Biodiversity loss in a saline lake ecosystem

Effects of introduced species and salinization in the Aral Sea

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The ecological crisis of the Aral Sea has been widely discussed during recent years in both the scientific and popular literature. However, only the consequences of anthropogenic desiccation and increased salinity were usually discussed with little note of the role played by introduced species in this ecosystem (Micklin, 1991; Williams, Aladin, 1991; Keyser, Aladin, 1991). We review the role of introduced species during periods of changing salinity.

Between the middle of the 19th century and 1961 the Aral Sea state was stable, its shape and salinity of practically did not change. The Aral Sea was the 4th largest lake in the world by water surface area in 1960. At that time its area was 67,499 km^2 (Large Aral 61, 381 km^2, Small Aral 6118 km^2) volume was 1089 km^3 (Large Aral 1007 km^3, Small Aral 82 km^3). The Aral Sea was +53.4 m above ocean level with maximum depth 69 m. area of the Aral Sea is about 1,500,000 km^2. The Aral Sea was a slightly saline lake with average salinity about 10 g/l.

Water salinity is one of major environmental factors influencing hydrobionts. Ascertainment of specificity of the attitude of aquatic animals and plants to this factor is important to understand both autoecological and synecologial rules. Conception of relativity and plurality of water barrier salinity zones was formulated more than 20 years ago (Aladin, 1986a, 1986b). The main theses were published in the Journal of General Biology (Aladin, 1988). Two main theses were stated:

1. Zones of barrier salinities are relative to the degree of perfection of hydrobionts osmoregulatory capacities and to the water chemical composition.

2. There are several zones of barrier salinities and they are unequal in their importance.

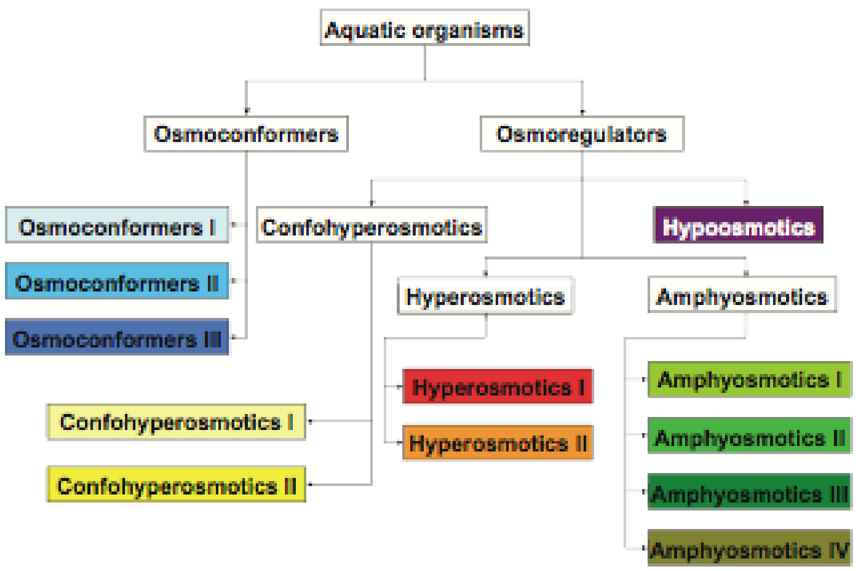
All the hydrosphere of our planet could be conditionally divided into freshwater, brackish water, marine and hyperhaline zones with their own types of ecosystems. Revealing barrier salinity zones in the hydrosphere supposes studying osmoregulatory capacities of aquatic organisms first of all. It is to reveal types of osmotic relations of internal media with the environment, to find experimentally limits of salinity tolerant ranges, to analyze data on salinity boundaries of aquatic organisms distribution in the nature (Fig. 1).

Pre-1960: Effects of Alien Species

At the beginning of the 1960s anthropogenic desiccation of the Aral Sea begun with tremendous implications for its salinity and hence the life within it. At that time the lake was inhabited by about 12 species of fishes and about 150 species of free-living invertebrates excluding Protozoa and small-size Metazoa. Figures 2 and 3 show the osmoconformity and osmoregulation characteristics of the native and alien species in that era. It is important to note that some of them were recently introduced by humans into the lake ecosystem. Figures 4 and 5 show the tremendous numbers of species that had introduced. The consequences of this were for the ecosystem as neutral, positive and negative.

The first introductions of exotic species into the Aral Sea occurred when in 1929-1932 there was unsuccessful an attempt to introduce (by developing eggs) plankton-eating Caspian shed *Alosa caspia*. This introduction was unsuccessful and had no influence on the Aral ecosystem. The next

Figure 1. Classification of osmoconformers and osmoregulators.



was also unsuccessful introduction in 1933-1934 of stellate sturgeon *Acipenser stellatus* in order to enrich commercial stocks of sturgeon fishes in the Aral Sea represented only by bastard sturgeon *A. nudiventris* (Karpevich, 1975). While transported from the Caspian Sea mature and young fishes didn't survive, the consequences were significant and negative. Introduced sturgeons infected aboriginal ones with gill parasite monogenetic trematode *Nitzschia sturionis* and parasite of sturgeon eggs coelenterate *Polypodium hydriforme* which were not in the Aral Sea before. So, the first parasite was pathogenic for aboriginal surgeons and caused epizooty between them and their mass death as a result (Dogel, Byhowsky, 1934; Dogel, Lutta, 1937). Commercial stocks of sturgeon fishes instead of enriching were undermined. Thus, the first attempts of exotic species introduction to the Aral Sea can be considered extremely unsuccessful.

Attempts to settle exotic species in the Aral Sea were continued after the Second World War. The main basis of these actions was an idea that because there were few sturgeons and plankton-eating fishes in the Aral Sea, introduction of new consumers of plankton and benthos would increase the fish productivity (Karpevich, 1947, 1948, 1953, 1960, 1975). On the basis of these considerations, in 1948-1963 from the Caspian Sea starred sturgeon *Acipenser stellatus* was introduced again, and in 1958 a subspecies of bastard sturgeon *A. nudiventris derjavini* from Ural River was introduced. These introductions were unsuccessful as before. Both species failed to persist and only in 1958 some individuals of starred sturgeon were caught last time (Karpevich, 1975).

