Results of Aral Sea studies

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Introduction

The Aral Sea is a terminal lake (a lake with inflow but no outflow) situated in the middle of the vast Central Asian deserts. Its size and water balance are determined by river and ground water inflow, precipitation and evaporation from its surface. Until the 1960s, the Aral was the world's fourth largest lake in surface area. Over the past decades, this water body has rapidly and steadily shrunk as countries in the Aral Sea Basin have increasingly taken inflow from its two influents, the Syr Dar'ya and Amu Dar'ya, for expansion of irrigation. In 1989 the Aral Sea split in two parts due to desiccation: the Small Aral in the north and the Large Aral in the south. Since then, although there remains periodic flow from the former to the latter via a connecting channel, the two lakes have evolved as separate water bodies with distinct biological and hydrological characteristics. The ecological crisis of the Aral Sea has been widely discussed during recent years in both scientific and popular literature. We believe sufficient data are currently available to summarize results of Aral Sea studies.

Key words: salt lakes, Aral Sea, biodiversity, anthropogenic desiccation, lake rehabilitation

At the beginning of the 1960s the most recent and rapid anthropogenic desiccation of the Aral Sea began. At that time the lake was inhabited by more than 30 fish species and more than 200 free-living invertebrates. It is important to emphasize that since the beginning of the 20^{th} century many exotic fishes and invertebrates were artificially introduced into the Aral Sea.

Following the division of the Aral Sea in 1989, the two lakes have evolved in different ways. The northern Small Aral Sea receives run-off of the Syr Dar'ya River. This inflow has been sufficient, along with precipitation on the sea's surface and groundwater inflow, to create a positive water balance and allow some flow from the Small Sea to the Large Sea via a connecting channel across the former Berg Strait. The Large Aral Sea in the south has a negative water balance, and evaporation from its huge surface is still higher than the small inputs of the Amu Dar'ya River, atmospheric precipitation and ground waters (Aladin et al. 1995). These differences in the hydrological regimes of the two new lakes have led to stabilization of the Small Aral Sea level and salinity, whereas the Large Aral Sea has continued to dry and salinize and suffer a steady drop in water level.

At the time of division into two lakes, the salinity of the Aral Sea was about 28–30 g/l, the level was about 40 m a.s.l. (Aladin et al. 1995), and the fauna and flora of the lakes were similar. But biological differences between these two water bodies appeared very quickly due to different hydrological regimes. 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 a.s.l. (Zenkevich 1963). The ecosystem was characterized by low biodiversity and biological productivity. With salinization and desiccation, biodiversity and productivity decreased and the brackish water ecosystem was transformed into one with mesohaline characteristics where surviving aboriginal and introduced euryhaline and marine species of fishes and invertebrates predominated (Plotnikov et al. 1991). When the lake divided in 1989, only seven species of fish, 10 common zooplankton species, and 11 common benthos species remained.

After division, the Small Aral Sea stabilized at 40 m a.s.l. and began to slowly rise due to a positive water balance (Aladin et al. 1995). As a result, waters of the Small Aral Sea began to flow southward into the Large Aral. This out-

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flow 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. In spring 1989, this canal was visible, and a slow southward current was present in autumn. Flow rose as the level of the Large Aral declined and the hydrologic gradient between the two water bodies increased, reaching 100 m^3/sec by the time the Large Aral level fell to 37.1 m and the difference between the lakes grew to 3 m. This strong stream eroded the bottom and threatened to nearly 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 ceased. In the ensuing years, this dike across the Berg Strait was partly destroyed by floods and restored several times. The dam raised the Small Aral Sea level to 42.8 m by April 1999 and led to a drop in salinity from 29.2 g/l (at division) to 18.2 g/l.

Unfortunately, in late April 1999, owing to the higher level of the Small Sea, the dam was destroyed after being over topped by wind-driven waves. The level returned to the mark 40 m, the same as before the dam was constructed. Dam restoration has not been undertaken and waters of Small Aral are again flowing to the south. Only a part of the flow from the Small Aral now reaches the Large Aral because much of it is lost in the sands and salt marshes north of the former Barsakelmes.

