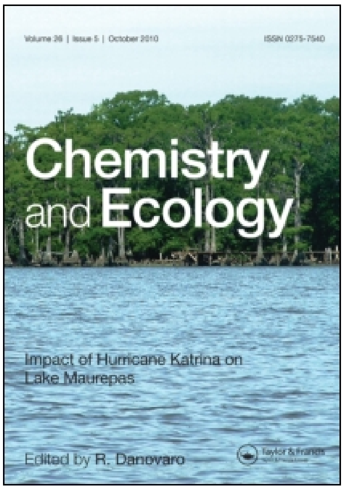

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N. V. Aladin[a]; W. T. W. Potts[b]; I. S. Plotnikov[a]; A. A. Filippov[a]; M. I. Orlova[a]
[a] The Zoological Institute of the Russian Academy of Sciences, St. Petersburg [b] Institute of Environmental and Biological Sciences, University of Lancaster, Lancaster, UK

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RECENT CHANGES IN THE HYDROBIOLOGY OF THE ARAL SEA

N. V. ALADIN[a], W. T. W. POTTS[b,*], I. S. PLOTNIKOV[a], A. A. FILIPPOV[a] and M. I. ORLOVA[a]

[a] *99034 St. Petersburg, The Zoological Institute of the Russian Academy of Sciences;*
[b] *Institute of Environmental and Biological Sciences, University of Lancaster, Lancaster, LA1 4YQ, UK*

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Since 1992 attempts have been made to isolate and conserve the northern part of the Aral Sea of means of a dam. Changes in the main aquatic communities between 1985 and 1994 based on field work, laboratory investigations and literature surveys are described and the future prospects for the region are discussed.

Keywords: Aral sea; biota; regression; conservation

INTRODUCTION

During the last decade two extremely important changes have occurred in the northern part of the Aral Sea (Micklin, 1991; Kuznetsov *et al.*, 1993). In 1989 the northern part, or Small Sea, became isolated from the main part of the Sea; Berg's Strait, which formerly linked the two parts, was reduced to a small stream which was effectively part of the delta of the Syrdar'ya (Aladin, 1989). Since then the development of the two basins has been very different. Previously both regions experienced increasing salinity with consequent changes in fauna (Aladin *et al.*, 1995; Filippov *et al.*, 1998;

*Corresponding author.

Rusakova, 1995). In 1991 the outflow of the Syrdar'ya increased as a result of both natural changes and human intervention and Berg's Strait widened again. At this time, it seemed likely that all the waters of the Syrdar'ya would flow into the southern basin (Aladin *et al.*, 1995) and the northern basin would dry out rapidly. In view of the considerable population still dependent on the northern basin, plans were made to build one or more dams to retain all the water available in the northern basin (Micklin, 1991; Aladin *et al.*, 1995; Bortnik, 1980; L'vovich and Zigelnava, 1978; Chernenko, 1983) and rehabilitate the northern part of the Sea. A dam was begun across the strait in 1992, and although it had to be repaired in 1994, it has already raised the water level by 2.5 metres.

This had led to the second important change, a fall in the salinity of the northern basin (Fig. 1, Tab. I). In the winter of 1993–4, the rising water level flooded the Sarychaganak Bay (or Bolshoi Bay) on which lie several important settlements including the port and city of Aralsk. So far there has been no evidence of the restoration of the earlier flora and fauna, but these still survive in the estuary of the Syrdar'ya and in some small lakes. The rise in water level has increased the areas of lower salinity and produced a wider salinity gradient (Tab. II), which should provide the conditions for the eventual restoration of the biota in the northern basin.

Field work in the Aral region is now extremely difficult. The shore line is now very inaccessible by land and few boats are available. Almost all recent observations have been made by boat in waters of three or more metres in depth. Financial restrictions have limited the collection of data to short-term expeditions during the summer.

Within these restrictions, representative, data are available for many of the coastal areas and these data can be extrapolated over the northern basin, most of which is between 3 and 6 metres in depth. This will provide a base line for the long term monitoring of the northern basin as it is conserved and restored. To complete the picture, we shall review here both our field work in the region during the period of relative stability, before the recent regression began, together with the work of other authors. Many papers in Russian are not readily available to the English readers but some of the work has been published in English or German (Aladin, 1991a and b; Williams and Aladin, 1991; Keyser and Aladin, 1991; Aladin *et al.*, 1993; Plotnikov