In the same years (1954-1956) mullets *Lisa auratus* and *L. salensis* were introduced from the Caspian. This attempt was also unsuccessful (Karpevich, 1975) possibly because these planktophages could not find sufficient amount of convenient food to survive.

Figure 2. Native aquatic animal species with the different types of osmoconformity and osmoregulation in the Aral Sea.

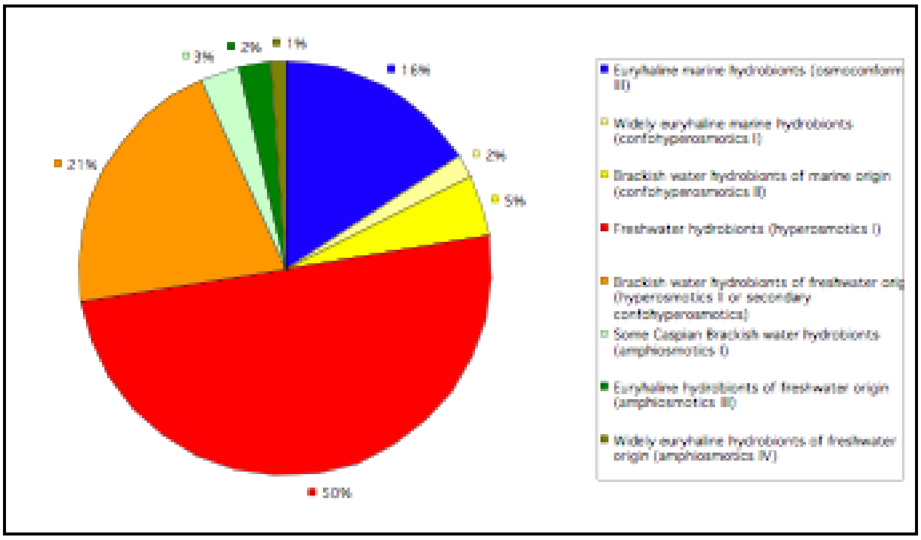
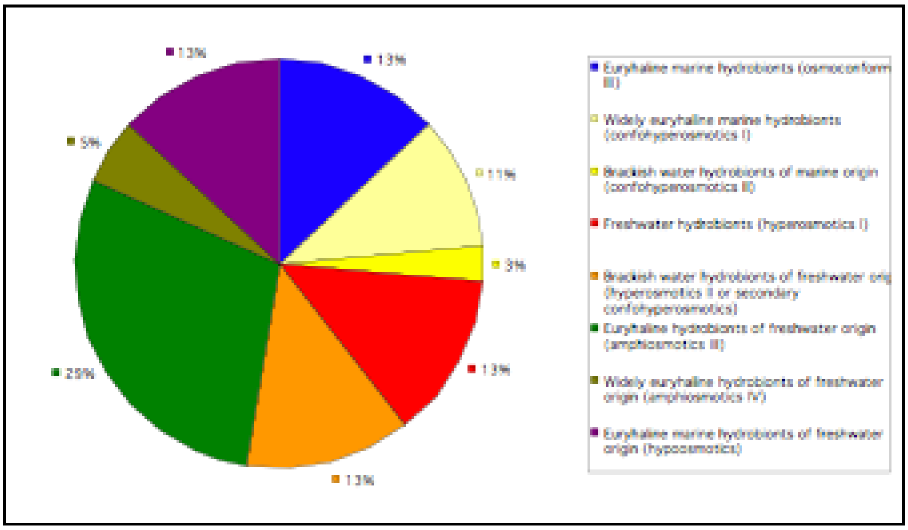


Figure 3. Alien aquatic animal species with the different types of osmoconformity and osmoregulation in the Aral Sea.



Successful was the introduction (1954-1959) and acclimatization of plankton-eater Baltic herring *Clupea harengus membras*. Beginning in 1957 this commercial fish appeared in catches in large number. The pressure on zooplankton increased sharply and the average summer biomass of zooplankton decreased by more than 10 times (Karpevich, 1975; Yablonskaya, Lukonina, 1962; Kortunova, 1975).

This exotic planktophage became naturalized in the Aral Sea, and caused significant changes in the zooplankton community. Beginning in 1957 Baltic herring appeared in catches in large number. The pressure on zooplankton increased sharply and the average summer biomass of zooplankton decreased more than 10 times - from 160 mg/m^3 to 10-15 mg/m^3 (Karpevich, 1975; Yablonskaya, Lukonina, 1962; Kortunova, 1975). Introduced this plankton-eating fishes led to the extermination and further extinction of such large crustacean zooplankters as *Arctodiaptomus salinus*, *Moina mongolica*, *Alona rectangula*, *Ceriodaphnia reticulata* predominated in the zooplankton. Decreased zooplankton abundance and biomass affected the number of herring and its number decreased fast (Kortunova, Lukonina, 1970).

During the aforesaid intentional introductions, many fish and invertebrate species were introduced into the Aral Sea accidentally. Among them there were many non-commercial and even undesirable fishes. For example, six species of gobies, three of them - bubyr *Knipowitschia caucasicus*, monkey goby *Neogobius fluviatilis pallasi* and round goby *N. melanostomus officinus* - had naturalized successfully. Also was successful accidental introduction of silverside *Atherina boyeri caspia* and pipefish *Syngnathus abaster caspius* and they quickly invaded the whole Aral Sea (Karpevich, 1975). These fishes became competitors for young aboriginal fishes.

It could be that accidently introduced and successfully naturalized shrimp *Palaemon elegans* competing with aboriginal euryhaline amphipod *Dikerogammarus aralensis* step by step caused its extinction.

At the same time (in 1958-1960), besides introductions into the Aral Sea proper, a complex of fishes and invertebrates was introduced into deltaic areas of Syrdarya and Amudarya. From river Don were successfully introduced 3 mysid species *Paramysis baeri*, *P. lacustris* and *P. ullskyi*. Two of them (*P. lacustris, P. intermedia*) became numerous the third (*P. ullskyi*) has naturalized but remained rare (Karpevich, 1975).

Also there were introduced three species of freshwater fishes of China complex: grass carp *Ctenopharyngodon idella*, silver carp *Hypophtalmichthys molitrix* and *Aristichtys nobilis* along with incidental introductions into the deltaic areas of three other species of this complex: black carp *Mylopharyngodon piceus* and snakehead *Channa argus*. Except for *A. nobilis*, all these species naturalized successfully and became of commercial value (Karpevich, 1975). These naturalized Chinese fishes and mysids invaded estuaries of Amudarya and Syrdarya and migrated from the deltas into the Aral Sea proper.

