Journal of Oceanology and Limnology
Vol. 36 No. 6, P. 2061-2084, 2018
https://doi.org/10.1007/s00343-018-8189-z

The history and future of the biological resources of the Caspian and the Aral Seas*

N. V. ALADIN[1, **], T. CHIDA[2], Yu. S. CHUIKOV[3], Z. K. ERMAKHANOV[4], Y. KAWABATA[5], J. KUBOTA[6], P. MICKLIN[7], I. S. PLOTNIKOV[1], A. O. SMUROV[1], V. F. ZAITZEV[8]

[1] *Zoological Institute RAS, St.-Petersburg 199034, Russia*
[2] *Nagoya University of Foreign Studies, Nisshin 470-0197, Japan*
[3] *Astrakhan State University, Astrakhan 414056, Russia*
[4] *Aral Branch of Kazakh Research Institute of Fishery, Aralsk 120100, Kazakhstan*
[5] *Tokyo University of Agriculture and Technology, Fuchu Tokyo 183-8509, Japan*
[6] *National Institutes for the Humanities, Tokyo 105-0001, Japan*
[7] *Western Michigan University, Kalamazoo 49008, USA*
[8] *Astrakhan State Technical University, Astrakhan 414056, Russia*

Received Jul. 11, 2018; accepted in principle Aug. 16, 2018; accepted for publication Sep. 10, 2018

Abstract The term 'biological resources' here means a set of organisms that can be used by man directly or indirectly for consumption. They are involved in economic activities and represent an important part of a country's raw material potential. Many other organisms are also subject to rational use and protection. They can be associated with true resource species through interspecific relationships. The Caspian and Aral Seas are continental water bodies, giant saline lakes. Both categories of species are represented in the benthic and pelagic communities of the Caspian and Aral Seas and are involved in human economic activities. The most important biological resource of the Caspian Sea and the Aral Sea is their ichthyofauna, represented by both aboriginal species and species introduced by man in the 20th century. Among invertebrates, the main biological resource of these saline lakes is the brine shrimp *Artemia*. The physical state of the Caspian as a water body is relatively stable but its biological resources are very seriously affected by irrational use. The Aral Sea since the second half of the 20th century has experienced catastrophic anthropogenic regression, which has led to the almost complete loss of its biological resources due to salinization. However, thanks to efficacious engineering measures, it has now become possible to preserve its northern part (Small Aral) and rehabilitate it, lowering the salinity to its former state. The result has been the restoration of its fish biological resources. In the southern part of Aral (Large Aral), which turned into a group of separated hypersaline reservoirs, the only resource species currently available is the brine shrimp *Artemia*. The main environmental threats for biological resources of the future Caspian and Aral as well as potential solutions are considered.

Keyword: Caspian Sea; Aral Sea; biological resources; fauna; fish; invertebrates

1 INTRODUCTION

The Caspian Sea is a continental water body, the largest lake in the world, both by area and volume. The Caspian is not a freshwater lake. Its waters are brackish; of the average salinity ~13 g/L. Like all closed lakes, the water balance of the Caspian depends on precipitation, river and groundwater runoffs and evaporation. The level of the Caspian is lower than mean sea level and is not stable. In the 20th century it dropped from -25 m in 1896 to the lowest, 29 m, in 1977. In the next year the Caspian Sea level began to rise, and after 10 years reached -27.6 m, but in the 21st century, a new slow fall began. With the fall in level, its area has shrunk and its outlines have changed. Shallow gulfs of the Northern Caspian, such as

* This paper is dedicated to the memory of Bill Williams.
** Corresponding author: nikolai.aladin@zin.ru

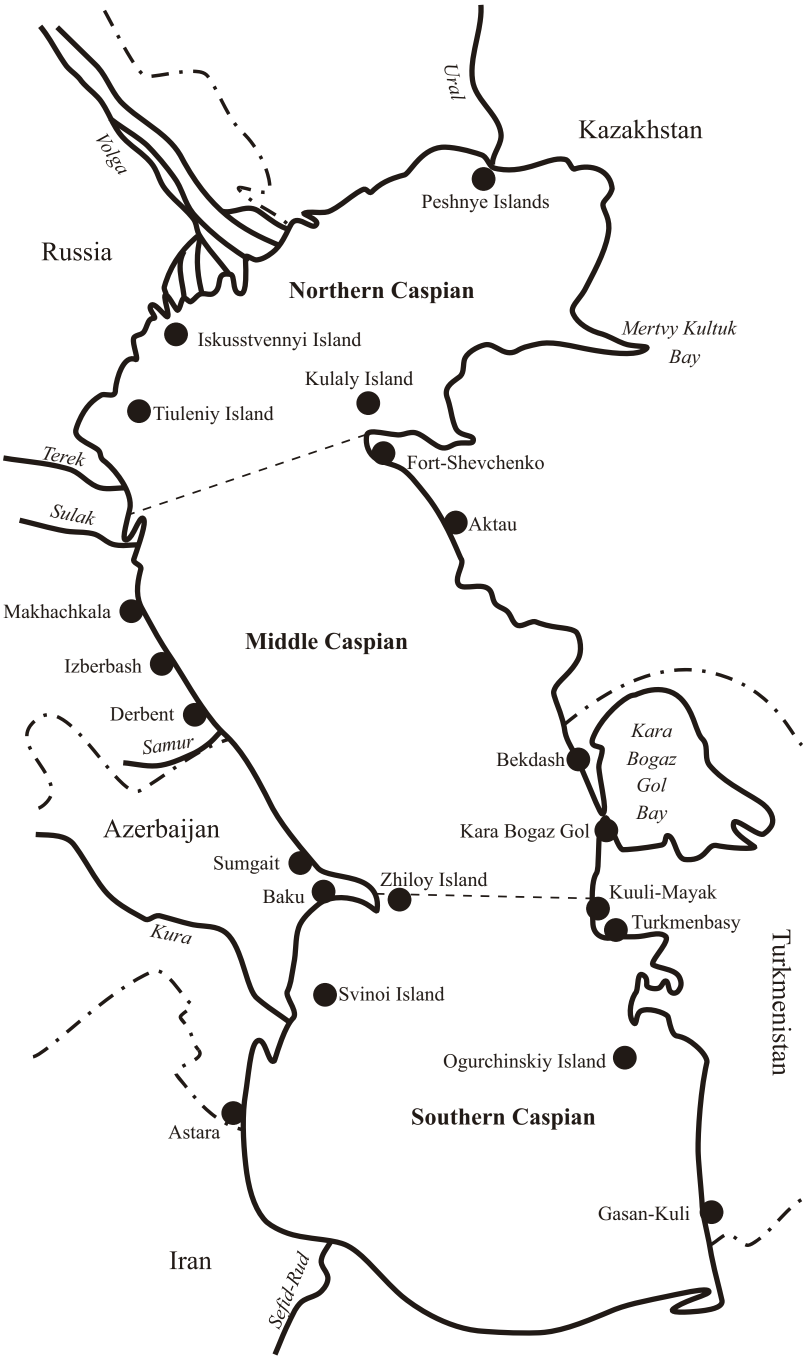

Fig.1 Map of the Caspian Sea

Mertvy Kultuk and Kaydak, dried in the 1940s. In 1930 the area of the Caspian was 422 000 km^2, but by 1970 it was only 371 000 km^2. Since 1978, with rising levels, the area increased again, and these gulfs are now filled with water (Aladin et al., 2001).

Within the Caspian Sea four parts are distinguished (Fig.1): The Northern, Middle, and Southern Caspian, and the bay Kara-Bogaz-Gol.

The Northern Caspian makes up ~29% of the entire sea area, but its volume comprises less than 1% because it is shallow. Its average depth is 6 m and the maximum is ~10 m. Depths over ~20% of the Northern Caspian are <1 m. The average water salinity here is ~5–10 g/L. Salinity in the areas adjacent to the mouths of the Volga, Ural, and Terek rivers is lower: 2–4 g/L. In their delta-fronts, salinity is <0.5 g/L. In shoals on the eastern coast, strong evaporation in calm weather causes salinity to reach 15–20 g/L. In the shallow gulfs of Mertvy Kultuk and Kaydak, water salinity can rise to 30 g/L or more

(Zenkevich, 1963).

The Middle and Southern Caspian areas are the largest and deepest. They contain ~99% of the total volume and occupy two-thirds of the sea surface. The Middle Caspian makes up ~36% by area and ~35% by volume of the whole sea. The average depth is ~175 m and the greatest ~790 m. The average salinity is 12.7 g/L. Salinity is reduced only in the delta-front of the Sulak River. The Southern Caspian makes up ~35% of the total area and ~64% of the total volume. It is the deepest part of the sea (average depth 300 m, maximum 1025 m). Its salinity is 13 g/L. Salinity is lower in areas adjacent to the deltas of the Kura and Sefidrud rivers (Zenkevich, 1963).

In open parts of the sea, salinity increases slightly with depth. Although at the surface of the Southern Caspian, the water salinity is 12.7 g/L; at the bottom at a depth of 700 m, it reaches 13.1 g/L (Zenkevich, 1963).

Kara-Bogaz-Gol Bay is the smallest part of the Caspian Sea by area (3%) and volume (very small). It is connected with the Middle Caspian by a narrow, ~200 m wide, strait. The water level in the Kara-Bogaz-Gol is lower than the level of the Middle Caspian by several meters. Consequently, water from the Middle Caspian overflows continuously into the bay and rapidly evaporates at shoals. The salinity in bays can reach 300–350 g/L or more. Vast quantities of salts accumulate at the bottom. Kara-Bogaz-Gol Bay acts as the major evaporator of the Caspian Sea, thus playing an important role in its water and salt balances. It has been described as a natural desalter (Zenkevich, 1963; Aladin et al., 2001).

The temperature regime of the Caspian Sea is characterized by considerable winter temperature differences between its northern and southern areas and equalizing of the temperature regime in summer. In winter, only the Northern Caspian is covered with ice. Here the winter average air temperature is -8–10°C. Under the ice, water temperature can be as low as -0.5°C. In mid-summer, the average surface water temperature is 24°C, but in shallow gulfs, it can be higher. In the Middle and Southern Caspian, winter mean air temperature is always >0°C. While in winter, surface water temperatures of the Southern Caspian are always 13°C or more. In summer they usually reach 25–30°C. In the Middle Caspian, the average winter surface water temperature is lower (6°C), while in summer it reaches 25°C. In Kara-Bogaz-Gol Bay summer surface water temperature can rise to 40°C (Zenkevich, 1963).

At depths, Caspian Sea water temperature is constant year-round. In the Southern Caspian it is 7°C at depths >150 m, and 6°C at depths beyond 500–600 m. In the Middle Caspian water temperature is ~6–5°C at >150 m and 4.5–5°C at >400–500 m. In summer there is a significant seasonal thermocline in the horizon 20–50 m. With the cooling of the surface water during late autumn and winter, the thermocline is destroyed. Due to the shallowness of the Northern Caspian, it shows no thermal water stratification (Zenkevich, 1963; Jamshidi, 2017).

Like the Caspian Sea, the Aral Sea is a terminal or closed basin (endorheic) lake. It lies amidst the vast deserts of Central Asia. The balance between inflows from the Amu Darya and Syr Darya rivers, direct precipitation on the lake surface and evaporation fundamentally determine the water level of Aral. In the relatively recent past (mid 20th Century), the Aral Sea was a unique, giant continental brackish water body (Fig.2). The hydrological regime of the Aral Sea was in reasonable balance from the 1600s to the 1960s, with a level variation of maximally 3–4 m. The average level from 1900 to 1960 was ~+53 m. The average salinity was 10.3 g/L (Bortnik and Chistyaeva, 1990). The Aral Sea was divided into two main parts, comprising the smaller northern basin (Small Aral) and the larger southern basin (Large Aral). These basins were largely divided by the elongate Kokaral Island but were connected by the narrow Auzy-Kokaral and wide Berg Straits (Fig.2) (Bortnik and Chistyaeva, 1990).

The water level and salinity of the Aral Sea, as of other water bodies in arid zones, depend closely on its water balance, which itself depends not only on climate change but also on human factors, mostly withdrawals of water for irrigation. The hydrological regime of the Aral Sea was originally controlled by local climatic factors influencing run-off of its influent rivers. The Aral Sea was essentially stable between 1911 and 1961. Major deterioration of the Aral Sea began in 1961, resulting from an increasing diversion of water from the Syr Darya and Amu Darya for agricultural irrigation, thereby considerably reducing riverine flows into the Aral Sea (Micklin, 2014b). This dramatic increase in water abstraction for irrigation seriously upset the equilibrium of water balance, causing a rapid drop in the water level and a corresponding rise in salinity of the Aral Sea (Table 1) (Bortnik and Chistyaeva, 1990).