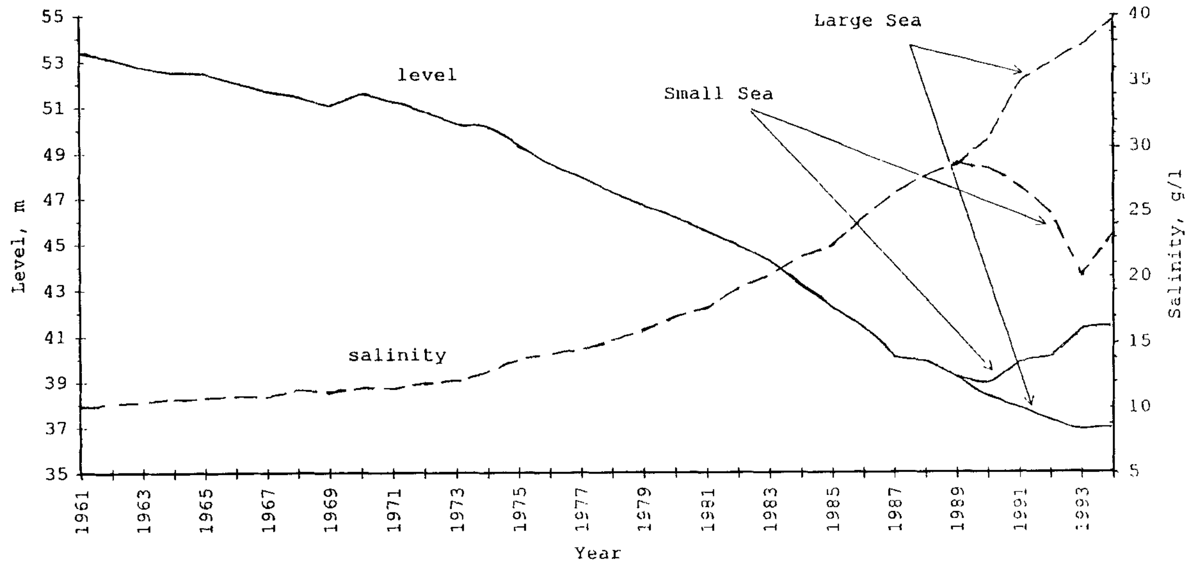


FIGURE 1 The Aral Sea level and salinity between 1961 and 1994.

TABLE I Changes in the ionic composition of the waters of the Syrdar'ya and Amudar'ya rivers and of the Aral Sea between 1960 and 1985 (Seas of the USSR., 1990)

District	*Period*	Concentrations of major inorganic ions, $mg\ l^{-1}$								*pH**
		HCO_3^{++}	SO_4^{++}	Cl^-	Ca^{++}	Mg^{++}	$Na^+ + K^+$	*Total*	PO_4*	
Syrdar'ya $g\ l^{-1}$	1911–1960	0.186	0.164	0.04	0.088	0.021	0.044	0.543	6–11	
	1961–1970	0.179	0.456	0.106	0.093	0.054	0.158	1.055	48–93	
	1971–1980	0.19	0.579	0.168	0.112	0.076	0.187	1.312	12–42	
	1981–1985	0.184	0.923	0.187	0.131	0.09	0.329	1.844		
Amydar'ya $g\ l^{-1}$	1911–1960	0.153	0.105	0.074	0.083	0.011	0.044	0.471	10–13	
	1961–1970	0.125	0.131	0.085	0.062	0.019	0.061	0.483	14–20	
	1971–1980	0.111	0.244	0.137	0.081	0.026	0.109	0.708	11–22	
	1981–1985	0.145	0.619	0.357	0.128	0.074	0.0315	1.64		
Small sea (in %)	1961–1965								3–5	8.1–8.15
	1971–1975								5	8.25
	1977	0.18	5.54	5.9	0.69	1.27	3.42	17		
	1981	0.16	6.28	7.01	0.77	1.15	4.82	20.19		
	1983	0.17	5.93	8.56	0.76	1.52	5.58	24.43		
	1981–1985								15–20	8.1–8.3
Large sea (in %)	1961–1965								3	8.1–8.15
	1971–1975								5	8.25–8.3
	1977	0.18	4.92	5.35	0.63	1.19	2.99	15.26		
	1981–1985								20–55	8.05–8.1
	1981	0.17	5.45	6.13	0.7	0.99	4.31	17.75		
	1983	0.17	5.86	7.3	0.69	1.23	4.9	20.15		
	1985	0.17	6.97	7.85	0.87	1.22	5.65	22.72		

* Spring average of surface water phosphate.