When comparing consequences of introductions in deltaic areas with those in the Aral Sea proper one may note that the first were more successful and practically had no negative impact. However, even in the case of the deltas, there were no significant rises in catches of commercial fishes or increasing food resources.

Post-1960: Effects of Salinity Rise

Since 1960 the Aral Sea has began steadily to shrink and become shallower owing to the overwhelmingly to irrigation withdrawals from its influent rivers (Amu Darya and Syr Darya). Fast anthropogenic desiccation and salinization of the Aral Sea prompted efforts to introduce euryhaline species able to endure constantly increasing salinity.

At the beginning of 1960s polychaete *Nereis diversicolor* and a bivalve *Abra ovata,* were introduced from the Sea of Azov. The first species became numerous since 1963 and the second since 1967. They both became valuable food for benthophage fishes. In the middle of 1960's there was an unsuccessful attempt to introduce bivalve mollusk *Monodacna colorata* (Karpevich, 1975). In the middle and end of 1960s and in the beginning 1970s there were attempts to introduce planktonic invertebrates. Candidate for introduction included two euryhaline copepods - *Calanipeda aquaedulcis* and *Heterocope caspia*. The first species naturalized successfully and since 1970 is a dominant zooplankter of the Aral Sea (Kazakhbaev, 1974; Andreev, 1978) and substituted for the former dominant *Arctodiaptomus salinus*,

Figure 4. Number of invertebrate species introduced by man including not naturalized.

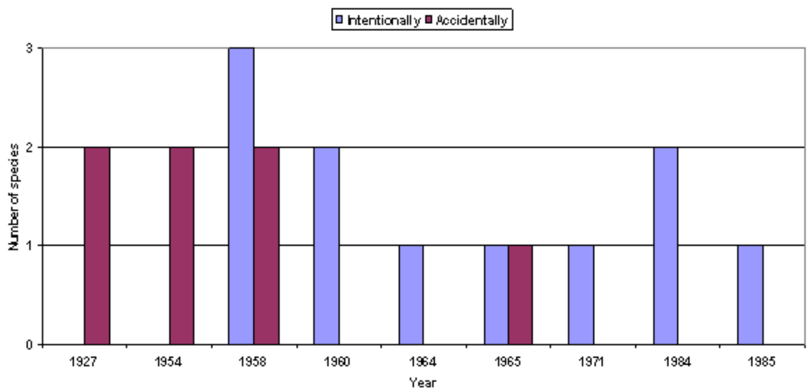
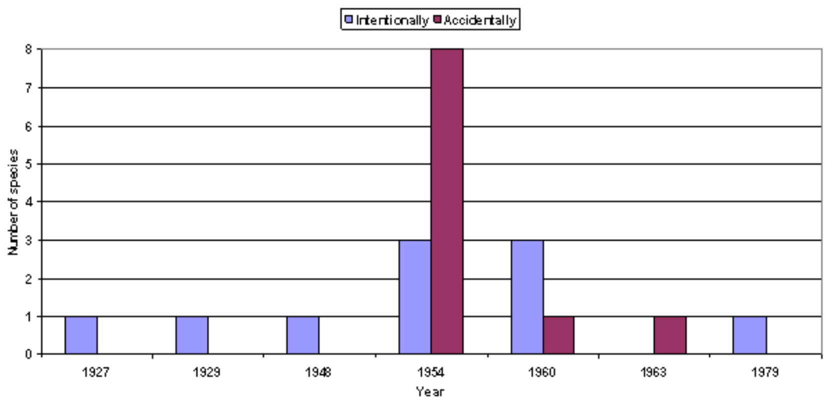


Figure 5. Number of fish species introduced by man including not naturalized.



exterminated by Baltic herring. The second exotic species did not naturalize. Due to their high euryhalinity these species survived further Aral Sea salinization and left dominants in zoobenthos and zooplankton.

During these introductions of planktonic copepods, larvae (zoëa) of crab *Rhithropanopeus harrisii tridentata* were accidentally introduced and since 1976 this benthic crustacean is widespread in the southern water area of Aral Sea (Andreev, Andreeva, 1988).

Acclimatization of euryhaline planktonic and benthic invertebrates could be regarded as an example of well thought-out and successful introduction. These euryhaline species succeeded to save the feeding value of zooplankton and benthos under conditions of the Aral Sea anthropogenic salinization.

A positive role of euryhaline acclimatizants is especially clear since the beginning and middle of 1970's when salinity of the Aral water exceeded 12-14 g/l and fresh and brackish water organisms of plankton and benthos began to die out.

However, rising salinity negatively affected the ichthyofauna. The early stages of ontogenesis in freshwater fishes originally dominating in the Aral Sea were particularly vulnerable. Survival of larvae and fries of these fishes sharply began to decrease even at salinity increases of 1-2 g/l from 8-10 g/l. Nearly all freshwater fishes and invertebrates existed in the Aral Sea at the upper limit of their salinity tolerance range, and this explains why they have disappeared so quickly (Karpevich, 1975; Aladin, Kotov, 1989; Plotnikov et al., 1991). During only one decade, since the anthropogenic desiccation began, more than 50-70% of fishes and free-living invertebrates became extinct in the Aral Sea.

Under these extreme conditions, when acclimatization of euryhaline invertebrates was successful, the idea of introducing euryhaline commercial fishes was suggested. At the end of 1970s flat-fish *Platichthys flesus* from the Sea of Azov were introduced. Since 1981 this commercial fish is ubiquitous in catches (Lim, Markova, 1981). Of the 20 aboriginal fish species in the Aral Sea, only the euryhaline stickleback *Pungitius platygaster aralensis* could remain. All other aboriginal fishes disappeared due to salinization and only some of them remain in deltas and deltaic water bodies of Amudarya and Syrdarya. Successful acclimatization of plaice allowed fisheries to continue on the Aral Sea. At the beginning of the1980s, besides these two fishes the accidentally introduced atherine and 2-3 species of gobies were also present.