By 1988–1989, when the Aral Sea level declined from +53 m to +40 m, the Berg Strait dried up. By this

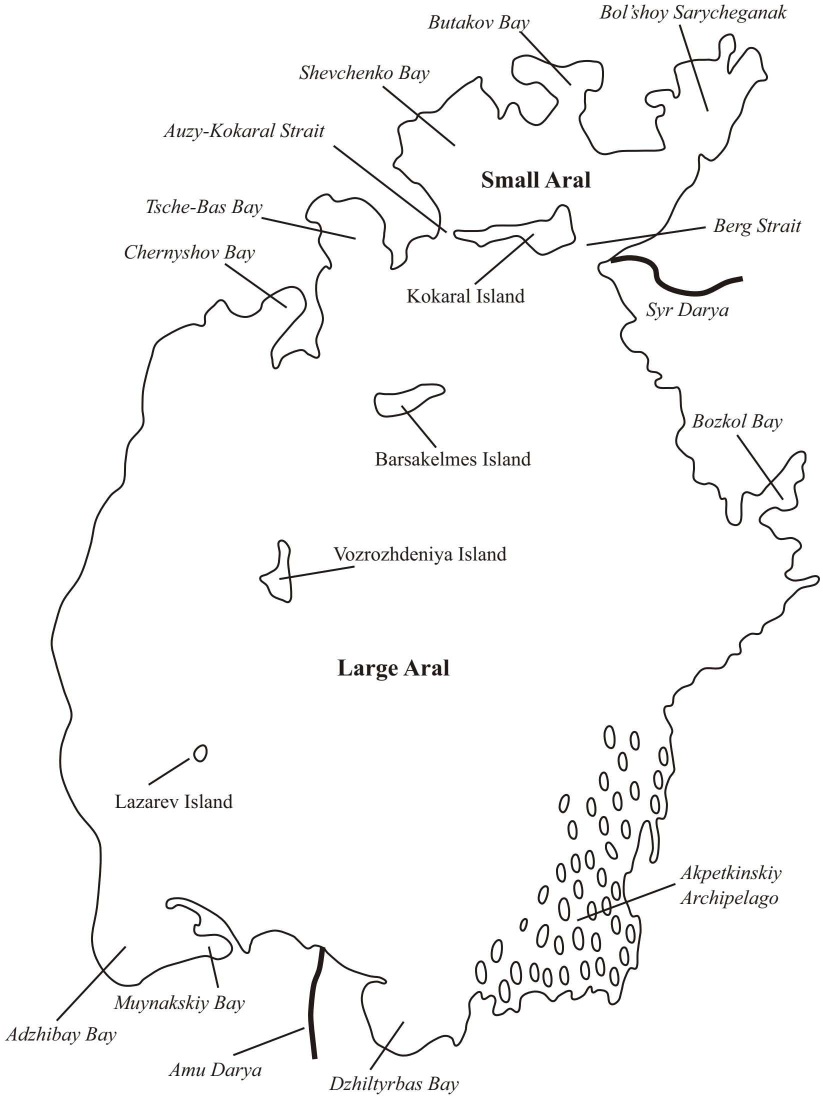

Fig.2 Map of the Aral Sea before the 1960s

time the Syr Darya mouth was moved northward from the strait. The Auzy-Kokaral Strait had dried up earlier, in 1968, so this event largely separated the northern Small and southern Large Aral Seas. The total area and volume of the sea at that time was reduced, the average salinity in both the Small and Large Aral increased from 10 to 30 g/L. A channel on the dried bottom of the Berg Strait continued to connect the two seas (Aladin and Plotnikov, 2008; Micklin, 2014b).

After the division of the Aral Sea into the Small Sea and the Large Sea, changes in the hydrological/hydrochemical regimes of these two lakes occurred independently. The Syr Darya runoff was sufficient not only to stabilize the Small Aral. Since its separation, the Small Aral Sea has exhibited a positive water balance and its level has stabilized. Surplus water began to outflow towards the Large Aral through a channel on the Berg Strait bottom. The Small Aral salinity increase has not only stopped but been substantially reversed. In contrast, despite a surplus water discharge from the Small Aral, the water balance of the Large Aral Sea has remained negative, with sustained drying of the lake and a continuing salinity increase that are both attributable to the greatly diminished inflow of the Amu Darya to the sea (Micklin, 2014b). Consequently, the biotic characteristics of the two seas began to diverge (Aladin and Plotnikov, 2008).

A low earthen Kokaral Dam (coordinates 46°06′07.29″N, 60°46′12.26″E) was built across the dried-up Berg Strait in 1992 in order to prevent the outflow of water from the Small Aral to the Large Aral, as well as to increase and stabilize the Small Aral's water level and to decrease its salinity. The level of the Small Aral increased >1 m, and the salinity

Table 1 Hydrological and salinity characteristics of the Aral Sea, 1960–2015

Year and portion of the sea	Level (m asl)	Area (km^2)	% 1960 area	Volume (km^3)	% 1960 volume	Average depth (m)	Average salinity (g/L)	% 1960 salinity
1960 (all)	53.4	67 499	100	1 089	100	16.1	10	100
Large	53.4	61 381	100	1 007	100	16.4	10	100
Small	53.4	6 118	100	82	100	13.4	10	100
1971 (all)	51.1	60 200	89	925	85	15.4	12	120
1976 (all)	48.3	55 700	83	763	70	13.7	14	140
1989 (all)		39 734	59	364	33	9.2		
Large	39.1	36 930	60	341	34	9.2	30	300
Small	40.2	2 804	46	23	28	8.2	30	300
09/22, 2009 (all)		7 146	10.6	83	7.7	10.8		
W. Basin Large	27	3 588	26.2	56	17.9	15.1	>100	>1 000
E. Basin Large	27	516	1.1	0.64	0.07	0.7	>150?	>1 500
Tshche-bas Gulf	28	292		0.51	7.1	1.4	~85	850
Small	42	3 200	52	27	33	8.4	8	100–130
08/29 and 11/25, 2014 (all)		6 990	10.4	81.7	4.4	6.9		
W. Basin Large	25.0	3 120	22.8	54	17.2	15.4	>150	>1 000
E. Basin Large	25	0	0	0	0	0	0	0
Tshche-bas Gulf	28.5	372		0.72		1.4	89	890
Small	41.9	3 197	52.3	27	33.2	8.5	6-8	0.6–0.8

Source: Micklin (2016).

declined (Aladin et al., 1995). This dam was breached every time spring water level rose and was then repeatedly rebuilt. It was finally destroyed by a storm in the spring of 1999 (Micklin, 2014a).

In 2004, construction of a soundly-engineered Kokaral Dam in the Berg Strait began. The work was completed in autumn 2005, and the new dam had a spillway for the discharge of excess water and for maintaining the level of the regulated Small Sea at a safe and stable level. After closing the gates, the water level of the Small Aral reached the designed height of +42 m by the spring of 2006 (Micklin, 2014a).

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

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

The Large Aral Sea desiccation continued and, by 2003 it had become divided into a group of residual water bodies (Figs.3, 4)—the Eastern Large Aral, Western Large Aral and Tschebas Gulf (Micklin, 2014a).

2 BIOLOGICAL RESOURCES

“Biological resources” here means a set of species of organisms that can be used by man directly or indirectly for consumption. In other words, they are involved in economic activities and may represent an important part of countries’ raw material potential (food, medicines, raw materials for industry, etc.). Many other species, though not being used by man, are also subject to rational use and protection. These latter species are associated with resource species through interspecific relationships. They form the

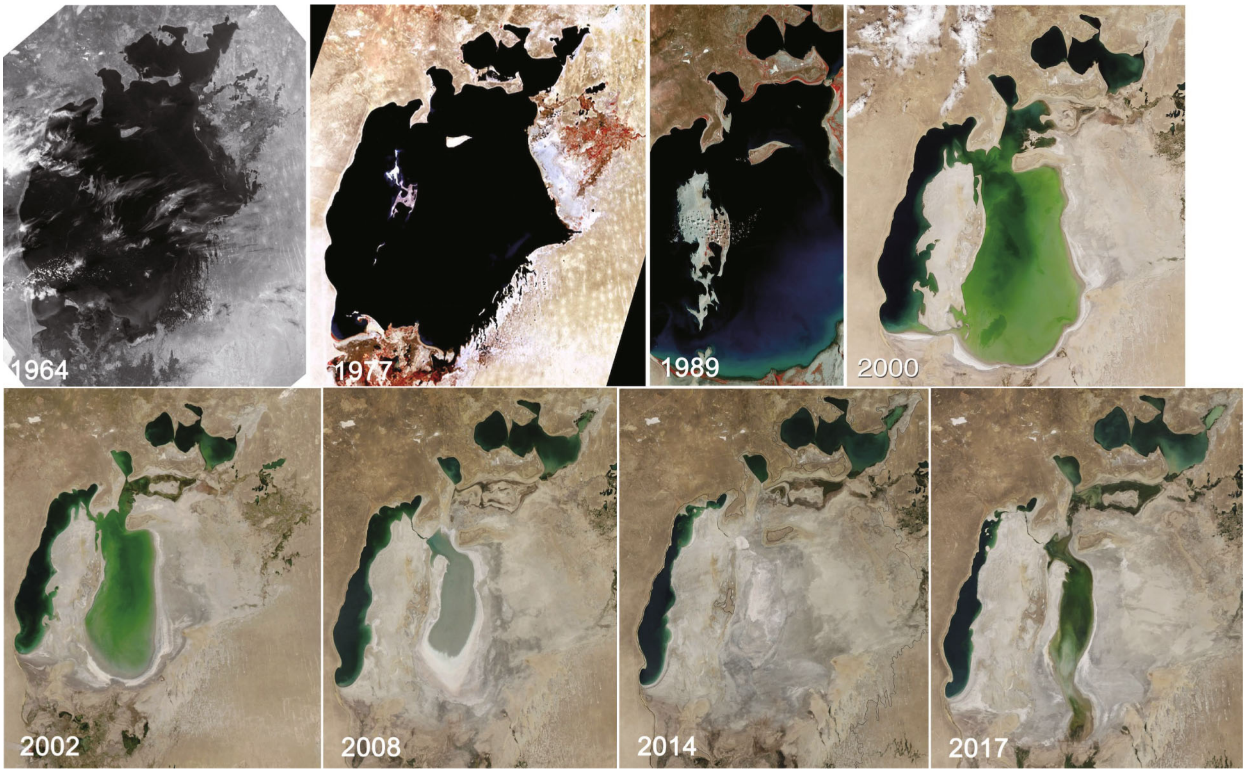

Fig.3 Desiccation of the Aral Sea

Space images by NASA.

quality of the habitat or affect the biosphere balance as a whole, ensuring the stability of ecosystems. Both categories of species are represented in the bottom and pelagic communities of the Caspian and Aral Seas and are hence involved in human economic activities.

2.1 Fishes

The most important biological resources of both the Caspian Sea and the Aral Sea are their ichthyofaunas (Tables 2, 3), represented by both aboriginal species and species introduced by man in the 20th century.

2.1.1 Caspian Sea

Order Petromyzontiformes—lampreys

The Caspian lamprey—*Caspiomyzon wagneri* (Kessler)—is endemic to the Caspian Sea basin. This anadromous species occurs everywhere in the sea. For spawning, they enter the Volga, the Ural, the Kura, the Terek, and the rivers of Iran. Before the construction of hydroelectric power stations dams, they migrated up these rivers for long distances. They enter the rivers in autumn. After overwintering, they

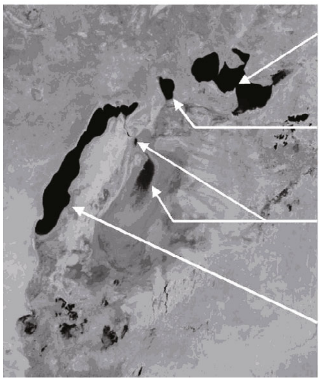

Fig.4 Satellite image of Aral Sea, September 22, 2009, Bands 7-2-1, 500-m resolution

Source: Micklin (2010) (Fig.2, p. 195).

spawn in May–June on stony, pebbled sections of rivers with strong currents. After metamorphosis, they return to the sea. They spend around 18 months at sea, before returning to the river to spawn. Almost nothing is known about the feeding of the Caspian lamprey at sea. In the river it does not feed. In the past, lamprey occupied a prominent place in the Caspian fishery, but by 1914 catches began a gradual decline. Caspian lampreys in Russia are on the verge of extinction. Artificial lamprey cultivation, plus conservation and regulatory measures to foster natural

Table 2 Main resource fishes in the Caspian Sea

Taxa	Ecological group	Occurrence	Status	Endangered
PETROMYZONTIDAE				
Caspiomyzon wagneri (Kessler)	A	N, M, S	E, C	+
ACIPENSERIDAE				
Acipenser gueldenstaedtii Brandt et Ratzeburg	A	N, M, S	C	-
Acipenser nudiventris Lovetsky	A	M, S	C	+
Acipenser persicus Borodin	A	N, M, S	E, C	+
Acipenser stellatus Pallas	A	N, M, S	C	+
Huso huso (Linnaeus)	A	N, M, S	C	-
CLUPEIDAE				
Alosa braschnikowi (Borodin)	M	N, M, S	E, C	-
Alosa caspia (Eichwald)	M	N, M, S	E, C	-
Alosa kessleri (Grimm)	A	N, M, S	E, C	-
Alosa volgensis (Berg)	A	N, M, S	E, C	-
Clupeonella caspia Svetovidov	M	N, M, S	E, C	-
Clupeonella engrauliformis (Borodin)	M	N, M, S	E, C	-
Clupeonella grimmi Kessler	M	S	E, C	-
CYPRINIDAE				
Luciobarbus brachycephalus caspius (Berg)	A	S	E, C	+
Luciobarbus capito capito (Gueldenstaedt)	A	M, S	E, C	-
Cyprinus carpio Linnaeus	Fv, Sa	N, M, S	C	-
Abramis brama (Linnaeus)	Fv, Sa	N, M, S	C	-
Ballerus ballerus (Linnaeus)	F	N	C	-
Ballerus sapa sapa (Pallas)	Fv, Sa	N	C	-
Ballerus sapa bergi (Belyayev)	A	M, S	C	-
Blicca bjoerkna bjoerkna (Linnaeus)	Fv, Sa	N	C	-
Vimba persa (Pallas)	A	S	E, C	-
Alburnus chalcoides (Gueldenstaedt)	A	S	E, C	+
Aspius aspius aspius (Linnaeus)	Sa	N	C	-
Aspius aspius taeniatus (Eichwald)	A	S	E, C	-
Rutilus caspicus (Yakovlev)	Sa	N, M, S	E, C	-
Rutilus kutum (Kamensky)	A	N, M, S	E, C	-
Pelecus cultratus (Linnaeus)	Fv, Sa	N, M, S	C	-
SALMONIDAE				
Stenodus leucichthys (Gueldenstaedt)	A	N, M, S	E, C	+
Salmo caspius Kessler	A	M, S	E, C	+
Salmo ciscaucasicus Dorofeyeva	A	N, M, S	E, C	+
MUGILIDAE				
Chelon auratus (Risso)	M	N, M, S	I, C	-
Chelon saliens (Risso)	M	N, M, S	I, C	-
ATHERINIDAE				-
Atherina caspia Eichwald	M	N, M, S	E, F	-
SYNGNATHIDAE				-
Syngnathus caspius Eichwald	M	N, M, S	E, F	-
PERCIDAE				
Sander lucioperca (Linnaeus)	Sa	N	C	-
Sander marinus (Cuvier)	M	N, M, S	C	+
GOBIIDAE				
12 genera and 35species (30 endemics)	M	N, M, S	E, F	-

Note: Fv: fluvial; A: anadromous; Sa: semi-anadromous; N: in Northern Caspian; M: in Middle Caspian; S: in Southern Caspian; E: endemic; I: introduced; C: commercial; F: food for predatory fishes.