TABLE II Brief description of methods used

1	*Collection* 2	*Preliminary processing* 3	*Fixation* 4	*Preservations* 5	*Analysis* 6
Measurements: Salinity	water sampler				Refractometer
Chloride Transparency	water sampler	none	none	cooled	Titration of Cl Secchi disc (m)
Sampling: Seston (total weight)	water sampler:	vacuum filtration through fibreglass of nitrocellulose filters	(none) drying to constant weight at 80°C		Scaling
(POM) (photosynthetic pigments)		vacuum filtration through fibreglass, nitrocellulose or "Sartorius" filters	(none), drying, drying in the air	cooled, frozen, in dark	Bichromatic method UNESCO-SCOPE
Living associations (phytoplankton)	water sampler:	vacuum concentration of 0.5 l of water to 10 ml on nitrocellulose filters. pore diameter 0.3–1 μ	formalin, 1%	room temperature	Light microscope identification Quantitative analysis
(ciliates)	water sampler	vacuum filtration through nitrocellulose filters, volume 300 ml	fixation after Kuzmin	room temperature	Light microscope Quantitative analysis
(other zooplankton)	plankton net mesh N72		formalin, 4%	room temperature	Binocular microscope identification. Quantitative analysis
(zoobenthos)	bottom samplers	rewashing through mesh N19–22	formalin, 4% after sorting. 70° alcohol	room temperature	Binocular microscope identification. Quantitative analysis

TABLE II (Continued)

1	*Collection* 2	*Preliminary processing* 3	*Fixation* 4	*Preservations* 5	*Analysis* 6
Field experiments Primary production and decomposition by plankton	water sampler	exposure in light and dark bottles, volume 100 ml conditions.			determination of dissolved oxygen by Winkler's method
Primary production in bottom associations	vacuum bottom sampler	extraction of intact cores with strata of water in plastic tubes, light and dark, water volume 0.3 – 1.51			Winkler's method

et al., 1991; Aladin and Potts, 1992; Aladin and Williams, 1993; UNEP, 1993). Emphasis will be placed on areas flooded in the years 1993–1994 (Fig. 2). Environmental details for the years 1990–1994 are collected in Table III. Particular attention has been given to regions where the salinity gradients are steep. The methods used are shown in Table II, the field work sites in Figure 2 and environmental conditions in Table III.

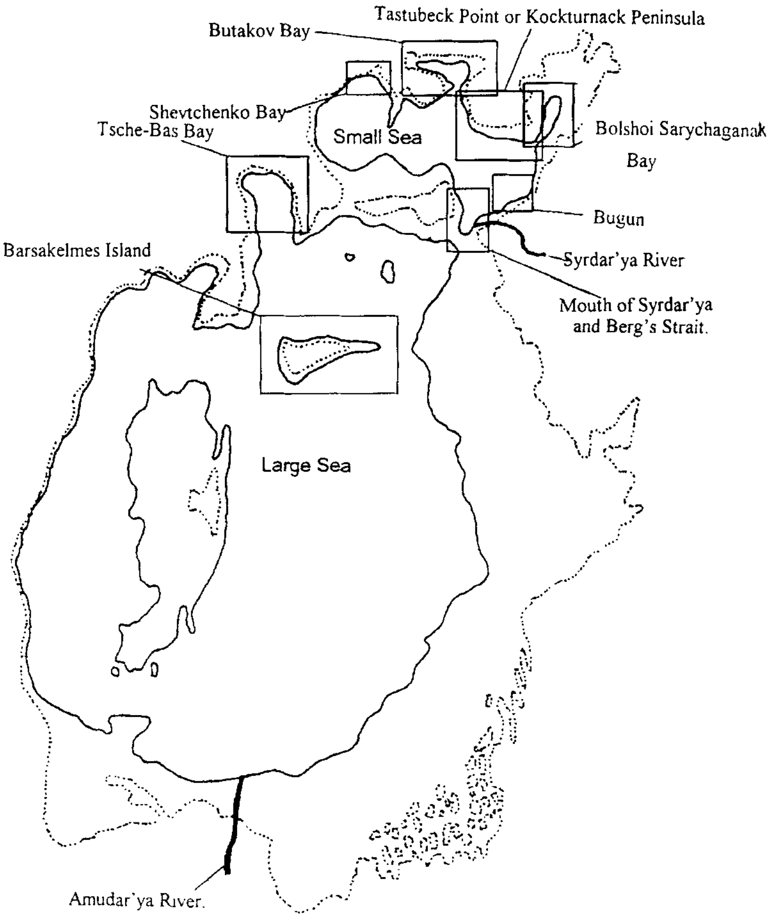


FIGURE 2 Field work sites in the Aral Sea. Dotted line is coastline in 1960.