At the end of 1970s and in the beginning 1980s the last attempt to introduce sturgeons in the Aral Sea was undertaken. In this case Russian sturgeon *Acipenser guldenstadti* was introduced (Lim, Markova, 1981). But this attempt could not be successful because the salinity of the Aral Sea reached 18-20 g/l, which is very high for this species. Besides, natural anadromous migration for spawning was prevented because the deltas of Amudarya and Syrdarya had become very shallow.

In the middle of 1980s attempts to introduce euryhaline invertebrates into Aral Sea continued. One tried to introduce bivalves *Mytilus galloprovincialis* and *Mya arenaria* from the Sea of Azov. Both introductions were unsuccessful. In the first case, it was because of the absence of solid bottom substrates essential for mussel attachment. The second species was released in shallows, which dried up within months due to continuous lake level lowering. If this quick desiccation of shallows had been taken into consideration, successful introduction of *Mya arenaria* could be possible.

In the same years was introduced planktonic copepod *Acartia clausi*, but it did not naturalized in the Aral Sea. Possibly due to insufficient number of released individuals but perhaps also because the ecological niche was already occupied by acclimatized *Calanipeda aquaedulcis*.

At the end of 1980s the history of planned and accidental introductions in the Aral Sea finished. Since then, only natural colonizations, unconnected with human activity, occurred.

Classifying Salinty Types

Following main principles of conception of relativity and plurality of salinity barrier zones (Aladin, 1986, 1988;

Table 1. Various Salinty Zones.

Zones	Aral	Caspian	Ocean
Basic freshwater	0-3 ‰	0-2.5 ‰	0-2 ‰
Transitional freshwater-brackishwater	3-8 ‰	2.5-7 ‰	2-5 ‰
Basic brackishwater	8-13 ‰	7-11 ‰	5-8 ‰
Transitional brackishwater-marine	13-29 ‰	11-28 ‰	8-26 ‰
Basic marine	29-42 ‰	28-41 ‰	26-40 ‰
Transitional marine-hyperhaline	42-51 ‰	41-50.5 ‰	40-50 ‰
Basic hyperhaline	> 51 ‰	> 50.5 ‰	> 50 ‰

Aladin, Plotnikov, 2007) the following salinity zones were suggested for oceanic, Caspian and Aral waters (Table 1).

Originally in the Aral Sea there were freshwater, transitional freshwater-brackishwater, brackishwater and transitional brackishwater-marine ecosystems. Brackishwater ecosystems occupied the largest area. By the end of 1980s, due to salinity growth, marine ecosystems appeared in the Aral Sea and occupied the largest area instead of brackishwater ecosystems. Now all parts of the Large Aral are occupied by hyperhaline ecosystems. In the Small Aral transitional brackishwater-marine ecosystems are prevailing due to salinity decrease (Fig 6.).

Since the end of 1980s, when the level dropped by about 13 m and reached about +40 m a.s.l., the Aral Sea divided into the Large and Small Aral. Figures 7 and 8 show the changes in the osmoconformity and osmoregulation characteristics of the native and alien species in this era compared with Figures 2 and 3.

In 1989 continued desiccation of the Aral Sea led to its division into two lakes, which have evolved in different ways. The Small Aral Sea, located in the North, receives run-off of the Syrdarya River and began to overfill due to positive water balance. The surface area of this lake is small, and evaporation from its surface is less than inflows from the Syrdarya, atmospheric precipitation and ground waters. As for the Large Aral Sea in the south, its water balance is negative, and evaporation from its huge surface is still higher than the small inputs of the Amudarya River, atmospheric precipitation and ground waters (Aladin, Plotnikov, Potts, 1995). This difference in the hydrological regimes of the two new lakes has led to stabilization of the Small Aral Sea level and continued desiccation and salinization of the Large Aral Sea.

The salinity of the Aral Sea was about 28-30 g/l at the moment it divided into two lakes at about +40 m asl (Aladin, Plotnikov, Potts, 1995; Aladin, 1995) and their fauna and flora were similar. But biological differences between this two water bodies appeared very quickly due to different hydrological regimes.

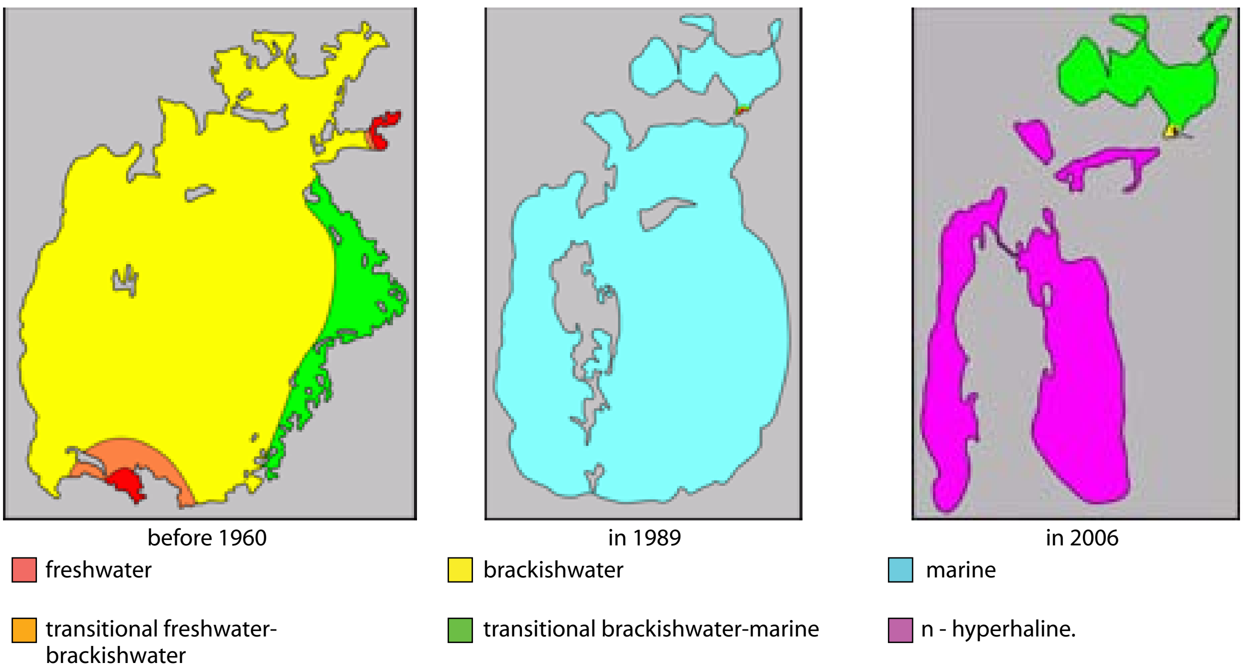
Overall, in 1961 before anthropogenic desiccation and salinization the Aral Sea was a brackish lake with average salinity 8-10 g/l, and its level was about +53 m asl (Zenkevich, 1963). Its ecosystem was characterized by low biodiversity and biological productivity. With salinization and level fall biodiversity and productivity decreased and the ecosystem was transformed from brackish water into mesohaline where surviving aboriginal and introduced euryhaline and marine species of fishes and invertebrates predominated (Plotnikov et al., 1991). At the time dividing into two lakes, only 7 species of fish, 10 common zooplankton species, and 11 common benthos species were present.