Table 3 Main resource fishes in the Aral Sea

Species	Years				Status
	1950	1960–1979	1980–1990	1991–2004	
ACIPENSERIDAE					
Acipenser nudiventris Lovetsky	+	+	-	-	E, AB
SALMONIDAE					
Salmo trutta aralensis Berg	+	+	-	-	E, AB
ESOCIDAE					
Esox lucius Linnaeus	+	+	-	+	C-, AB
CYPRINIDAE					
Rutilus rutilus aralensis Berg	+	+	-	+	C, AB
Ctenopharyngodon idella (Valenciennes)	-	+	-	+	C-, AC
Leuciscus idus oxianus (Kessler)	+	+	-	+	C-, AB
Aspius aspius iblioides (Kessler)	+	+	-	+	C, AB
Scardinius erythrophthalmus (Linnaeus)	+	+	-	+	C-, AB
Barbus capito conocephalus Kessler	+	+	-	-	RB, AB
Barbus brachycephalus brachycephalus Kessler	+	+	-	+	RB, AB
Abramis brama orientalis Berg	+	+	-	+	C, AB
Abramis sapa aralensis Tjapkin	+	+	-	+	C-, AB
Chalcalburnus chalcoides aralensis (Berg)	+	+	-	+	C-, AB
Pelecus cultratus (Linnaeus)	+	+	-	+	C-, AB
Carassius carassius gibelio Bloch	+	+	-	+	C-, AB
Cyprinus carpio aralensis Spitshakow	+	+	-	+	C, AB
Hypophthalmichthys mobilitrix (Valenciennes)	-	+	-	+	C-, AC
Aristichthys nobilis (Richardson)	-	+	-	+	C-, AC
SILURIDAE					
Silurus glanis Linnaeus	+	+	-	+	C-, AB
ATHERINIDAE					
Atherina boyeri caspia (Eichwald)	-	+	+	+	I
PERCIDAE					
Stizostedion lucioperca (Linnaeus)	+	+	-	+	C, AB
Perca fluviatilis Linnaeus	+	+	-	+	C-, AB
CHANNIDAE					
Channa argus warpachowskii Berg	-	+	-	+	C-, AC
GOBIIDAE					
Pomatoschistus caucasicus Berg	-	+	+	+	I
Neogobius fluviatilis pallasi (Berg)	-	+	+	+	I
Proterorhinus marmoratus (Pallas)	-	+	+	+	I
Neogobius melanostomus affinis (Eichwald)	-	+	+	+	I
Neogobius kessleri gorlap Iljin	-	+	+	+	I
Neogobius syrman eurystomus (Kessler)	-	+	+	+	I
PLEURONECTIDAE					
Platichthys flesus luscus (Pallas)	-	+	+	+	C, AC

Note: +: present; -: absent; C: commercial; C-: commercial but low stocks; AB: aboriginal; AC: acclimatized; I: introduced accidentally; R: in Red Book; E: extinct.

reproduction in modern conditions of the rivers of the Caspian Sea are needed urgently. Only in Iran does the number of Caspian lampreys remain relatively high; the local people do not consume it for religious reasons (Bogutskaya and Naseka, 2013).

Family Acipenseridae—sturgeons

The Russian sturgeon—*Acipenser gueldenstaedtii* Brandt et Ratzeburg is an anadromous fish. In the Caspian Sea, it is found everywhere but is most numerous in the deep-sea region of the Northern Caspian. For spawning, it migrates mainly to the Volga and the Ural, and to a lesser extent to the Terek. In the Volga, the Russian sturgeon ascends to Rzhev, enters the Sheksna, and goes to the Kama and to the Oka as far as to Kaluga. In the Ural it reaches Orenburg. It spawns during the hydrological spring, and populations are mainly represented by a wintering form migrating long distances upstream. In the Ural spawners of the spring race dominate. The Russian sturgeon in the Caspian Sea is in critical condition. The main reason for the decline in its numbers is illegal fishing in the feeding areas (Bogutskaya and Naseka, 2013).

The beluga—*Huso huso* (Linnaeus) is an anadromous fish. In the Caspian Sea, it occurs everywhere. Belugas of the Volga origin migrate to the south of the Caspian for feeding. The main spawning river is the Volga, though it can migrate for spawning to all other rivers. In the Volga, belugas reach the mouth of the river Shoshai; in the Ural, they reach to Orenburg, in the Kura to Tbilisi, and in the Terek to Mozdok. Belugas spawn in spring, and the populations are mainly represented by a wintering form migrating long distances upstream. Unlike other sturgeons which are predominant benthophagous, beluga is a predator, consuming mainly fish, but also birds and even pups of the Caspian seal (*Pusa caspica*). In the Caspian, the beluga is critically-endangered. Natural reproduction of this species is preserved in the Volga and the Ural. Populations are maintained mainly due to artificial breeding in fish-rearing stations of the Caspian states (Bogutskaya and Naseka, 2013).

Ship sturgeon—*Acipenser nudiventris* Lovetsky is an anadromous fish. In the Caspian Sea they occur mainly in the middle and southern parts, in the Northern Caspian it is rare. The food spectrum consists mainly of crustaceans, insect larvae, plus fish. For spawning, ship sturgeons migrate mainly to the Kura and the Ural, rarely to the rivers of the Iranian coast and to the Volga. In the Caspian Sea basin, they spawn during the summer, and the populations are mainly represented by the spring form, migrating for relatively short distances upstream. In the Caspian Sea, ship sturgeons are critically-endangered. There is a small population of the Ural and the remnants of the population of the Kura. At present, ship sturgeons are fished only in Iran (Bogutskaya and Naseka, 2013).

Persian sturgeon—*Acipenser persicus* Borodin is endemic to the Caspian Sea basin. It is an anadromous fish. In the sea Persian sturgeons live mainly in the deeper zone of the northern Caspian, as well as in the middle and southern parts of the sea. As for the Russian sturgeon, their main food items are mollusks and fish (sprat, shad, atherine, gobies). Spawning is present mainly in the Kura and the rivers of the Iranian coast, but in earlier times it also spawned in the Terek, Volga, and Ural rivers. The population is dominated by spring spawners migrating to rivers in late spring. They spawn mainly in short mountain rivers with fast currents. Persian sturgeons are critically-endangered (Bogutskaya and Naseka, 2013).

Stellate sturgeon, sevruga—*Acipenser stellatus* Pallas is an anadromous fish. Among sturgeon species, the stellate sturgeon is the most thermophilic species. It hibernates in the middle and southern parts of the Caspian. It swims to the rivers Ural, Volga, Terek, and Sulak to spawn. Stellate sturgeons spawn during summer, and the populations are mainly represented by spring forms, which migrate for relatively short distances upstream. Natural spawning is preserved in the Volga and Ural. Stellate sturgeons are critically-endangered (Bogutskaya and Naseka, 2013).

In the 1950s the main dams blocking migratory routes of anadromous fish species to the places of spawning were built on many rivers of the Caspian basin. After the construction of the dam of the Volga Hydroelectric Power Station (1958), the total area of the spawning grounds of all sturgeons shrank by around 90%. In order to compensate for losses of natural spawning grounds and to protect sturgeon stocks, special sturgeon rearing stations were built. From the early 1960s, sturgeon catches steadily increased for almost 20 years. After 1980 there was a sharp decline in catches. This was caused both by the increased catch of previous years (which targeted larger fish that potentially laid more eggs) and by a decrease in the number of mature fish as a result of a decrease in natural reproduction due to loss of spawning grounds. By the early 1990s, the catches were almost halved and continued to decline. In 1990 the total catches of all sturgeon fishes were 16 455 tons, decreased to 850 tons in 2005, and to ~200 tons in 2010 (Velikova et al., 2012). Poaching of sturgeons significantly increased. At present poaching represents at least 50% of the total catch and probably more. Currently, there are two main types of sturgeon conservation measures in the Caspian basin, where up to 85% of their (much depleted) world reserves are concentrated: 1) limitation of fishing; 2) artificial reproduction and release of juveniles into natural waters. The prohibition of sea fishing led to the end of the catching of immature individuals during their feeding whilst at sea. The introduction of these measures in the early 1960s gave an immediate positive effect and led to a marked increase in the number of all sturgeon species in the Caspian basin. Limitation of fishing in rivers promotes the protection of the spawning population, which leads to more successful natural reproduction. Most of these measures were introduced in the Soviet Union in the early 1960s and, as a result, the numbers of sturgeons markedly increased. Effective regulation has since broken down and most of the established rules of sturgeon protection are not currently observed, even including the prohibition of sturgeon fishing at sea. Artificial reproduction in rearing stations and the release of juveniles into the sea is considered one of the main ways to preserve sturgeons in the Caspian Sea (Bogutskaya and Naseka, 2013), but will be overwhelmed if capture at sea and in the rivers is not rigorously controlled.

Family Clupeidae—clupeids

Caspian marine shad—*Alosa braschnikowi* (Borodin) is endemic to the basin of the Caspian Sea. It is a brackish-water, non-anadromous fish (Bogutskaya and Naseka, 2013).

Caspian shad—*Alosa caspia* (Eichwald) is endemic to the basin of the Caspian Sea. It is a non-anadromous fish (Bogutskaya and Naseka, 2013).

Caspian anadromous shad—*Alosa kessleri* (Grimm) is endemic to the basin of the Caspian Sea. It is an anadromous fish (Bogutskaya and Naseka, 2013).

Volga shad—*Alosa volgensis* (Berg) is endemic to the basin of the Caspian Sea. It is an anadromous fish (Bogutskaya and Naseka, 2013).

Shad is one of the most numerous fish of the Caspian Sea, and until the 1960s they formed the bulk of the fishery. It was the shad fishery that determined the direction of the initial stage of development of the Caspian marine fisheries from the middle of the 19th century. With the development of sea fishing, the importance of fishing in rivers began to decline gradually. By the end of the 1890s, the shad sea fishery became the main one, providing in some years up to 90% of all shad catches. The basis of the shad fishery in 1940–1960 consisted of two species—*Alosa volgensis* and *A. caspia* (from 70% to 90% of all shad catch). In addition to shad, a large number of juveniles of valuable commercial fish were caught in fishing nets, which adversely affected their populations. In 1965, the shad sea fishery was stopped. Significant damage to shad stocks was caused by sprat fishing with stern seines, which was intensively carried out for 30 years (1929–1960) and was accompanied by a large catch of juveniles of commercial fish, mainly shad. After a decade of depression since 1968, there has been an increase in the number of Caspian shad. Caspian shad constitute a strategic reserve for the bioproduction of the Caspian Sea (Bogutskaya and Naseka, 2013).

Subfamily Clupeinae—clupeins

Caspian tyulka—*Clupeonella caspia* Svetovidov is endemic to the basin of the Caspian Sea. It is a marine, occasionally semi-anadromous, species. It is distributed throughout the Caspian but is mainly found in shallow waters. It is a euryhaline fish, found both in absolutely freshwater areas of the sea, as well as in zones of high salinity (Bogutskaya and Naseka, 2013).

Anchovy sprat—*Clupeonella engrauliformis* (Borodin) is endemic to the basin of the Caspian Sea. It is a marine species (Bogutskaya and Naseka, 2013).

Southern Caspian sprat—*Clupeonella grimmi* Kessler is endemic to the basin of the Caspian Sea. It is a marine species (Bogutskaya and Naseka, 2013).

