the drop in Large Aral Sea water level (about 3 km^3 per year) and increased its salinity. However, this process was impossible to stop or retard (Aladin et al. 1995).

The construction of the dam in the former Berg's strait in 1992 was insufficient; in particular the absence of any flood control outlet had a huge negative impact. For this reason, the dam was broken repeatedly, especially during the vernal level increases of the Small Aral, and was repaired each time. However, after its complete destruction in April 1999 by a storm, the dam was not restored. After some years, the government of Kazakhstan has decided to construct a new solid dam in Berg's strait. The construction began in 2004 and was completed in the autumn of 2005. This modern dam is well-constructed and has flood-control outlets for dumping surplus water and maintaining the Small Sea level at the secure +42–43 m mark.

Animals reappeared in the Small Aral Sea soon after the division and before the construction of the dam. The cladoceran *Podonevadne camptonyx,* which vanished in 1980, re-emerged from eggs resting in Small Sea plankton (Fig. 1). In 1999, the larvae of chironomids (Aladin et al. 2000), which were not observed since 1974, appeared again in the benthos.

The present salinity of the Small Aral Sea (except for Butakov Bay) has decreased to 14 g/l, and as its salinity continues to decrease, the recovery of the Small Sea as a brackish-water lake appears possible.

The fresh-water zone area and the population of commercial fish species increased considerably. The fish fauna expanded their zone of spawning and feeding to include nearly the entire Small Aral Sea, with the exception of Butakov Bay, where the salinity remained too high. The relative stabilization of the hydrological regime and the freshening of the Small Aral Sea resulted commercial-level abundance of valuable food fish species (e.g., carp, bream, zander, and asp) (Table 4).

The salinity of the Small Aral Sea is expected to decrease further, and it is expected to become, once again, a brackish-water body. Because of this shift, an increase in the number of indigenous generative-freshwater fishes and a recovery of fishery importance can be expected for this part of the Aral Sea.

Presently under examination is a project to fill the Bolshoy Sary-Cheganak Bay and increase its levels up to the +47–48 m mark. For this to occur, a dam needs to be built in the narrow entrance to the bay with an overflow and a channel to feed the water supply from Syr Dar'ya to this bay directly, thus creating the Bolshoy Sary-Cheganak Bay as a new, mostly freshwater body. Thus, the Small Aral Sea may be transformed into a cascade from 2 water bodies and not exist as a stagnant, almost freshwater body with a level +47–48 m levels and a brackish-water body with a level +42–43 m.

Table 4. Dynamics of fish catch in the Small Aral Sea from 2005 to 2008 in metric tons (post-construction of Kokaral dam).

Year	Total	Fish species							
		Flounder	Bream	Zander	Carp	Roach	Asp	Sabrefish	Others
2005	695	303	57	30	181	-	-	-	124
2006	1360	700	120	70	190	250	30	-	-
2007	1910	640	410	260	260	370	80	40	-
2008	1490	410	360	170	170	340	90	-	-
2009	1885	615	470	185	125	410	80	-	-
2010	2810	715	835	245	115	765	70	65	-

The Large Aral Sea

After the division of the Aral Sea and the construction of the dam in Berg's strait in the 1990s, the runoff from the Small Aral Sea was reduced. The water level in the Large Aral Sea dropped considerably and its salinization accelerated. The runoff of Amu Dar'ya reaches the Large Sea from the south only occasionally and in small volumes.

Because the Large Aral Sea level dropped below the +34 m mark, Vozrozhdeniya Island greatly increased in size, and in 2001, was connected at its south end to the mainland to form a peninsula. The Large Aral Sea has divided into the Western and Eastern Large Aral bodies that are connected only by a channel in the north stemming from Vozrozhdeniya Island. As a result, the salinity in the shallow eastern basin of the Large Sea has risen more sharply than the salinity in the western, deeper portion. The strait joining them is shallow, and because of bottom erosion by currents between western and eastern basins, a narrow channel formed in 2001–2002 (Zavyalov et al. 2006). In 2006, the Tsche-Bas Bay separated from the Eastern Large Aral. By the end of 2009, the Eastern Large Aral had nearly dried up.

The rapid rise in the Large Aral Sea's salinity led to rapidly changing biota composition. By the end of the 1990s, the separate Large Aral Sea had become a hyperhaline water body with fauna that display characteristics of adaptation to the new environmental conditions.

By 1997, a salinity concentration of 57 g/l allowed the zooplankton *Calanipeda aquaedulcis* to dominate, whereas rotifers of the genus *Synchaeta* disappeared. In the second half of the 1990s, the majority of the remaining few rotifer species disappeared, along with the original copepod *Halicyclops rotundipes aralensis*, the shrimp *Palaemon elegans*, and the crabs.

By 2001, a salinity of 67 g/l caused the composition of zoobenthos species to change significantly. The polychaete worm *Hediste diversicolor* and bivalve mollusk *Cerastoderma isthmicum* disappeared. By 2002, the bivalve mollusk *Syndosmya segmentum* disappeared as well.

According to some authors, the benthic fauna of the Western Large Aral – the gastropods *Caspiohydrobia* spp. (Mirabdullayev pers. comm.) and ostracod *Cyprideis torosa* – still exist (Zavyalov et al. 2006).

Since the shift to hyperhaline conditions, a series of invertebrate species have been identified in the Large Aral. These species were absent in the Sea previously, but lived in the saline water bodies of the Aral Sea region. The introduction of this species followed natural distribution mainly by aeolian transfer of resting stages.

In 1996, *Moina mongolica*, which disappeared in 1973, returned to the Large Aral, and the brine shrimp *Artemia parthenogenetica* Bowen et Sterling appeared, becoming the dominant zooplankton species. In 2004, the halophilous copepod *Apocyclops dengizicus* (Lepeschkin) appeared in the Western Large Aral (Mirabdullayev pers. comm.; Mirabdullayev et al. 2007). Two original rotifer species, *Hexarthra fennica* Levander and *Brachionus plicatilis*, are found in abundance now, but formerly, they were few in number. During the summer months, the infusorium *Fabrea salina* Henneguy is a common zooplankton species. Further, the halophilous ostracod *Eucypris inflata* Sars and the original *Cyprideis torosa* are found in the Western Large Aral (Aladin and Plotnikov 2008).

A large number of larvae of the halophilous chironomid *Chironomus salinarius* (Mirabdullayev pers. comm.; Mirabdullayev et al. 2007), euryhaline indigenous turbellarian worm *Mecynostomum agile* Jensen, and large infusorium *Frontonia marina* Fabre-Domergue comprise part of the benthic fauna of the Western Large Aral. The Eastern Large Aral contains *Artemia parthenogenetica* alone (Aladin and Plotnikov 2008).

When the salinity of the Large Aral Sea reached 60–70 g/l in the late 1990s, the flounder introduced also was extinct and no fish fauna remained.

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