Recent History

The recent history of the Aral Sea can be viewed as including three critical periods (Plotnikov et al., 1991) followed by the current period in which two distinct lakes are evolving differently. As seen above, the first crisis in 1957-1960 was associated with planned and accidental introductions into the Aral Sea ecosystem.

The second crisis period took place in 1971-1976 when salinity of Aral increased to above 12-14 g/l and brackish water species of fresh water origin disappeared. Freshwater and

Figure 6. Ecosystems in the Aral Sea in the relation to salinity:

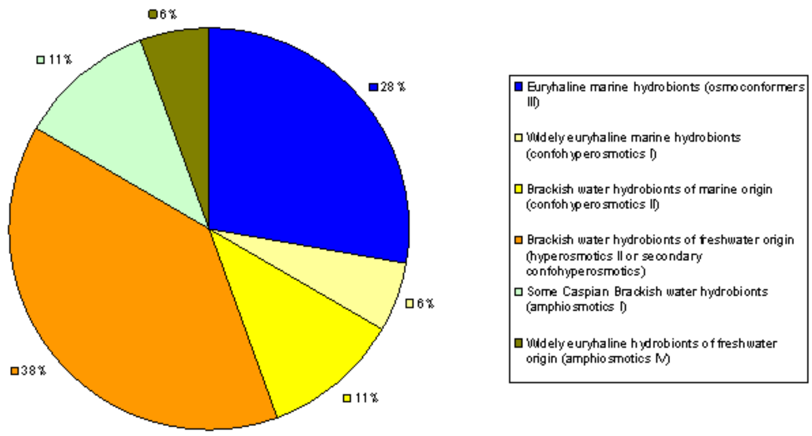


brackish water species of freshwater origin disappeared in 1971-1976, when salinity exceeded 12-14 g/l.

The third crisis was initiated in 1986 when salinity exceeded 23-25 g/l and lasted until the Aral Sea division in 1989. During this time brackish water species of Caspian origin became extinct (Plotnikov et al., 1991). The current period began with partition of the Aral Sea in which both parts inherited a common fauna.

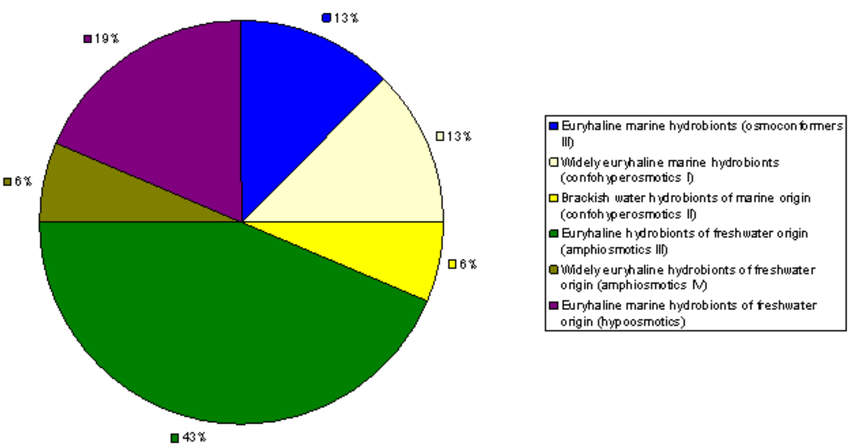
After division in 1989 the Small Aral Sea stabilized at +40 m asl and began to rise due to positive water balance (Aladin, 1995; Aladin, Potts, Plotnikov, 1995). As a result waters of the Small Sea began to flow southward into the Large Aral. This outflow did not occur over all the surface of the dried bottom of former Berg's strait but only in its central part, which was earlier dredged. This dredging had begun in 1980s when water level in Berg's strait has fallen so much as to cause troubles for shipping. At that time a navigation canal was cut between the northern and southern basins. In spring 1989, this canal was visible and a slow southward current was present in autumn. This flow was due to declining lake levels in the Large Aral. The flow sharply increased with continuing desiccation of the Large Aral and reached 100 m^3/sec as the Large Aral level fell to +37.1 m, a difference between the two lakes reaching 3 m. This strong stream eroded the bottom and threatened to almost completely drain the Small Aral Sea (Aladin et al., 1995). To prevent this, the canal between the Large and Small Aral was dammed in July-August 1992 and the flow stopped. In the next years this dam in Berg's strait was partly destroyed by floods and restored several times. The dam existence allowed to raise the Small Aral Sea level up to +42.8 m at April 1999 and to decrease salinity from 29.2 g/l (at division) to 18.2 g/l. Unfortunately in late April 1999 the dam was completely destroyed by waves due to the rise of Small Aral level. After 7 years the level returned to the mark +40 m. Dam restoration has not been undertaken and waters of Small Aral are again flowing out to the south. They do not reach the Large Aral and are lost in sands and salt marshes north of former Barsakelmes Island.

Figure 7. Native aquatic animal species with the different types of osmoconformity and osmoregulation in the Aral Sea during separation.



The Russian company "Zarubezhvodstroy" built the new dike in Berg strait. It was completed in autumn 2005. In 2006 spring the level of Small Aral reached the design level of 42-42.5 m, well ahead of schedule. The Small Aral area now is about 3,382 km^2, volume 29.5 km^3, inflow from Syr Darya 3.5 km^3/year, and outflow via Berg strait 1.15 km^3.