Three species of sprat (*Clupeonella engrauliformis*, *C. grimmi*, *C. caspia*) are marine species and important objects of the fishery. Sprat is the most abundant fish of the Caspian Sea. The biomass of these three species makes up to 50% of the lake's total fish biomass. As the most abundant species, sprat play a central role in food chains, being food for many predatory fish species, fish-eating birds and Caspian seals. The extensive commercial development of the stocks began after the 1950s. First, catches quickly grew, which was due to the introduction of the practice of fishing with light. The catches reached their maximum in the early 1970s. After that, for almost 20 years the catches constantly fell. Since 1995, the catches have again slightly increased, mainly due to increased catches by Russia and Iran. However, this increase was short-term, as by 2000 the catches declined again and in subsequent years continued to fall.

In the Volga-Caspian region, total catches in 1990 were 136500 tonnes, in 2 000—120 000 tonnes, and by 2010 they sharply fell to 2 400 tonnes. Stocks of sprats in the Caspian Sea are in a critical state (Velikova et al., 2012). Many authors see the reason for the decrease in sprat catches in the appearance of the ctenophore *Mnemiopsis leidyi* Agassiz in the Caspian Sea. This new, accidentally introduced, species may be the cause of a reduction in the forage base of sprats and the eating of their spawned eggs and fry. While the situation for *Clupeonella engrauliformis* and *C. grimmi* continues to be unfavorable, the stocks of *C. caspia* have remained stable in recent years. This may be explained by a peculiarity of its ecology: the reproduction of the Northern Caspian breeding stock takes place in the springtime, when the ctenophores are actually absent, and the reproduction of the Southern Caspian stock occurs in the coldest period (January–February), when the biomass of *Mnemiopsis leidyi* and its feeding activity remain at low seasonal levels (Bogutskaya and Naseka, 2013).

Family Cyprinidae—cyprinids

Caspian barbel—*Luciobarbus brachycephalus caspius* (Berg) is endemic to the basin of the Caspian Sea. It is a subspecies endemic to the basin of the Caspian Sea. It is an anadromous fish and is distributed in the southern and western parts of the sea from where it enters the Terek, the Kura, the Lenkoranchay, the Sefidrud, and the Gorganrud rivers for spawning. Before the construction of the Mingechaur power plant, Caspian barbel migrated to the Kura, to the lower reaches of the Alazani. Some individuals of this fish were caught in the Volga, Terek, Samur. Caspian barbel is on the verge of extinction (Bogutskaya and Naseka, 2013).

Barbel bulat-mai—*Luciobarbus capito capito* (Gueldenstaedt) is a subspecies endemic to the basin of the Caspian Sea, and is an anadromous fish. It lives in the southern and middle parts of the Caspian Sea. It enters all the rivers of the western coast from the Terek to the Kura and the Lenkoranchay and all the rivers of the Iranian coast (Bogutskaya and Naseka, 2013).

Carp—*Cyprinus carpio* Linnaeus is widely distributed in the basin of the Caspian Sea, it has river and semi-anadromous forms. It occurs not only in freshwater reservoirs but also in brackish water zones of the sea with salinity 3.1–10.7 g/L (Bogutskaya and Naseka, 2013).

Bream—*Abramis brama* (Linnaeus). Breams of the Caspian Sea are semi-migratory fish. In the sea, it is limited to a zone of weakly brackish or fresh water, including the Anzheli and Gorgan gulfs in Iran. For spawning, it goes to the Volga, the Ural, the Terek, the Kura, the rivers of the Lenkoran region, and large rivers of the Iranian coast (Bogutskaya and Naseka, 2013).

Blue bream—*Ballerus ballerus* (Linnaeus) is predominantly a river fish; the semi-anadromous population is small. It occurs in the Volga, the Ural and in the freshened zones of the Northern Caspian up to salinity 4 g/L (Bogutskaya and Naseka, 2013).

White-eye bream—*Ballerus sapa sapa* (Pallas) inhabits the Volga, the Ural, the Terek, plus the freshened zone of the Northern Caspian. It fattens in the freshened zones of the sea, adjacent to the mouths of rivers, and goes into the delta reservoirs or lower reaches only for spawning (Bogutskaya and Naseka, 2013).

Southern Caspian white-eye bream—*Ballerus sapa bergi* (Belyayev) is endemic to the basin of the Caspian Sea. It is an anadromous fish. It inhabits the entire western and southern coast of the Caspian Sea and enters all the major rivers of this region for spawning (Bogutskaya and Naseka, 2013).

Silver bream—*Blicca bjoerkna bjoerkna* (Linnaeus) is a freshwater fish, which also lives in the slightly saline zones of the sea, adjacent to the mouths of rivers. Before the Caspian Sea level decrease in the 1930s, this fish showed signs of being a semi-migratory fish: most of the annual cycle was spent in freshened zones adjacent to deltas and river mouths, and in spring the spawners migrated to spawning grounds located in the lower reaches of rivers. With the decrease in sea level and decreases in the flow of rivers, silver breams are more tied to the reservoirs of river systems than previously (Bogutskaya and Naseka, 2013).

Caspian vimba—*Vimba persa* (Pallas) is endemic to the basin of the Caspian Sea. It is an anadromous fish. In the sea, it lives mainly near the western and southern coasts and enters the Terek, Samur, Kusarchay, Kura, Vilyashchay, Kumbashinka, and Lenkoranchay rivers. In Iran, the Caspian vimba is known from many rivers. In the sea, it is associated with water with a salinity of 8.4–11.2 g/L (Bogutskaya and Naseka, 2013).

Caspian shemaya—*Alburnus chalcoides* (Gueldenstaedt) is endemic to the basin of the Caspian Sea. It is an anadromous fish. The Caspian shemaya predominantly inhabits the southwestern part of the sea; in the Northern Caspian it is very rarely encountered. It withstands salinity up to 10–11 g/L and goes to the spawning rivers, mainly the Kura, the Terek, and the rivers of the Iranian coast. At present, the Caspian shemaya is on the verge of extinction (Bogutskaya and Naseka, 2013).

Asp—*Aspius aspius aspius* (Linnaeus) is a semi-anadromous fish of the Northern Caspian, found in waters with salinity up to 11 g/L (Bogutskaya and Naseka, 2013).

Asp-hasham—*Aspius aspius taeniatus* (Eichwald) is endemic to the basin of the Caspian Sea. It is an anadromous fish that occurs in the southern part of the Caspian Sea but is sometimes found much further north, up to the mouth of the Terek. It migrates to the Kura and other rivers flowing into the South Caspian (Bogutskaya and Naseka, 2013).

Vobla—*Rutilus caspicus* (Yakovlev) is endemic to the basin of the Caspian Sea. It is a semi-anadromous fish. It inhabits the entire Caspian Sea, mainly in the coastal zone and almost throughout the Northern Caspian. The North Caspian vobla is predominantly found in a shallow and slightly saline (up to 7–8 g/L) zone. For spawning, it goes to the deltas of the Volga and the Ural and in a small amount to the delta of the Terek. The Azerbaijanian vobla is spread along the entire western coast of the Southern Caspian; a more euryhaline form occurs from freshwater areas to waters with a salinity of 12–13 g/L (Bogutskaya and Naseka, 2013).

Caspian kutum—*Rutilus kutum* (Kamensky) is endemic to the basin of the Caspian Sea. It is an anadromous fish. The main area of the distribution of the kutum is the Middle and Southern Caspian from the mouth of the Terek to the Gorgan Gulf (Bogutskaya and Naseka, 2013).

Sabrefish—*Pelecus cultratus* (Linnaeus) is a primarily freshwater fish that has adapted to the habitat of the slightly saline sea areas in the basin of the Caspian Sea. It is a semi-anadromous form that migrates, covering the pre-estuarine zones and deltaic parts of the sea. In the Northern Caspian, it occurs at a salinity of 3–4 g/L, rarely up to 9–10 g/L (Bogutskaya and Naseka, 2013).

Cyprinids, except for the vobla, never played such a significant role in the Caspian fishery as sturgeons or shads. However, some species, not so numerous, have always been valuable commercial targets. The most valuable were anadromous fish of the predominantly southern part of the sea (asp-khasham, Caspian barbel, shemaya, Caspian vimba). Among the semi-migratory fish, vobla and bream always played a key role, especially in the Northern Caspian region. The period after the regulation of the Volga can be considered unfavorable for the reproduction of semi-anadromous fish species (Bogutskaya and Naseka, 2013).

Family Salmonidae

Subfamily Coregonidae—coregonids

Whitefish, beloribitsa—*Stenodus leucichthys* (Gueldenstaedt) is endemic to the basin of the Caspian Sea and one of the most valuable species in ichthyofauna. It is a predator that feeds mainly on sprat, gobies, atherine and young fish. In summer the whitefish lives in the middle and southern parts of the sea, and in the autumn and winter period, it also feeds in the Northern Caspian. It is an anadromous fish. Prior to the regulation of the Volga runoff, the whitefish came to spawn in its tributaries: the Oka, the Sura, the Kama, and others. It earlier visited the Terek and the Ural. Since dams on the Volga were built, its natural spawning grounds have been lost. In the 1970s, special artificial spawning grounds were created downstream of the dam of the Volga Hydroelectric Power Station, but their effectiveness was very low. Also, whitefish can be reproduced in rearing stations. Now the number of whitefish is very low and it is on the brink of extinction. According to IUCN, this species is extinct in the wild. But there are data that some natural spawning takes place (Bogutskaya and Naseka, 2013).

Subfamily Salmoninae

Caspian trout—*Salmo caspius* Kessler is endemic to the Caspian Sea basin. It is an anadromous fish that fattens in the sea and spawns in the rivers of the Southern Caspian, mainly the Kura. It was known from many rivers on the Iranian coast. It has lost all natural spawning grounds in the Kura (located at a distance of ~1 000 km from the mouth) due to the construction of the Mingechaur and Varvarinskaya hydroelectric power plants. In the sea it lives along the western and southern coasts, but it migrates extensively. The species is in a threatened state, preserved only by artificial breeding (Bogutskaya and Naseka, 2013).

Caspian salmon—*Salmo ciscaucasicus* Dorofeyeva is endemic to the basin of the Caspian Sea. It is an anadromous fish. It fattens in the sea and spawns in the rivers of the northern and western coast of the Caspian Sea from the Volga to northern Azerbaijan. Single specimens came to the Volga in the first half of the 20th century. Prior to the regulation of the flow of the Terek, it spawned in all mountain tributaries of that river. Following the construction of a dam in the lower reaches of the Terek, all spawning grounds lost their importance. Nowadays, the species does not occur in the Russian sector of the sea. This species is on the verge of extinction, and can only be preserved by artificial breeding (Bogutskaya and Naseka, 2013).

Family Mugilidae—grey mullets

Golden grey mullet—*Chelon auratus* (Risso) [= *Mugil auratus* Risso]. Young and year-old fishes were transported to the Caspian Sea from the Black Sea in 1930–1931. The acclimatization period took 30–35 years and the species was completely naturalized by the second half of the 1960s. At present, golden grey mullet are distributed throughout the sea, but in the freshened northern part of the sea, they are rare. They never enter rivers (Bogutskaya and Naseka, 2013).

Leaping mullet—*Chelon saliens* (Risso) [= *Mugil saliens* Risso]. This species was introduced at the same time as the golden grey mullet. In contrast to it, leaping mullet occur further away from the coast. At the end of April and in May they appear near the western coast of the Middle Caspian. They spawn at a distance of 40–90 km from the shore, at depths up to 780 m. In autumn, after spawning, they retreat south to overwinter. They are detritophagous; adults eat the upper film of the lagoon silt and the fouling of stones in the sea, but also consume worms, crustaceans and small mollusks (Bogutskaya and Naseka, 2013).

Family Atherinidae—atherines

Caspian atherine—*Atherina caspia* Eichwald is endemic to the basin of the Caspian Sea. The Caspian atherine is widespread throughout the Caspian Sea at depths of more than 100 m. It is also common in bays, freshened lagoons, and river mouths. The Caspian atherine is a food object for many omnivorous and predatory fish, such as sturgeon, beluga, pike perch, and predatory shad, as well as the Caspian seal. It is caught as a by-catch when fishing sprats and is used to make fishmeal (Bogutskaya and Naseka, 2013).

Family Syngnathidae—pipefishes

Caspian pipefish—*Syngnathus caspius* Eichwald are endemic to the basin of the Caspian Sea. It is a euryhaline fish that lives in all areas of the sea at salinities up to 59.5 g/L. In the saline Metvy Kultuk and Kaydak bays, a dwarfed form has been found. It is common in fresh water in the deltas of the Volga, Ural, Terek, Kura, rivers of the southern coast. The Caspian pipefish is an object of feeding for predatory fish (Bogutskaya and Naseka, 2013).

Family Percidae—perches

Zander, pike-perch—*Sander lucioperca* (Linnaeus). The ordinary pike-perch lives in all the rivers that flow into the Caspian Sea, in pre-estuary areas and along the shores of the sea. The area of distribution in the Northern Caspian is limited to salinity up to 12 g/L (Bogutskaya and Naseka, 2013).

Estuarine perch—*Sander marinus* (Cuvier) is widely distributed throughout the whole Caspian Sea. Estuarine perch do not make large migrations. They avoid freshened areas and do not enter rivers. After the 1960s, following the intensive development of the offshore oil industry, stocks of estuarine perch throughout the Caspian greatly decreased, and the species disappeared from many fishing areas of the sea. In Russian waters, this fish is on the verge of extinction (Bogutskaya and Naseka, 2013).

Family Gobiidae—gobies

Biodiversity of gobies in the Caspian Sea is very high. This family is represented here by many genera and species. Gobies are an important component of the ecosystem of the Caspian Sea. In the Northern Caspian, where the main commercial fish forage, the gobies serve as food for beluga, sturgeon, catfish, zander, predatory shad, and also for the Caspian seal (Bogutskaya and Naseka, 2013).