After the dam was built in 1992, rising lake levels and declining salinity partially restored the ecology of the Small Aral. Biodiversity increased, the desiccated Bolshoy Sary-Cheganak gulf again filled with water, and rehabilitation processes began in the Syr Dar'ya delta. Reeds began to regrow, forming an environment for hydrobionts and amphibiotic animals (ALADIN et al. 1995). The rise of the Small Aral increased the depth of water in the Syr Dar'ya and allowed for aboriginal and introduced freshwater fishes to forage in the estuary as before. The peak of such foraging was at the end of 1990s when the Small Aral level reached more than 42 m. The foraging of fresh water fishes also was favored by the decrease of average salinity to about 18 g/l. Before the dam in Berg Strait was built, the Syr Dar'ya estuary was poorly developed, and the zone of fresh and saline water mixing was practically absent because most of the fresh water moved directly to the canal between Small and Large Seas. After construction of the dam, fresh water was retained in the Small Aral and the average salinity in the estuary decreased to 11 g/l.

The dam collapse in late April 1999 reestablished outflows from the Small Aral Sea, and the Bolshoy Sarycheganak bay practically dried up, and the straits connecting Shevchenko and Butakov bays with Small Aral became shallow. Nevertheless, there is no threat of the Syr Dar'ya changing course to flow into the Large Aral as it did in the early 1990s because in the late 1990s the Syr Dar'ya had its flow artificially channeled, and it now enters the Small Aral north of its former natural mouth. Meanwhile, quick restoration of the dam in Berg's strait is required to maintain and enhance biodiversity and productivity of the Small Aral.

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. After partition of the Aral Sea, the southern part was quickly transformed from a mesohaline to a hyperhaline water body. Biodiversity of the Large Aral changed, with typical hyperhaline species becoming dominant and most of its former inhabitants, including fishes, becoming extinct.

The rapid decline of the Large Aral level actually destroyed large parts of the lower delta of the Amu Dar'ya. Unlike the delta of Syr Dar'ya, where natural rehabilitation processes began after the dam was built, rapid degradation of Amu Dar'ya delta continues. Moreover, deltaic water bodies of the Syr Dar'ya are near the Small Aral and are regularly fed with fluvial waters, while those of Amu Dar'ya are far from the Large Aral and receive no regular flows. Thus the ecological situation in the south is more complicated than in the northern Aral Sea. However, since 1990, several projects to reestablish wetlands and shallow lakes in the lower Amu Dar'ya delta have been implemented, which have slowed the pace, and in some cases reversed, the trend of ecological degradation.

Restoration of the Small Aral is possible and depends on construction of a new dam with a spillway. Increased biodiversity and productivity would accompany rising lake level and decreasing salinity. Apparently, natural migration of euryhaline species with fluvial waters from artificial and natural water bodies located in the delta and lower reaches of Syr Dar'ya will also occur. This natural process could be expedited by the introduction of food species of some valuable invertebrates from lakes Kamyslybas, Zhalanash, Tuschibas and others directly into the Small Aral. Many aboriginal and introduced species that perished in Aral survived in deltaic water bodies and, after the dam restoration, could be re-introduced into the Small Sea. However, these actions could succeed only after the average salinity of Small Aral decreases to below 14 g/l. Reintroduction at higher salinity would fail. Construction on a World Bank-funded project to install a new, properly engineered dam and raise the level of the Small Aral to around 44 or 45 m was begun in 2003.

Continued desiccation of the Large Aral is almost assured. In a few years its water area will inevitably be divided into at least three 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 in the near future. The isolated Tsche-Bas bay will salinize more slowly if underground fresh waters inflow is significant. Nevertheless, sooner (2020) or later (2025), Tsche-Bas bay will salinize, because low mineralized underground waters in arid climate lakes simply cannot compensate for the high evaporation for long.

The deepwater basin situated in the western part of the larger Aral Sea will obviously exist the longest, because it has the largest water volume and the lowest area/volume ratio, and as with Tsche-Bas bay, has some subterranean inputs from the Ustjurt plateau. Such inflows were found at Aktumsyk cape. 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 cannot compensate for evaporation. Consequently, the last part of the Large Aral will become smaller and more saline until water balance stability is reached.

Before salinity increases to 200–300 g/l in all these water bodies, only euryhaline halophylic species will survive, and their numbers 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 are already present or could easily come into it naturally as dormant 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 their feathers and muddy feet.