Figure 8. Alien aquatic animal species with the different types of osmoconformity and osmoregulation in the Aral Sea during separation.



In spite of the significant decrease in salinity which allowed fishes from Syrdarya to forage in the Small Aral, the number of fish species resident in the Small Aral remained at seven, the same ones present at the prior partitioning of the Aral Sea. Of these only plaice is of commercial value. Some fishes from Syrdarya, pike-perch (*Zander lucioperca*) for example, that can now forage in a large part of the Small Aral cannot be considered as the salinity of the Small Aral is still high for reproduction of these fishes.

Level raise and salinity decrease were favorable not only for ichthyofauna of Small Aral, but for its zooplankton and zoobenthos as well. Thus, two species of Cladocera: *Moina mongolica* and *Evadne anonyx* reappeared, and the number of *Podonevadne camptonyx* increased. Appearance of *E. anonyx* could be explained by peculiarities if its life cycle. Cladocera from family Podonidae, to which *E. anonyx* belongs, have latent (resting) eggs, sinking in water and capable of surviving under unfavorable conditions for some years in a stage of diapausing embryos. Before the Aral Sea division *E. anonyx* was observed for the last time in the northern water area in summer 1988 when salinity exceeded 25 g/l. Later this species was not found in zooplankton during some years. But, when in 1993 salinity of Small Aral decreased below 25 g/l, *E. anonyx* probably hatched from resting eggs surviving on the sea bottom.

New species appeared in the Small Aral zoobenthos. Two species of Ostracoda - *Eucypris inflata* _ *Heterocypris salina* were added to remaining *Cyprideis torosa*. They were never recorded in the Aral Sea before and were first noted in 1995 in Bolshoy Sary-Chaganak bay after refilling due to construction of the dam. Invasion of these species of Ostracoda, was evidently the result of their spreading by dust-salt storms. Both these euryhaline species have latent stages, enduring freezing and desiccation and are easily transported by wind. We conclude that aeolian transfer is becoming a significant factor in maintaining and introducing new species into water bodies of Aral Sea region.

At the end of 1990s, when the average salinity of Small Aral decreased to 18 g/l, larvae of Chironomidae appeared in the benthos again. Before anthropogenic desiccation and increased salinity some species of Chironomidae were main components of the zoobenthos. Now, following more than 30 years absence, larvae of *Chironomus halophilus* have re-appeared (Aladin et al., 2002). In the near future, larvae of other Chironomidae may appear in the Small Aral, as the deltaic water bodies of Syrdarya and others saline water bodies of the Aral Sea region contain many species of Chironomidae, imagoes of which are able to actively (flight) or passively (aeolian transfer) reach the Small Aral area and lay eggs. Return of Chironomidae larvae into Small Aral (natural reintroduction) is a sign of increased benthic productivity. The >10 g/l salinity decrease that occurred during the period of dam in the Berg's strait, positively affected other components of the zoobenthos as well.

After division in 1989, the Large Aral Sea level continued to decline due to a negative water balance and salinity rapidly increased. After the dam in Berg's strait was built in 1992, the Large Aral level declined slightly faster, because inflows from Small Aral ceased. Nevertheless, the increased rate of desiccation due to dam construction was small as indicated by comparative measures of Large and Small Aral levels by satellites. The increasing salinity is negatively impacting the biota and biodiversity is decreasing.

The recent salinity increase in the Large Aral has caused extinction of almost all marine and euryhaline fish and invertebrate species except a few remaining halophiles. Of seven fish species present at partition of the Aral Sea none were present in autumn 2002 when salinity exceeded 70 g/l. Along the shoreline there were a lot of dead decaying bodies of plaices and silversides. But there is a possibility that in Chernyshov and Tsche-Bas bays and near Aktumsyk cape, where there is increased outcome of freshened subterranean waters, adult plaices still may survive during some years. Unfortunately, the output of ground waters is so little that it has influence on the salinity only near the bottom; so, plaices will die sooner or later. However, it is possible to say with certainty there is no natural reproduction of fishes in the Large Aral.

The zooplankton of the modern Large Aral Sea includes four euryhaline species, widespread in the region. *Brachionus plicatilis* and reintroduced *Moina mongolica* cannot be considered invaders, as they were present before. However, *Artemia salina* and *Fabrea salina* are invaders.

Of eight zoobenthic species only two species of widely euryhaline gastropods from the genus *Caspiohydrobia* and one euryhaline species of ostracods *Cyprideis torosa* remain. All other bottom inhabitants, present at partition of the Aral Sea, such as Gastropoda, Polychaeta and Decapoda, have disappeared due to increased salinity or are near extinction. As in the case of zooplankton, the Large Aral Sea zoobenthos was enriched by aeolian transfer of new halophylic invaders. Euryhaline ostracod *Eucypris inflata* and halophylic protozoans appeared in zoobenthos and along with larvae of halophylic Chironomidae.

Higher zoobenthic biodiversity in Tsche-Bas and Chernyshov bays deserves special note. Here and probably near Aktumsyk cape biodiversity is higher than in the rest of the Large Aral Sea. Near the bottom of these bays and at Aktumsyk cape, inflowing underground freshwaters from under cliffs of Ustjurt plateau occur and reduced salinity provides more favorable benthic conditions than in other areas of Large Aral. Field samples collected from these bays in August-September 2002 contained not only species of *Caspiohydrobia*, Chironomidae and euryhaline ostracod *Cyprideis torosa*, but also some recent (*Abra ovata*) and ancient (*Cerastoderma isthmicum*) invaders. Also in Tsche-Bas bay, where salinity was somewhat lower than in Chernyshov bay, adult *Cerastoderma isthmicum* and *Abra ovata* were present. Also, the presence of *A. ovata* juveniles suggests continuing reproduction of this species. However, *Nereis diversicolor* was not found on any stations in Tsche-Bas bay. As for more saline Chernyshov bay, no bivalves were present, but *Nereis diversicolor* was found.

These data indicate that after partition of the Aral Sea, the southern part was quickly transformed from a mesohaline to a hyperhaline water body. Biodiversity of Large Aral changed with typical hyperhaline species becoming dominant and most of its former inhabitants, including fishes, extinct. The phytoplankton of modern Large

Aral is the halophylic alga, Dunaliella, which has become the dominating autotrophic organism of this hyperhaline water body. This alga came into Large Aral from neighboring hyperhaline water bodies. As in the case of Small Aral, the Large Aral fauna is enriched mainly by aeolian transfer of resting stages of hydrobionts from other water bodies of Aral region.