2.1.2 Aral Sea

The Aral Sea ichthyofauna, in comparison with the Caspian, is very poor by species and essentially freshwater and euryhaline. In the aboriginal ichthyofauna of the Aral Sea, 20 fish species from 7 families were known. The family Cyprinidae was represented by 12 species, family Percidae—by 3 species. From each of the families Acipenseridae, Salmonidae, Siluridae, Esocidae, and Gasterosteidae there was only one species. The Aral Sea fish fauna had no endemic fish genera or species; only some

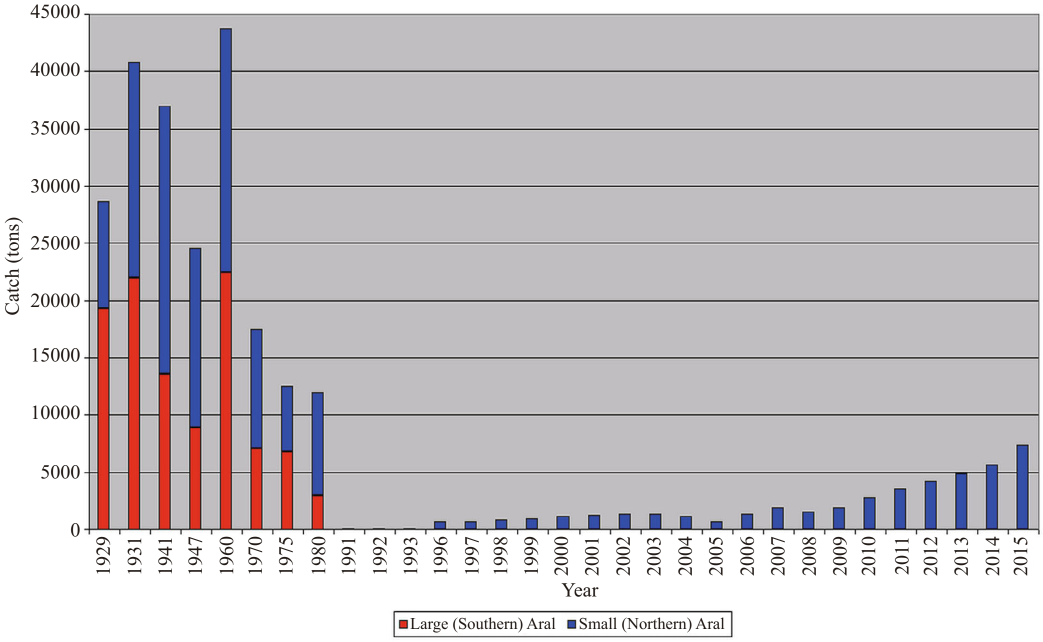

Fig.5 Dynamics of the Aral Sea fish catches

endemic subspecies (Nikolsky, 1940).

Aboriginal fishes of the Aral Sea, except ruff *Gymnocephalus cernuus* (Linnaeus) and nine-spined stickleback *Pungitius platygaster aralensis* (Kessler), were commercially valuable and were subjects of targeted fisheries (Ermakhanov et al., 2012). Most aboriginal fishes were benthophages. Only pike, zander, wels, asp and trout were predators. The nine-spined stickleback was the only planktivorous species (Ermakhanov et al., 2012).

All aboriginal fishes of the Aral Sea were generatively freshwater species. For reproduction they mainly migrated to fresh or almost fresh waters: freshwater bays near deltas, lakes in the deltas and rivers where spawning occurred, although they could also spawn in brackish water (Nikolsky, 1940; Bervald, 1964; Ermakhanov et al., 2012).

The first changes in the composition of ichthyofauna occurred appreciably before the onset of Aral Sea desiccation and salinization in the 1960s. This was a result of attempts (not all of them successful) to enrich the fauna and biological resources with valuable commercial fish species. In 1954–1956 unsuccessful introductions from the Caspian Sea of two species of mullets were attempted. As a result, 6 species of gobies, atherine, and pipefish (all having no commercial value and being undesirable as competitors for aboriginal fishes) were brought accidentally into the Aral Sea and naturalized. In 1954–1959, the plankton-eating Baltic herring *Clupea harengus membras* (Linnaeus) was acclimatized as a commercial fish but did not become a fishery target as numbers remained very low. Later, in 1958–1960, fishes of the China complex—grass carp, silver carp and spotted silver carp were successfully acclimatized in the Aral Sea. Together with them, black carp and snakehead were introduced accidentally. This last acclimatization had no negative impact on biological resources, but total fish catches grew insignificantly (Karpevich, 1975; Ermakhanov et al., 2012). After these acclimatizations, 14 new fish species appeared in the Aral Sea ichthyofauna, but only 6 of them became commercially valuable (Ermakhanov et al., 2012).

When salinity in the mid-1960s increased to 12–14 g/L, a harmful impact of salinization on the state of commercial fish populations became apparent, since this salinity level affected roe development in freshwater fishes. From 1971, further negative effects of increasing salinity on adult fishes appeared. Growth rate became slower, while abundances of many fish species decreased noticeably. When in the mid-1970s salinity exceeded 14 g/L, the natural reproduction of fish in the Aral Sea broke down, and there was no replenishment of many freshwater fish species populations. From 1961, commercial fish catches (Fig.5) fell by more than 75%. By the 1980s, salinities exceeded 18 g/L, and, of the Aral Sea fish fauna, only euryhaline stickleback, gobies, atherine, and Baltic herring remained; as a result, all fisheries stopped.

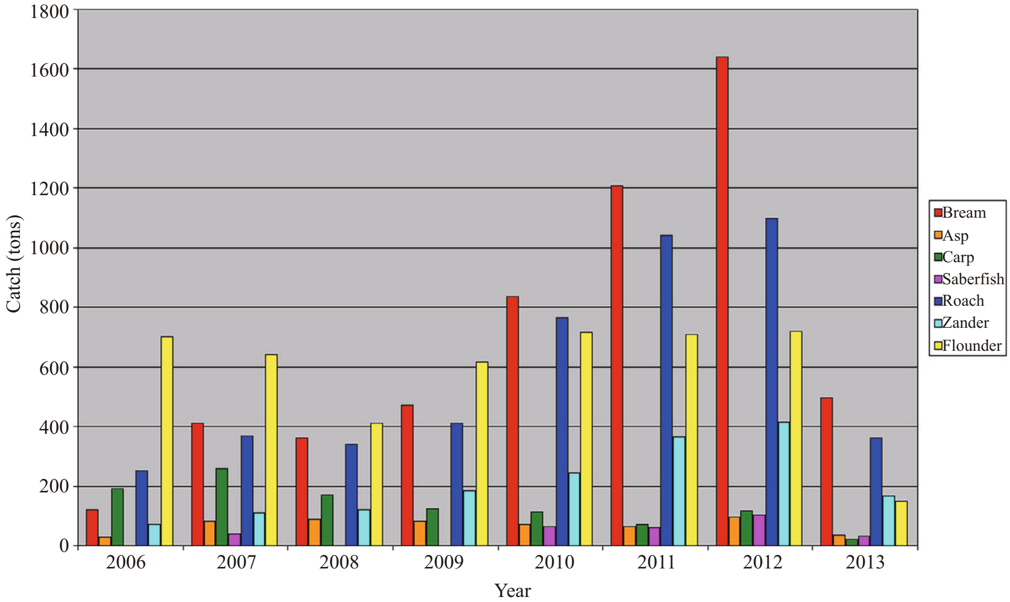

Fig.6 Small Aral Sea composition of fish catches (2013 data for only 9 months)

However commercial freshwater fishes survived in attendant rivers, and lakes connected with them (Ermakhanov et al., 2012).

In 1979–1987, the Azov-Black Sea flounder-gloss *Platichthys flesus* was successfully acclimatized in the Aral Sea for the restoration of its biological resources and fisheries. This marine fish is capable of reproduction at water salinity 17–60 g/L. It inhabited the entire Aral and in the 1990s remained the only commercial fish (Ermakhanov et al., 2012).

In the Large Aral Sea salinity rose steadily. By the end of the 1990s, it reached 60–70 g/L and this part of the sea became a hypersaline water body. As a result, the Large Aral completely lost its ichthyofauna (Ermakhanov et al., 2012).

Owing to the dam built in the Berg Strait, the flow of the Syr Darya accumulated and the salinity of the Small Aral decreased. As a result, aboriginal commercial fishes began to migrate to the Small Sea from the Syr Darya and its connected lacustrine systems. After a long absence, over time, the aboriginal ichthyofauna settled almost the whole area of the Small Aral Sea, except for the western part of the Butakov Bay, where relatively high salinity still exists. Populations of valuable fishes, such as roach, carp, bream, zander, asp, sabrefish and some others reached numbers sufficient for the commercial fishery. Catches are growing (Figs.5, 6). This biological resource is therefore restored. Now 17 species from the ichthyofauna of the Small Aral Sea can be used by commercial fishers. The main targets for them are bream, roach, sabrefish, carp, zander and asp (Ermakhanov et al., 2012, 2013).

Family Esocidae—esocids

Pike—*Esox lucius* Linnaeus is a piscivorous predator, but is not numerous. The population is in a dynamic state and normal range, indicating a satisfactory condition (Plotnikov et al., 2016).

Family Cyprinidae—cyprinids

Bream—*Abramis brama orientalis* Berg is a species with high adaptive abilities, especially to changing environmental conditions, and this supports its sustainable economic importance. Bream is a typical benthophage, and can eat plants and also plankton. The temperature regime of the sea and the presence of reeds and underwater vegetation are favorable for intensive spawning. Bream spawn on vegetation in brackish areas of the sea, in deltaic water bodies, and even in marine spawning grounds where there is no inflow of fresh water. Bream arrive at their spawning grounds in late April and May (Ermakhanov et al., 2013; Plotnikov et al., 2016).

White-eye bream—*Abramis sapa aralensis* Tjapkin is a benthophage, and is not numerous. For spawning, it migrates to the Syr Darya (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Asp—*Aspius aspius iblioides* (Kessler) is a predator, with fish fry and crustaceans dominating its diet. This semi-anadromous fish feeds in the sea and spawns in the Syr Darya River into which it migrates up to the Kyzylorda Dam in October–November for reproduction. The asp lays eggs in stony places and between roots of plants. Spawning occurs immediately after the start of the ice cover melting, with the spawners then migrating back to the sea. Due to the freshening of the Small Aral in recent years, the habitat area of asp has significantly changed. Although asp was found only in the mouth area of the Syr Darya in 2001–2004, its habitat area had spread almost all over the lake by 2005, except for Butakov Bay, where it appeared in 2008 (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Common carp—*Cyprinus carpio aralensis* Spitshakow is a benthophage, with a diet including bivalves, worms, and insect larvae, as well as vegetation and detritus. The fish spawns principally in mid-May, although it also continues from April to July. *Cyprinus* lays eggs in underwater vegetation. Given the presence of reeds and underwater vegetation over almost the entire Small Aral it spawns almost everywhere (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Grass carp—*Ctenopharyngodon idella* (Valenciennes) were introduced into the Aral Sea in 1960–1961. Stocks are currently small, being concentrated in the sea near the mouth of the Syr Darya. The fish is herbivorous, feeding on higher aquatic plants, submerged terrestrial vegetation, and on detritus, insects and other invertebrates (Plotnikov et al., 2016).

Silver carp—*Hypophthalmichthys molitrix* (Valenciennes) was introduced into the Aral Sea in 1960–1961. It is a filter feeder, consuming phytoplankton, zooplankton, and detritus. The fish are concentrated in the sea near the Syr Darya mouth, with only small stocks (Plotnikov et al., 2016).

Bighead carp or spotted silver carp—*Aristichthys nobilis* (Richardson) was introduced into the Aral Sea in 1960–1961. It is a filter feeder, consuming phytoplankton, zooplankton, and detritus. It is rare in the Aral Sea (Plotnikov et al., 2016).

Sabrefish—*Pelecus cultratus* (Linnaeus) is an adaptable omniphage, feeding mainly on planktonic crustaceans, larvae, and imagoes of Diptera, mysids, amphipods and fish fry. Most of the sabrefish in the Small Aral spawn along the sea coast at 2 to 6 m depths. Spawning occurs between late May and early June, and the eggs are bathypelagic (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Aral roach—*Rutilus rutilus aralensis* Berg is found over the entire Small Aral but is more plentiful near the Syr Darya mouth. The basis of the roach diet is chironomid larvae, although it also consumes mollusks, vegetation, and detritus. Roach was found in the mouth of the Syr Darya only from 2001–2003. By 2005, however, its habitat had expanded to almost the entire water body, except in Butakov Bay where it appeared in 2008. The fish spawns mainly in the second half of April, usually laying its eggs on submerged vegetation. An increased number of roach numbers is undesirable, however, since the fish competes for food and spawning areas with the commercially valuable common carp (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Rudd—*Scardinius erythrophthalmus* (Linnaeus). For spawning it migrates to the Syr Darya. Its numbers are small. The rudd population is in a satisfactory state (Ermakhanov et al., 2012, 2013).

Ide, orfe—*Leuciscus idus oxianus* (Kessler). Its stocks are very small in the Aral. Ide are omnivorous, with their diet includes insects, crustaceans, mollusks and small fish (Plotnikov et al., 2016).