Restoration and rehabilitation of Large Aral is practically impossible because it would require large amounts of both the Syr Dar'ya and Amu Dar'ya waters, which are diverted for irrigation. Syr Dar'ya inflows to the Aral Sea have been greatly reduced, and almost nothing remains of Amu Dar'ya inflows because all countries in the upper basin continue to divert almost all waters for irrigation. The withdrawal of river water during the next years will increase as peace and economic development return to Afghanistan bringing further development of irrigated agriculture in this country. Although there are no accurate figures, Afghanistan likely draws no more than 1 km^3 from the Amu Dar'ya and its tributaries on Afghan territory. As a basin riparian whose territory generates around 8% of the flow of the Amu Dar'ya, this nation would have the right under international water law to significantly increase its withdrawals, which it is almost certain to do as a means of increasing food production.

Fortunately, the situation for the Small Aral, lying entirely within Kazakhstan, is more promising. With the construction of the new, soundly engineered dam in the Berg Strait, the hope is becoming reality that the level of this water body will rise significantly and its ecology will be restored. The accompanying decrease in salinity should lead to increased biodiversity due to natural and possibly intentional reintroduction of fishes and invertebrates from deltaic lakes of the Syr Dar'ya. Successful implementation of this plan provides the possibility in some distant future that the Small Aral could be a donor for the restoration of the Large Aral. Such a scenario is validated by medieval desiccation. In the 15–16th centuries the Large Aral was desiccated by anthropogenically caused diversion of the Amu Dar'ya westward into the Sarykamysh depression, so that little or no flow reached the Large Aral. The lake level fell to 30 m, salinity rose dramatically, and ecological diversity was destroyed, as is the case today. But subsequent redirection of flow into the sea led to the restoration of the former level (53 m), salinity (around 10 g/l), and ecology by the 19th century. Future generations could benefit from not only a partially restored Small Aral but a Large Aral Sea as well.

Results of the Aral Sea studies

1. Prior to the anthropogenic desiccation of the Aral Sea its ecosystem suffered from exotic species introductions that began in the 1920s.
2. The main and the only reason of present desiccation and salinization of the Aral Sea is redirection of Syr Dary'a and Amu Dary'a waters for irrigation.
3. Decrease of biodiversity due to salinization could be divided into the following main stages:
• In 1971–1976 brackish water species of fresh water origin disappeared when water salinity exceeded 12–14 g/l.
• In 1986–1989 brackish water species of Caspian origin became extinct when water salinity exceeded 23–25 g/l.
• In 1999–2003 marine origin species became extinct in the Large Aral Sea when water salinity exceeded 80–100 g/l.
4. In 1989 the Aral Sea due to desiccation split in two parts: the Small Aral in the north and the Large Aral in the south. Instead of one lake , two sister lakes were formed.
5. The Small Aral since separation has had a positive water balance (its salinity constantly is going down and its level is going up when the man-made dam in Berg's strait is operational). Rehabilitation of biodiversity and fisheries will be possible when the dam now under construction is completed.
6. The Large Aral since separation continues to have a negative water balance (its salinity constantly is going up and its level is going down). Rehabilitation of biodiversity and fisheries is not possible. Only harvesting of brine shrimp *Artemia salina* cysts could be a profitable business.
7. In 2004–2008 the Large Aral Sea will separate into three separate water bodies: The Eastern and Western lakes plus Tsche-Bas lake. Between Eastern and Western lakes a channel with current from east to west will form as long as the Amu Dary'a discharges to the eastern Large Aral. When the Amudarya is not reaching the eastern lake, the current is from the Western to the Eastern lake. Due to this current the channel will get progressively deeper.
8. Heavy use of water from the Syr Dar'ya and Amu Dar'ya rivers for irrigation accounts for nearly all of the desiccation and accompanying salinization of the Aral Sea since the 1960s.
9. Significant improvements in irrigation efficiency in the Aral Sea drainage basin could save considerable water that, if delivered to the Aral Sea, would measurably improve its water balance; however, this would require massive and very expensive reconstruction of irrigation systems as well as fundamental social and economic changes – a very unlikely probability for many years to come.
10. Ground water contribution to the Large and Small Aral is much bigger than it was considered before.
11. Vozrozhdenie Island, now a peninsula, because of its former use during Soviet times as a testing ground for bio-weapons, is an "environmental time bomb" that could result in the transfer of any remaining active genetically altered pathogens to the mainland.
12. Plans of oil and gas excavation from dried Aral Sea bottom could decrease desire of decision makers to save the lake.

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