Continued desiccation of the Large Aral is almost assured. In a few years its water area will inevitably be divided into at least 3 parts separate lakes. Tsche-Bas bay will soon be separated in the north, with a deep basin in the west and a shallow water body in the east basin. The latter could dry up completely by 2010 or even earlier. Separated Tsche-Bas bay will become saline slowly more, if underground fresh waters income noted by some authors (Radjabov, Tahirov, personal communication) are significant. Nevertheless, sooner (2020) or later (2025), Tsche-Bas bay will salinize anyway, because low mineralized underground waters in arid climate lakes couldn't compensate evaporation for the long time.

Figure 9. Dynamics of fish catches in the Northern and Southern Aral Sea.

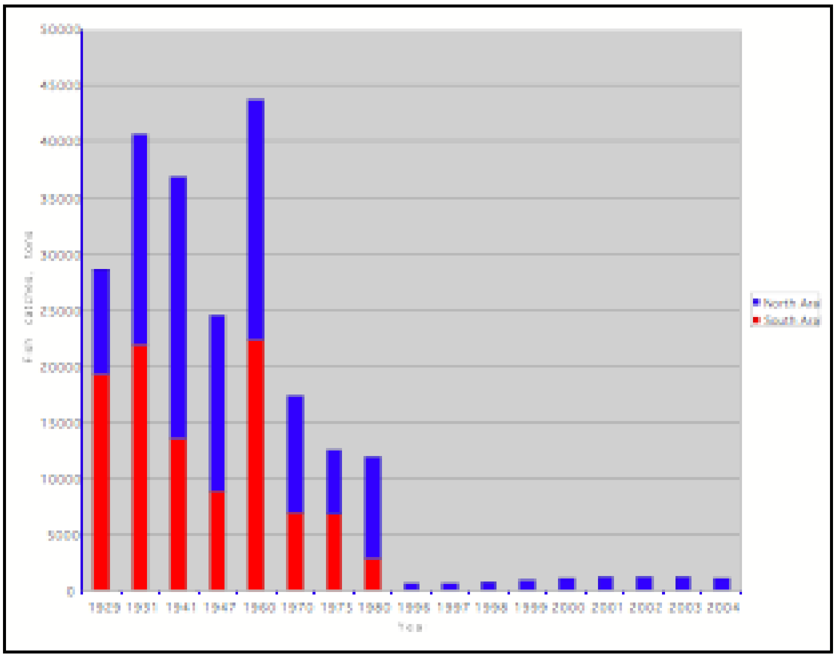
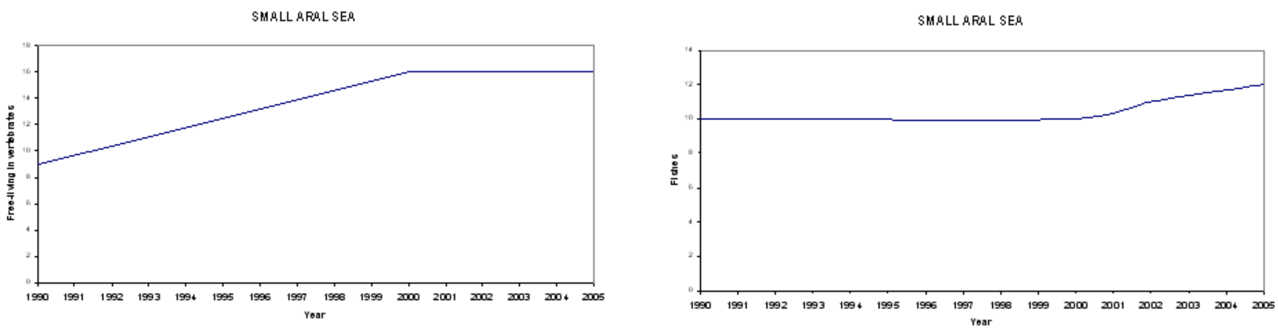


Figure 10. Change of species number in the Small Aral Sea.



The deepwater basin of the north will obviously exist the longest, because it has the largest water volume and the lower area/volume ratio, and as with Tsche-Bas bay, has some subterranean inputs from Ustjurt plateau. Such inflows were found at Aktumsyk cape (Radjabov, Tahirov, personal communication). It is also probable that analogous underground inflows occur at other points along the steep shore of Large Aral, but as usual in arid climate lakes ground waters couldn't compensate evaporation for the long time. So, year after year the last part of the Large Aral will become smaller and more saline until the stability will be reached.

Before salinity will increase to 200-300 g/l in all these water bodies, there will be only euryhaline halophylic species, and their number will decrease as salinity increases. As salinity reaches 300-350 g/l, only bacteria will survive. No introductions into the Large Aral are necessary or warranted. All hydrobionts able to survive in it are already present or could easily come into it naturally, as resting stages or by aeolian transfer or with migrating birds. It is well known that flamingos, eating zooplankton of hyperhaline lakes, often transfer cysts of euryhaline hydrobionts on its feathers and muddy feet.

Figure 9 shows how fish catches have been devastated by these changes in the ecosystem. However, it should be noted the increase in fish catch since the rising level of the Small Aral Sea (show in Blue). The trends in the Small Aral Sea are shown in more detail in Figure 10. Table 2 discusses the species of zooplankton, zoobenthos and fish. Finally, figure 11 shows the re-appearance of grass carp in 2004 catches.

For the still salinizing Large Aral, the story has been different. Figure 12 shows the flounder which is likely to disappear soon. Figure 13 shows the declining number of species present. Tables 3a and 3b present the species of zooplankton, zoobenthos and fish in the Western

Table 2. Zooplankton zoobenthos and fishes of the Small Aral Sea (2005-2007). Average salinity about 11-17 g/l.