Aral shemaya—*Chalcalburnus chalcoides aralensis* (Berg) is a semi-anadromous fish living in the Small Aral, lakes of the lower Syr Darya and in the river itself. It produced ~6% of the total fish production in the Aral Sea in the past, mainly (~70%) in its northern part. Its numbers have recently decreased sharply and it is now rare (Plotnikov et al., 2016).

Aral barbel—*Luciobarbus brachycephalus brachycephalus* Kessler is a benthophage, mostly feeding on bivalve mollusks. The fish was common in the Aral Sea Basin in the past, with great commercial value. Regulation of inflowing rivers and large water withdrawals resulted in a sea level decrease that subsequently led to a serious collapse of fish reproduction, including fingerling mortality in irrigation channels, etc. The fish numbers are now low, with the fish being rare and considered an endangered species. A small population survives in the lower reaches of the Syr Darya. As a result of the partial restoration of the Small Aral Sea, barbel is beginning to be found at the mouth of the Syr Darya and, most recently in the freshened north-eastern part of the sea (Plotnikov et al., 2016).

Turkestan barbel—*Luciobarbus capito conocephalus* Kessler is endangered, and considered a very rare species in the Aral. Its small self-reproducing populations survived in the lower reaches of the Syr Darya (Plotnikov et al., 2016).

Family Siluridae—catfishes

Wels—*Silurus glanis* Linnaeus is a piscivorous predator, which prefers to spawn on vegetation. The state of the wels population is stable (Plotnikov et al., 2016).

Family Percidae—perches

Pike-perch, zander—*Sander lucioperca* (Linnaeus) is mostly a piscivorous predator. Zander lived only near the Syr Darya mouth in 2001–2003. Due to subsequent freshening of the Small Sea, its habitat area then increased, being widely distributed by 2005, though absent from Butakov Bay. It has more recently been encountered in all parts of the sea. Zander are phytophilic fish, with spawners migrating into the Syr Darya from late September until March–April, when they mainly spawn (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Family Channidae—snakeheads

Snakehead—*Channa argus warpachowskii* Berg was accidentally introduced into the Aral Sea in 1960–1961 together with grass carp and silver carp. It is primarily a piscivorous predator, but also consumes crustaceans, other invertebrates and amphibians. The fish is found near the mouth of the Syr Darya. Its catch is small (Plotnikov et al., 2016).

Family Pleuronectidae—righteye flounders

Flounder—*Platichthys flesus* (Linnaeus). This euryhaline fish was introduced to the Aral Sea in the 1970s by a Danish initiative. In its native coastal N. Atlantic habitat, it is an essentially marine fish that forages tidally in estuaries, though it also lives in the brackish Baltic Sea where salinities are continuously lower than in coastal areas of the N. Atlantic. It lays pelagic eggs, and if salinity is too low (ca. 14 g/L; Nissling et al., 2002), the eggs sink and will not survive. Currently, it only lives in Butakov Bay and adjacent areas that exhibit high salinities. Flounders are benthophages, mainly eating mollusks. They start spawning at temperatures close to 0°C in February–March, with the main spawning taking place from mid-March to early April. Due to freshening in the eastern and north-eastern parts of the sea, flounder have spawned only in Shevchenko and Butakov bays (where the salinity is relatively high) since 2004–2005. The decreased salinity of the Small Aral Sea, and increases in the number of native freshwater fish, has worsened the flounder food base and environmental conditions for natural flounder reproduction. Accordingly, the area inhabited by flounder is shrinking and its stocks are dropping. If salinities in the Small Aral continue to decline, the flounder will inevitably become extinct (Ermakhanov et al., 2013; Plotnikov et al., 2016).

Family Acipenseridae—sturgeons

Ship sturgeon—*Acipenser nudiventris* Lovetsky. It is an anadromous fish. In the past, this species lived in the Aral and had a high commercial value (Nikolsky, 1940). In the 1930s when there was an attempt to introduce the stellate sturgeon *Acipenser stellatus* from the Caspian Sea, the monogenean parasite worm *Nitzschia sturionis* (Abildgaard) was also introduced and infected ship sturgeon. Ship sturgeon in the Aral Sea had not previously encountered this parasite (Dogiel and Bykhovsky, 1934). As a result, the epizootic caused mass deaths of the new host that had no immunity to *N. sturionis* (Dogiel and Lutta, 1937). Later, after dams built on the Syr Darya and Amu Darya rivers had blocked migration routes to the spawning areas located far upstream, ship sturgeon became extinct in the Aral Sea (Ermakhanov et al., 2012). Fortunately, this fish had been acclimatized in 1933–1934 to the basin of Balkhash Lake (a large lake in Kazakhstan) where it now lives.

Family Salmonidae—salmonids

Aral trout—*Salmo trutta aralensis* Berg. It is anadromous fish. This fish was always extremely rare in the Aral Sea and was little studied (Nikolsky, 1940). This endemic subspecies is now extinct (Ermakhanov et al., 2012).

Fisheries in the Small Aral Sea are recovering, and the fishery catch changed substantially since 2006 (Figs.5, 6, 7). Commercial catches have grown from 650 tonnes in 1996 to 7 397 tonnes in 2015. At the same time, their composition has been changing. In 2013 the flounder contribution decreased from 52% to 28% of the total, the roach increased from 18% to 30% and the bream increased from 8% to 26%. The contribution of zander increased from 4% to 10% and asp from 0.4% to 2.7%. The share of carp during the study period declined from 26% to 2.0%, while the sabrefish increased somewhat from 1.9% to 2.3% (Plotnikov et al., 2016).

In the east of the Small Aral many commercial fish aggregates and the bulk of their juveniles are concentrated in low salinity areas near the delta of the Syr Darya that is adjacent to the Kokaral dam. When the dam gates open, the outflowing water from the Small Sea contains both valuable adult commercial fish and a large number of their juveniles. All are lost

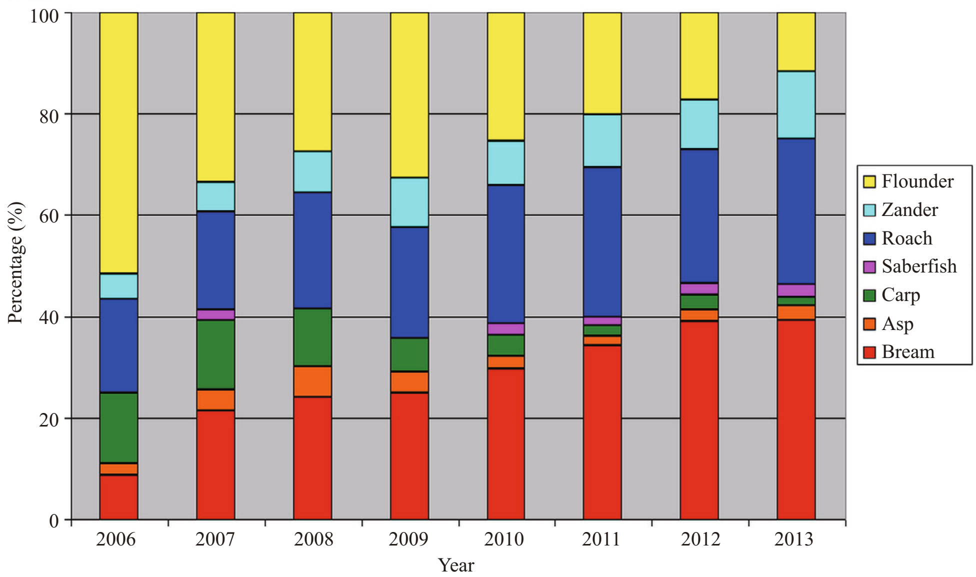

Fig.7 Share of main commercial species in Small Aral Sea fish catches

in the shoals between the Small and Large Aral. This happens because the dam does not have any retaining devices. Unless this deficiency is dealt with, the mass loss of commercially valuable fish will obviously continue to be an avoidable biological resource loss.

2.2 Mammals in the Caspian Sea

The Caspian seal *Pusa caspica* Gmelin is the only aquatic mammal in the Caspian Sea. It is a small species (<1.4 m body length; see Goodman and Dmitrieva (2016)). It is almost exclusively fish-eating. In winter, seals concentrate in the Northern Caspian at the ice cover edge. Almost all (>99.9%) of whelping, mating and molting takes place on ice; the pups stay on ice until March. Small numbers of seals winter on islands off the coast of Turkmenistan. In summer, seals migrate for feeding to the Middle and Southern Caspian. Some of the herds remain in the Northern Caspian (Aladin et al., 2001). At the end the 19th century the seal population exceeded 1 million despite sustained heavy commercial exploitation for fur, meat, and oil since the late 18th century. During the 20th century hunting pressure increased and the population declined, being halved by the 1950s. Since that time sealing quotas have been reduced, but population decline has continued due to many factors (e.g. direct capture, by-catch in illegal fishing nets, environmental pollution, declining populations of prey (fish) and changes in amounts of ice). By 2005, the population was estimated at 34 000 (see Goodman and Dmitrieva, 2016). At the end of the 20th century (1997–2001), ~25% of the depleted Caspian seal population had died out due to various diseases, particularly canine distemper (CDV). The very warm winter of 2000 and consequent lack of solid ice in the Northern Caspian Sea also created serious difficulties for seal reproduction.

2.3 Invertebrates

In the Caspian and the Aral, invertebrates, as a biological resource, are food for the fish. Among them, the main role is played by polychaetes, oligochaetes, rotifers, planktonic and benthic crustaceans, mollusks, insect larvae, first of all, chironomids. Rotifers and planktonic crustaceans are consumed by fish juveniles and by obligate fish-planktophages. Benthic invertebrates serve as food for benthophages.

Rotifers and planktonic crustaceans—cladocerans and copepods — are represented in the fauna of the Caspian and the Aral Seas by a large number of species. Their species diversity in the Caspian Sea, however, is much the higher.

In the Caspian Sea, there are 8 species of Polychaeta. Of these, *Hypania invalida* (Grube), *Hypaniola kowalewskii* (Grimm) and *Parhypania brevispinis* (Grube) are endemics, *Manayunkia caspica* Annenkova, *Fabricia sabella caspica* Zenkewitsch are aboriginal, while *Hypania antiqua* (Ostroumoff), *Ficopomatus enigmaticus* (Fauvel) are invasive species that have penetrated the Caspian Sea independently. The most important species acclimatized during the 1930s as a valuable and accessible food for sturgeons is *Hediste diversicolor* (O. F. Müller) (Karpevich, 1975; Khlebovich, 2015).

In the Caspian, resource benthic crustaceans from Malacostraca are represented by Mysida (genera *Mysis*, *Lymnomysis*, *Diamysis*, *Schistomysis*, *Katamysis*, *Hemimysis*, *Caspiomysis*, *Paramysis*), cumaceae (Cumacea—*Schisophynchus*, *Pterocuma*, *Volgocuma*, *Pseudocuma*, *Stenocuma*, *Caspiocuma*, *Hyrcanocuma*), Isopoda (genera *Jaera* and *Mesidotea*), Amphipoda (genera *Chelicorophium*, *Corophium*, *Niphargus*, *Behningiella*, *Cardiophilus*, *Zernovia*, *Caspicola*, *Gammaracanthus*, *Akerogammarus*, *Amathillina*, *Axelboeckia*, *Baku*, *Cephalogammarus*, *Chaetogammarus*, *Derzhavinella*, *Echinogammarus*, *Gammarus*, *Gmelina*, *Gmelinopsis*, *Kuzmelina*, *Lanceogammarus*, *Scytaelina*, *Shablogammarus*, *Sowinskya*, *Yogmelina*, *Iphigenella*, *Compactogammarus*, *Dikerogammarus*, *Niphargogammarus*, *Niphargoides*, *Obesogammarus*, *Pandorites*, *Paraniphargoides*, *Pontogammarus*, *Stenogammarus*, *Turcogammarus*, *Uroniphargoides*, *Wolgagammarus*, *Onisimus* and *Monoporeia*) and Decapoda (accidentally introduced shrimps *Palaemon elegans* (Rathke), *P. adspersus* (Rathke) and the aboriginal crayfishes *Astacus leptodactylus* Eschscholtz and *Caspiastacus pachypus* (Rathke)) (Birshein and Romanova, 1968; Daneliya and Petryashov, 2015). Among benthic crustaceans, only crayfishes have some commercial importance. The other malacostracans play an important role in the nutrition of fish.

Among mollusks the main role as food for fish is played by native bivalves (~40 species) of the genera *Adacna*, *Didacna*, *Monodacna*, *Hypanis*, *Dreissena* represented in the fauna of the Caspian Sea by a large number of species and subspecies. Also important is the mollusk *Syndosmya segmentum* Récluz, introduced in 1939. The importance of aboriginal *Cerastoderma* and the invader *Mytilaster lineatus* (Gmelin) is low because they both have thicker shells. This invader, moreover, had a negative effect, displacing some species of *Dreissena* (Karpevich, 1975).

In the Aral Sea fauna polychaetes, mysids, cumaceans and decapod crustaceans initially were absent. Amphipods were represented by only one species *Dikerogammarus aralensis* (Uljanin). Bivalve mollusks were represented only by 4 species and subspecies of *Dreissena*, 4 species and subspecies of *Hypanis* and 2 species of *Cerastoderma* (Mordukhai-Boltovskoi, 1974).

In 1954–1956, during an unsuccessful attempt to introduce mullets from the Caspian, the shrimp *Palaemon elegans* was inadvertently introduced. This crustacean caused first a decrease in the number and then the complete disappearance of *Dikerogammarus aralensis* the Aral Sea by 1973. This was unfortunate as *D. aralensis* had been more valuable as a food. This amphipod, however, is highly euryhaline, and it still remains in the rivers and the lakes in their lower reaches (Mordukhai-Boltovskoi, 1972).

Introduction in 1954–1956 of the planktophagous Baltic herring had very negative impact on the Aral Sea zooplankton. More than 70% of the zooplankton biomass consisted of the low-productivity copepod (Karpevich, 1975; Kortunova, 1975) *Arctodiaptomus salinus* (Daday). It was possible because there were no obligate planktophages except for stickleback. Because of the impact of Baltic herring, as well as that of atherine and gobies, the abundance and biomass of zooplankton decreased more than tenfold due to large crustaceans *A. salinus*, *Cercopagis pengoi aralensis* M.-Boltovskoi, *Moina mongolica* Daday, *Ceriodaphnia reticulata* (Jurine), and cyclopoids. This led to the mass death of herring and atherine from starvation (Osmanov, 1961; Kortunova, 1975). After this, the numbers of plankton-eating fishes in the Aral Sea never again reached a high level.

In 1958–1960 Ponto-Caspian mysids were introduced in the Aral Sea. These crustaceans can inhabit environments of salinity of up to 17–20 g/L. Of the three introduced species—*Paramysis lacustris* (Czerniavsky), *P. intermedia* (Czerniavsky), and *P. baeri* Czerniavsky, only the former two became successfully naturalized. The other species of this *Paramysis* genus, *P. ullskyi* Czerniavsky, had undergone auto-acclimatization in the Aral from the water reservoirs on Syr Darya (Karpevich, 1975).

In the early 1960s marine euryhaline invertebrates—the polychaete worm *Hediste diversicolor* and bivalve mollusk *Syndosmya segmentum* were introduced into the Aral Sea successfully as valuable and accessible food for benthophagous fishes (Karpevich, 1975). As a result, *S. segmentum* became the major component of the benthic fauna. Due to its high eurysalinity *S. segmentum* survived the further salinization of the Aral Sea and replaced in this role the mollusks *Dreissena* and *Hypanis* whose numbers were greatly reduced by 1970 and which later entirely disappeared because of increasing salinity.

In 1965 and in the 1970s, the highly productive marine planktonic crustacean *Calanipeda aquaedulcis* Kritchagin was introduced in the Aral Sea in order to restore and increase the productivity of zooplankton after the extermination of *Arctodiaptomus salinus*. This copepod became one of the dominant species in the zooplankton of the Aral Sea and replaced the native copepod *A. salinus* and the cladocerans *Moina mongolica*. (Mordukhai-Boltovskoi, 1972; Karpevich, 1975; Plotnikov, 2016).

Since the 1960s, changing water salinity has been the main factor affecting the Aral Sea biota. Increasing water salinity has caused the diminution in numbers of chironomids, oligochaetes and the bivalves, *Dreissena* and *Hypanis*, in the Aral Sea and finally their disappearance (Karpevich, 1975).

The most species-rich, freshwater and brackish-water components of the fauna disappeared gradually. By the end of the 1980s in the Aral Sea, there were only a few invertebrate resource species resistant to the increased salinity: rotifers *Synchaeta*, copepods *Halicyclops rotundipes aralensis* Borutzky and *Calanipeda aquaedulcis*, polychaete *Hediste diversicolor*, shrimp *Palaemon elegance*, bivalves *Syndosmya segmentum* and *Cerastoderma isthmicum* Issel (Plotnikov, 2016).

A significant decrease in salinity in the Small Aral since the 1990s and the formation of a highly freshened zone near the Syr Darya delta opened a possibility of natural reintroduction of many freshwater and brackish-water invertebrate species associated with Syr Darya, its lower reaches and associated lakes, or invertebrate species, with resting eggs that retain their viability for a long time (Plotnikov et al., 2016). On the other hand, the sharp decrease in salinity became unfavorable for the species of marine fauna and fauna of more saline continental water bodies.

The biodiversity of rotifers and planktonic crustaceans has increased significantly. Freshwater crustaceans have reappeared. Mysids have returned to the Small Aral from the lower reaches of the Syr Darya. Reintroduction of the bivalve mollusk *Dreissena polymorpha aralensis* (Andrusov) has occurred in the freshened water area. At least eight species of larval chironomids are found. The numbers of the mollusk *Cerastoderma isthmicum* have decreased significantly due to lowered salinity (Plotnikov et al., 2016).

The transformation of the Large Aral into a hypersaline water body led to another reduction in biodiversity (Plotnikov, 2016). All remaining resource invertebrates became extinct and conditions for successful natural introduction of the halobiont brine shrimp *Artemia* developed. This crustacean was first found there in 1998 when salinity approached 60 g/L (Zholdasova et al., 2000). It occurs exclusively as parthenogenetic populations (clones), traditionally united under one common name: *A. parthenogenetica*. The introduction of brine shrimp occurred by aeolian transfer of cysts (latent eggs) from other hypersaline reservoirs in the Aral Sea region. With the final disappearance of the last few remaining planktivorous fish, brine shrimp soon became the dominant form of free-living planktonic invertebrates in the hypersaline residual reservoirs of the Large Aral (Plotnikov, 2016). Nowadays, *Artemia* forms the only biological resource in the hypersaline environment of the Large Aral Sea, and its cysts are now harvested. In the Caspian Sea, brine shrimp are found in hypersaline bays (Mertvy Kultuk, Kaydak, and Kara-Bogaz-Gol). Nauplii of brine shrimp are also an excellent food for small or young aquatic animals. Because of this, the harvesting and storage of *Artemia* resting eggs/cysts represent a profitable business.

3 THREATS TO THE BIOLOGICAL RESOURCES OF THE CASPIAN SEA

Regulation of rivers (e.g. damming, diversion, abstraction) that flow into the Caspian represents one of the most significant anthropogenic impacts on its biological resources. In the 20th century, many reservoirs were created on these rivers and several dams were built to aid the hydroelectric power industry. The Volga and its tributaries changed into a chain of huge reservoirs (Kochurov et al., 2012: 25–26). The water withdrawal for irrigation in the Volga, Terek and Kura basins also affected the hydrological and hydrochemical conditions of the Caspian Sea, leading to serious biological and ecological changes (Matri and Ratkovich, 1976). Every year ~3% of the annual flow of the Volga is lost due to evaporation (Zonn, 2001). Simultaneously, natural "tectonic" factors, seemingly, also have influenced the long-term fluctuation of the hydrological regime (Frolov, 2000: 80). These anthropogenic and apparently natural changes have caused natural spawning grounds to collapse for anadromous and semi-anadromous fish species. The shallowing of delta regions now hampers migratory fishes from moving to spawning areas. The Cascades of hydroelectric dams are also huge obstacles to migratory fishes, especially sturgeons (Table 4) and salmonids. While populations of

Table 4 The number of sturgeons in the Caspian Sea, millions of individuals (from Ermolin and Svolkinas, 2018: 286)

Year	Fish species		
	Beluga (*Huso huso*)	Russian sturgeon (*Acipenser guldenstaedtii*)	Sevruga (*Acipenser stellatus*)
1978	12.1	60.5	69.7
1983–1988	14.1	43.8	46.6
1991–1994	8.3	26.9	17.7
1998–2000	7.5	31.6	10.5
2003–2005	2.8	23.66	8
2006–2010	2.9	15.3	5.9
2011	1.5	9.4	1.64

Caspian salmon have almost completely disappeared, populations of sturgeons are being maintained by rearing stations, the latter being most numerous on the Volga. Available natural spawning grounds are located only in the Ural and the Iranian rivers where no dams were built (Aladin et al., 2001).

Over-fishing and poaching are other significant anthropogenic impacts on the biological resources. Considering the Kazakhstani part of the Caspian Sea, the allocation of fishing grounds is well institutionalized. Fish enterprises have to win a tender and buy a fishing quota. Local fishermen are hired by these enterprises and fish, getting low salaries from the enterprises. These practices encourage local fishermen to poach and poaching has drastically increased in these years (Mitrofanov and Mamilov, 2015: 166). Biological resources of the Caspian are of high commercial significance. The Caspian holds ~90% of the world's sturgeon stocks, although these are much depleted. Sturgeons are endangered most of all due to the high commercial prices of sturgeon-based products (e. g. caviar). Nowadays, the "official" catch of sturgeons in the Caspian has been reduced very significantly, especially since 2017. All the riparian states of the Caspian Sea banned wild sturgeon harvesting in 2014, which paradoxically "has led to the further criminalization of sturgeon catches". Organized criminals are engaging in poaching sturgeons and smuggling caviars from the Caspian coastal states to Europe (van Uhm and Siegel, 2016: 71). International and internal law cannot well regulate the regime of living resources of the Caspian Sea due to the unclear status of the water body itself (Janusz-Pawletta, 2015: 83-94). At present such commercial fishes as Caspian lamprey, Volga shad, Caspian trout, and whitefish are also included in the Red Books whereas in the 1920–1940 period they were important commercial species. After the Soviet Union collapsed, fishing regulations were not observed, controlling authorities disintegrated, and marine fishing of sturgeons resumed. Over-fishing also affects other commercial fishes. Thus, Caspian trout, bream, and zander have completely disappeared from some areas of the Caspian Sea. For species with a short life cycle, over-fishing is less dangerous. Their reduced abundance can recover within a few years whereas recovery of stocks of fishes with long life cycles such as sturgeon will take at least 30–50 years (Aladin et al., 2001).

Another significant threat to the biological resources of the Caspian Sea is anthropogenic pollution. Its main sources are industry, agriculture, accidental discharges, and sewage. A lot of pollutants enter into the Caspian from the Volga River, but nowadays the most dangerous is oil pollution due to the intensive development of offshore oilfields in the Caspian Sea, including the big Kashagan project in the Kazakhstan part of the Caspian Sea. Petroleum hydrocarbons cause various physiological, biochemical and morphological changes in aquatic organisms. In some cases the changes can be reversible; otherwise, they cause chronic pathological sublethal and lethal effects. Pollution with pesticides, oil products, and heavy metals have primarily impacted sturgeon. For example it caused a disease not recorded previously—hepatotoxic hypoxia, the external manifestation of which was exfoliation of muscle tissue (Aladin et al., 2001). Furthermore, sturgeons, well-known for their long life, have become threatened by the dangerous concentration of toxic pollutants (German, 2016: 48). So far, however, there is "no data on the influence of the existing pollution levels on the biodiversity of fishes of the Caspian Sea" (Mitrofanov and Mamilov, 2015: 166).

At the end of the 20th century, the planktonic ctenophore *Mnemiopsis leidyi* was introduced to the Caspian with ballast water of shipping. This species is an example of a negative impact on the biological resources of the Caspian (Ivanov, 2000). It consumes zooplankton and hence causes starvation for plankton-feeding fish. This is probably the most dangerous alien species in the Caspian Sea.

4 CONCLUSION

The Caspian Sea and the Aral Sea both have rich (but currently much depleted) biological resources, mostly in the form of their fish and crustacean faunas.

Many fish species in the Caspian (especially sturgeons) and the Aral are valuable targets for the commercial fishery.

The biodiversity and biological resources of the Caspian Sea are important to mankind because of their unique ecological, genetic and commercial qualities. The main threats to the biological resources of the Caspian Sea are river modifications and withdrawals for irrigation and power generation, overfishing and illegal poaching, alien species introductions, water pollution originating from oil and gas excavation and transportation, plus agricultural, industrial and military activities. To protect the biological resources, all of these threats should be overcome or strictly regulated. New rearing stations for artificial reproduction of sturgeons should be created. New conservation programs should be developed for sturgeon populations. Brine shrimp cyst harvesting businesses should be enlarged in the saline bays of the Caspian Sea. It should be remembered that properly organized exploitation of the Caspian biological resources could generate total profits comparable with the profit from oil and gas production. Biological resources, when properly used, are almost inexhaustible, while oil and gas will eventually end. Any new oil and gas fields in the Caspian Sea should be exploited only with environmental-friendly technology. Threats to the environment by pollution loading from all types of the industry should be minimized, and where practical prevented. New irrigation fields around the Caspian Sea should also use environmental friendly technology and new cultivars of plants that need less irrigation water should be used. Eutrophication of the Caspian Sea must be avoided at all costs.

During the Aral Sea post-1960s anthropogenic regression, which resulted from increasing upstream withdrawal of Amu Darya and Syr Darya waters for irrigation, almost all commercial ichthyofauna and fisheries were lost. Subsequent to the construction of dams between the northern and southern parts of the Aral in the late 1990s and early 2000s, the water level in the Small Aral has increased and its salinity eventually returned to levels that can sustain the pre-1960s-type ecosystem. Now biodiversity and biological resources are rehabilitated, and the commercial fisheries have revived. Unfortunately, the Large (Southern) Aral continues its retreat and salinization and is now transformed into a group of residual hypersaline water bodies without fish fauna. Nowadays the only biological resource remaining consists of naturally-introduced brine shrimp (*Artemia*). The only possible economic activities lie is the harvesting of their eggs.

Some scientists, including authors of this paper, are more optimistic about the possible future of the Western Large Aral. If all available water of the Amu Darya River could go to this part of the lake, instead of to the shallow Eastern Large Aral, its salinity will decrease slowly. Achieving this would need improvements to irrigation efficiency. At first, the residual flow of the Amu Darya would have to be directed into the former Adzhibay Bay. Next, nearly fresh water would flow from the Bay via a channel into the Western Large Aral and would eventually discharge at the North to the Eastern Large Aral. After a long time (~40 years) it would be possible to reintroduce flounder. After one century, salinity could reach 15 g/L, sufficient for the existence of aboriginal fish fauna. In contrast, Eastern Large Aral will remain hypersaline indefinitely (Micklin, 2010, 2014a).