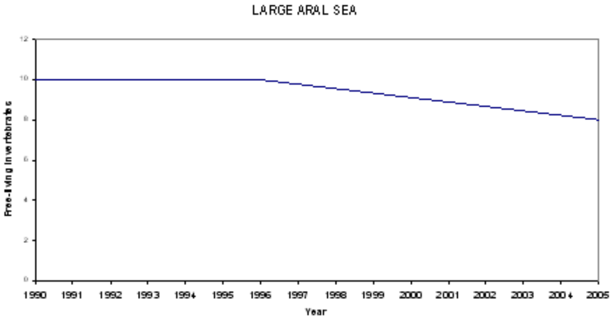
Zooplankton	Zoobenthos	Fishes
Rotatoria *Synchaeta vorax* *Synchaeta gyrina* *Synchaeta cecilia* Cladocera *Podonevadne camptonyx* *Evadne anonyx* Copepoda ** Calanipeda aquaedulcis* *Halicyclops rotundipes aralensis* Bivalvia Larvae ** Abra ovata* *Cerastoderma isthmicum*	Bivalvia ** Abra ovata* *Cerastoderma isthmicum* Gastropoda *Caspiohydrobia* spp. Polychaeta ** Nereis diversicolor* Ostracoda *Cyprideis torosa* *Eucypris inflata* Decapoda ** Palaemon elegans*	Stickleback - *Pungitius platygaster* Baltic herring - *Clupea harengus membras* Flounder - *Platichthys flesus* Silverside - *Atherina boyeri caspia* Bubyr goby - *Knipowitschia caucasicus* Sand goby - *Neogobius fluviatilis* Round goby - *Neogobius melanostomus* Grass carp - *Ctenopharyngodon idella* Pike perch - *Sander lucioperca*

and Eastern Aral Seas, respectively. Finally, at the end of 20th century brine shrimp *Artemia salina* (*A. parthenogenetica*) appeared in the Large Aral Sea (Figure 14). Nowadays industrial harvesting under aegis of international company INVE Aquaculture is being considered, but in 2005 the company postponed activities until salinity increase to levels more favorable for brine shrimp.

Figure 11. When in 1992 a dike in Berg strait was built, fishing on the Small Aral was recommenced. According reports of fishermen, in 2004 grass carp (*Ctenopharyngodon idella*) reappeared in Small Aral.

Figure 12. Flounder (*Platichthys flesus*) is about to disappear from the Large Aral Sea because of rising salinity. The stocks of flounder in the Small Aral also should decrease due to freshening effect in this water body.

Figure 13. Change of species number in the Large Aral Sea.



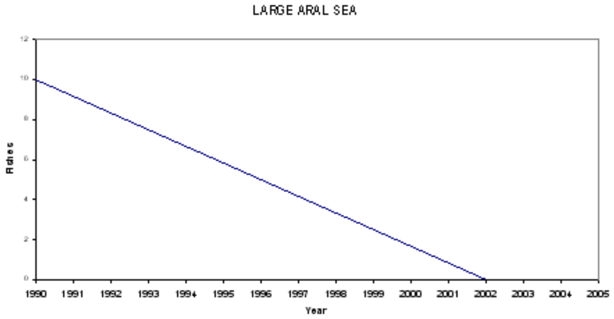


Table 3a. Zooplankton zoobenthos and fishes of the Western Large Aral Sea (2005). Average salinity 80-90 g/l.

Zooplankton	Zoobenthos	Fishes
Infusoria *Fabraea salina* Rotatoria *Brachionus plicatilis* *Hexarthra fennica* Cladocera ? *Moina mongolica* Copepoda *Halicyclops rotundipes aralensis* Branchiopoda *Artemia salina*	Infusoria *Frontonia* sp. Turbellaria *Mecynostomum agile* Bivalvia * *Abra ovata* Gastropoda *Caspiohydrobia* spp. Polychaeta * *Nereis diversicolor* Ostracoda *Cyprideis torosa* *Eucypris inflata* Insecta Chironomidae gen. sp.	Stickleback - *Pungitius platygaster* - ? Flounder - *Platichthys flesus* - ? Silverside - Atherina *boyeri caspia* - ? Round goby - *Neogobius melanostomus* - ?

Table 3b. Zooplankton zoobenthos and fishes of the Eastern Aral Sea (2005). Average salinity 150-160 g/l.

Zooplankton	Zoobenthos	Fishes
Branchiopoda		
Artemia salina	Alive macro- and mezo- Metazoa are not available	Only in Tsche-Bas bay flounder (*Platichthys flesus*) was observed in water with salinity 80-90 g/l. In the remnants of the strait between Small and Eastern Large Aral silverside (*Atherina boyeri caspia*) was found in water with salinity 60-80 g/l.

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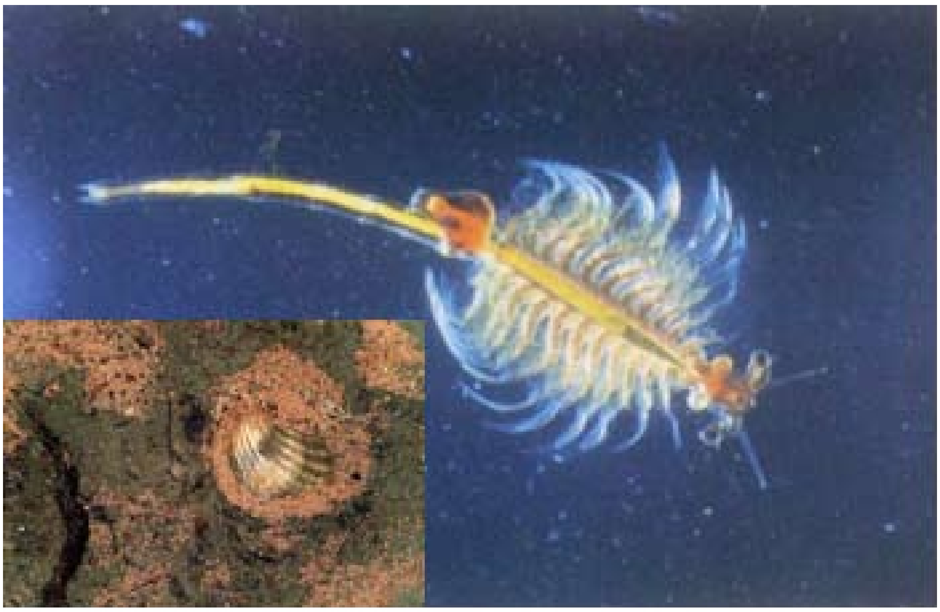
Figure 14. The brine shrimp *Artemia salina.*



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