Meanwhile, there are also new initiatives in prospect to improve biological resource availability by promoting aquaculture rather than the harvesting of natural resources. For example, in the Republic of Kazakhstan, there was a project to reintroduce ship sturgeon back to the Small Aral Sea either from Balkhash Lake or from the Kapchagay reservoir on the Ili River. Because migration routes of this fish to spawning areas are blocked by dams on the Syr Darya and natural reproduction is hence impossible, a special rearing station for artificial reproduction would need to be created. In Kazakhstan, there are discussions about the creation of domestic brine shrimp culture too. If this is done, greater profits from the Kazakh areas of the Caspian and Aral will be received from brine shrimp trade. Similarly, in the Republic of Uzbekistan ideas to create crustacean aquaculture in the Zarafshan River area are under discussion. If this is done, larger profits from the Aral will be received from the crustacean aquaculture business (Aladin et al., 2017).

5 ACKNOWLEDGEMENT

This work was supported by the program of the Presidium of the Russian Academy of Sciences "No. 41. Biodiversity of natural systems and biological resources of Russia" and by the theme of the State assignment for 2017–2019 "AAAA-A17-117030310206-6. Systematization of the biodiversity of salt lakes and brackish water inland seas in the zone of critical salinity".

References

Aladin N, Plotnikov I, Bolshov A, Pichugin A. 2001.

Biodiversity of the Caspian Sea. *In*: Caspian Sea Biodiversity Project under umbrella of Caspian Sea Environment Program. https://www.zin.ru/projects/caspdiv/biodiversity_report.html.

Aladin N V, Plotnikov I S. 2008. Modern fauna of residual water bodies formed on the place of the former Aral Sea. *Proc. Zool. Inst. RAS*, **312**(1-2): 145-154. (in Russian)

Aladin N V, Plotnikov I S, Potts W T W. 1995. The Aral Sea desiccation and possible ways of rehabilitating and conserving its northern part. *Environmetrics*, **6**(1): 17-29.

Aladin N V, Keyser D, Plotnikov I S, Karimov B K. 2017. Distribution of crayfish (Crustacea) in the Zarafshan river basin and their suitability for aquaculture. *In*: Proceedings of the International Conference on Integrated Innovation Development of Zarafshan Region: Achievements, Challenges and Prospects. Volume II. Muharrir Nashriyti, Navoi, Uzbekistan. p.262-268.

Bervald E A. 1964. Ways of Organizing Rational Fish Economy on Inland Water Bodies. Universitet, Rostov-on-Don, Rostovskiy Gos. 148p. (in Russian)

Birshein Y A, Romanova N N. 1968. Order amphipoda. *In*: Birshtein Y A, Vinogradov L G, Kondakov N N, Astakhova M S, Romanova N N eds. Atlas of Invertebrates of the Caspian Sea. Pishchevaya Promyshlennost, Moscow. p.241-289. (in Russian)

Bogutskaya N G, Naseka A M. 2013. Fish of the Caspian Sea. *In*: Identification Keys for Fish and Invertebrates. Volume 1. KMK, SPb-Moscow. p.67-297. (in Russian)

Bortnik V N, Chistyaevaya S P. 1990. Gidrometeorologiya i gidrokhimiya morey SSSR [Hydrometeorology and hydrochemistry of the Seas of the USSR], vol. VII: Aral'skoye more [Aral Sea]. Gidrometeoizdat, Leningrad. 196p. (in Russian)

Daneliya M E, Petryashov V V. 2015. Order mysids-Mysida. *In*: Identification Keys for Fish and Invertebrates. Volume 2. KMK, SPb-Moscow. p.193-23. (in Russian)

Dogiel V A, Bykhovsky B E. 1934. Fauna of parasites of fishes of the Aral Sea. *Parasitol. Sbornik*, **4**: 241-346. (in Russian)

Dogiel V A, Lutta A S. 1937. About death of sturgeon ship on the Aral Sea in 1936. *Rybnoe hoz'aystvo*, **21**: 26-27. (in Russian)

Ermakhanov Z K, Plotnikov I S, Aladin N V, Micklin P. 2012. Changes in the Aral Sea ichthyofauna and fishery during the period of ecological crisis. *Lakes Reserv. Res. Manag.*, **17**(1): 3-9.

Ermakhanov Z K, Aladin N V, Plotnikov I S. 2013. Evaluation of biological status of main commercial fish species populations in the Small Aral Sea. *Proc. Zool. Inst. RAS*, **317**(S3): 105-112. (in Russian)

Ermolin I, Svolkinas L. 2018. Assessment of the sturgeon catches and seal bycatches in an IUU fishery in the Caspian Sea. *Mar. Pol.*, **87**: 284-290.

Frolov A V. 2000. New Methods for Managing Caspian Sea Level Fluctuations. *In*: Ascher W, Mirovitskaya N eds. The Caspian Sea: A Quest for Environmental Security. Springer, Dordrecht. p.79-88.

German T. 2016. Energy exploration and the Caspian region: sturgeon, seals, and sulfur. *In*: Freedman E, Neuzil M eds. Environmental Crises in Central Asia: from Steppes to Seas, from Deserts to Glaciers. Routledge, London. p.41-51.

Goodman S, Dmitrieva L. 2016. Pusa caspica. The IUCN Red List of Threatened Species 2016: e.T41669A45230700. http://www.iucnredlist.org/details/41669/0.

Ivanov V P. 2000. Biological Resources of the Caspian Sea. KaspNIRH, Astrakhan. 100p.

Jamshidi S. 2017. Assessment of thermal stratification, stability and characteristics of deep water zone of the southern Caspian Sea. *J. Ocean Eng. Sci.*, **2**(3): 203-216.

Janusz-Pawletta B. 2015. The Legal Status of the Caspian Sea: Current Challenges and Prospects for Future Development. Springer, Berlin.

Karpevich A F. 1975. Theory and Practice of Acclimatization of Aquatic Organisms. Pishchevaya Promyshlennost, Moscow. 432p. (in Russian)

Khlebovich V V. 2015. Class polychaete worms—Polychaeta. *In*: Identification Keys for Fish and Invertebrates. Volume 2. KMK, SPb-Moscow. p.29-37. (in Russian)

Kochurov B I, Lobkovskii V A, Lobkovskaia L G. 2012. The evaluation of potentials of nature in Russian Federation. *In*: Water Resources of Volga: History, Today and Future Problems of Management. Materials of the Second Interregional Scientific-Practical Conference (Astrakhan Province, October 25-27, 2012). Astrakhan: Astrakhan Institute of Engineering and Construction. https://nat.astrobl.ru/sites/nat.astrobl.ru/files/materialy_vtoroy_mezhregionalnoy_nauchno-prakticheskoy_konferencii_vodnye_resursy_volgi_istoriya_nastoyashchee_i_budushchee_problemy_upravleniya_25-27_oktyabrya_2012_g.pdf Accessed: 10.07.0218.

Kortunova T A. 1975. On the changes in Aral Sea zooplankton between 1959 and 1968. *Zool. Zhurnal*. **54**(5): 567-669. (in Russian)

Matri I I, Ratkovich D I. 1976. The problems of water economy in the Sea of Azov and the Caspian Sea. *Water Resour.* (*Vodnye Resur.*), **3**: 21-34. (in Russian)

Micklin P. 2010. The past, present, and future Aral Sea. *Lakes Reserv. Res. Manag.*, **15**(3): 193-213.

Micklin P. 2014b. Aral Sea basin water resources and the Changing Aral Water balance. *In*: Micklin P, Aladin N V, Plotnikov I eds. The Aral Sea: the Devastation and Partial Rehabilitation of A Great Lake. Springer, Berlin, Heidelberg. p.111-135.

Micklin P. 2014a. Efforts to revive the Aral Sea. *In*: Micklin P, Aladin N V, Plotnikov I eds. The Aral Sea: the Devastation and Partial Rehabilitation of A Great Lake. Springer, Berlin, Heidelberg. p.361-380.

Micklin P. 2016. The Future Aral Sea: hope and despair. *Environmental Earth Science*, **75**(9): 1-15.

Micklin P, Aladin N V, Plotnikov I S. 2014. An expedition to the northern part of the Small Aral Sea (August 29 to September 16, 2011). *In*: Micklin P, Aladin N V, Plotnikov I eds. The Aral Sea: the Devastation and Partial Rehabilitation of A Great Lake. Springer, Berlin, Heidelberg. p.337-351.

Mitrofanov I V, Mamilov N S. 2015. Fish diversity and fisheries in the Caspian Sea and Aral-Syr Darya basin in

the Republic of Kazakhstan at the beginning of the 21st Century. *Aquat*. *Ecosyst*. *Health Manag*., **18**(2): 160-170.
Mordukhai-Boltovskoi F D. 1972. Modern state of the Aral Sea fauna. *Gidrobiol*. *Zhurn*., **3**: 14-20. (in Russian)
Mordukhai-Boltovskoi F D. 1974. Atlas of the Aral Sea Invertebrates. Pischevaya Promyshlennost, Moscow. 272p. (in Russian)
Nikolsky G V. 1940. Fishes of the Aral Sea. MOIP, Moscow. 216p. (in Russian)
Nissling A, Westin L, Hjerne O. 2002. Reproductive success in relation to salinity for three flatfish species, dab (*Limanda limanda*), plaice (*Pleuronectes platessa*), and flounder (*Pleuronectes flesus*), in the brackish water Baltic Sea. *ICES J*. *Mar*. *Sci*., **59**(1): 93-108.
Osmanov S O. 1961. On the death of atherine in the Aral Sea. *Vestnik Karakalpakskogo filiala AN UzSSR*, **3**(5): 95-96. (in Russian)
Plotnikov I S. 2016. Long-Term Changes of the Free-Living Aquatic Invertebrate Fauna of the Aral Sea. ZIN RAS, SPb. 168p. (in Russian)
Plotnikov I S, Ermakhanov Z K, Aladin N V, Micklin P. 2016. Modern state of the Small (Northern) Aral Sea fauna. *Lakes Reserv*. *Res*. *Manag*., **21**(4): 315-328.
van Uhm D, Siegel D. 2016. The illegal trade in black caviar. *Trends Organ*. *Crim*., **19**(1): 67-87.
Velikova V N, Shaudanov A K, Gasimov A, Korshenko A, Abdoli A, Morozov B, Katunin D N, Mammadov E, Bokova E B, Emadi H, Annachariyeva J, Isbekov K, Akhundov M, Milchakova N, Muradov O, Khodorevskaya R, Shahifar R, Shiganova T, Zarbaliyeva T S, Mammadli T, Velikova V, Barale V, Kim Y. 2012. Review of the environment and bioresources in the Caspian Sea ecosystem, 2000–2010. CaspEco Report. http://www.caspianenvironment.org/.
Zenkevich L A. 1963. Biology of the Seas of the USSR. Interscience Publishers, New York. 955p.
Zholdasova I M, Kazakhbaev S, Elbaeva M K, Embergenova U S, Lyubimova S K, Mirabdullaev I M. 2000. Finding of *Artemia* in the open part of the Aral Sea. *Doklady Akademii Nauk Respubliki Uzbekistan*, **12**: 48-50. (in Russian)
Zonn I S. 2001. Trista let na Kaspii (Khronologiya osnovnykh istoricheskih sobytii XVIII–XX vekov) (Three hundred years in the Caspian Sea (Chronology of the main historical events). Edel-M, Moscow. 96p. (in Russian)

To make a diagnostic study for the Aral Sea ecological crisis, Prof. Vale William (Bill) Williams was invited to attend a UNEP (United Nations Environment Program) meeting on the Aral Sea in Almaty Academy of Sciences in Kazakhstan in the mid-June 1992. The meeting was from an initiative of the former USSR president Mikhail Sergeyevich Gorbachev (1930–). This photo was taken in the meeting (cropped from the scene). The photographer was Dr. Dietmar KEYSER from Hamburg University. This scientist from Germany and the first author of this paper Prof. Nikolai Aladin were also invited to this meeting.

The photo on the left was made June, 12th 1990 by Valeri Kagan. A flight to the Aral Sea for a field study on a plane landed on Barsa-Kelmes Island. Barsa-Kelmes (Kazakh: Барса келмес; from Kazakh: "the place of no return") is a former island, the largest in the Aral Sea.

From left to right:

Sergey Vasil'evich Kotov, a member of our Zoological Institute Expedition to the Aral Sea (with a suitcase)

Sabirbay Musaevich Musaev, the head of Barasakelmes Wildlife Reserve

Mzrzhan, the head of the Meteorological station on Barasakelmes Island

Nikolai Vasil'evich Aladin, the head of our Zoological Institute Expedition to the Aral Sea

Lady Klavdiya Romanovna, the staff of Barasakelmes Wildlife Reserve

Prof. Vale William (Bill) Williams (1936–2002)

Sergei Vasilyevich Apraksin (in straw hat), a professional diver from Leningrad a member of our Zoological Institute Expedition to the Aral Sea

Seisen Sultanovich Mauzhanov, attached to our expedition specialist on tractors (he was actually captain of local KGB)

The two pilots of AN-2 (Kaibalda and Valentin)