TABLE III Environmental conditions at Aral Sea stations 1992–1994 (from Bortnik 1990: Orlova, 1993 and 1995: Rusakova 1995 and Filippov 1994)

District	*Date*	*Surface temperature °C*	*Transparency metres*	*Depth metres*	*Salinity ‰*	*Seston*		
						Total weight $g\ m^{-2}$	*POM (in carbon) $g\ m^{-2}$*	*Chlorophyll "a" μg/l*
1	2	3	4	5	6	7	8	9
Barsakelmes	15–25.05.90	–	–	–	30	–	–	–
Syrdar'ya,	24.05.92	20	0.3	0.6–0.7	1.8	22.4	0.74	–
St. 1–3	24.05.93	17	0.1	2 (6–7)	1.8	329	3.42	39.84
	22.05.92	19	0.3	0.6–0.7	1.8	–	–	–
	24.05.93	17	0.1	2	1.8	376	5.67	–
Syrdar'ya mouth	25.05.92	16	0.7	1.5	7	19.4	4.31	13.06
	22.05.93	17	0.65	1.4	18.5	27	21.86	–
Pre-mouth Bay								
St. 1	27.05.92	16	To the bottom	1.2	22–23	9.1	0.67	–
St. 1	22.05.93	16	To the bottom	1.4	22	–	–	–
St. 2	27.05.92	20	To the bottom	2	25	10	0.93	–
Berg's Strait	27.05.92	–	–	0.8	–	10.2	1.02	–
Near Bugun'								
St. 1	30.05.93	17	To the bottom	0.4	24	25	4.73	11.05
St. 1	31.05.93	18	To the bottom	1.5	20	39	1.66	5.04
St. 3	1.06.93	18	1.3	3	21	60	1.51	41.72
St. 4	1.06.93	20	1.7	3	11.5	16.5	2.04	11.02
Butakov Bay	1.06.1992	21	To the bottom	–	36	–	3.61	–
Shevchenko Bay	09.1992	12	To the bottom	2–2.5	29.5	–	–	–
Tsche-Bas Bay	09.1992	15	To the bottom	1.8–3	41	–	–	–

Near Tastubek								
St. 1	10.09.93	18	To the bottom	0.5	–	177	2.20	14.33
St. 2	10.09.93	17	To the bottom	1.3	17	63.75	2.13	11.64
St. 3	18.09.93	18	0.6	3	17	48	2.11	3.66
St. 4	12.09.93	19.5	1.8	5	25	48	2.19	9.02
St. 4	13.09.93	17.5	2.4	5	25	123	2.96	5.06
St. 5	16.09.93	17.5	1.8	6	25	50.75	2.19	2.90
Sarychaganack Bay								
St. 1**	22.06–22.06	18–35	To the bottom	0.35–0.6	23–24	–	70.05	11.82
St. 2**	22.06–26.7	19–35	To the bottom	0.35–0.5	24–31	–	101.89	184.61
St. 3**	22.06–26.8	20–35	To the bottom	0.5–0.15	34–43	–	125.95	145.97
St. 4	23.06–26.06	19–30	To the bottom	0.2–0.45	19–23	–	27.72	12.18
St. 5	23.06–26.06	25	To the bottom	0.5–0.65	20–23	–	12.94	11.06
St. 6	25.06	23	To the bottom	1.2	20	–	(surf) 9.94	(surf) 20.39
						–	(1/2S) 7.47	(1/2S) 11.47
						–	(bottom) 8.84	(bottom) 31.23
St. 7	25.06	24	To the bottom	1.4	20	–	(surf) 8.22	(surf) 40.25
						–	(1/2S) 12.21	(1/2S) 32.08
						–	(bottom) 10.84	(bottom) 34.62

THE BIOTA

The Aral Sea has been characterised by a very low diversity of plants and animals from the time of the first observation in the nineteenth century down to the present. It has always had a more restricted fauna and flora than either the Caspian Sea or Lake Balkash. The first changes in the fauna took place as a result of a policy of deliberate acclimatization of alien species in a misguided attempt to increase the productivity (Karpevich, 1975). The introduced fishes and invertebrates produced marked changes in the population structure as a result of pressure of the introduced species on a fragile ecosystem of low productivity. These shocks were followed by the effects of increasing salinity as the inflow of fresh water was reduced. These changes and can be divided into a number of stages. Between 1971 and 1975, the salinity increased from 12‰ to 14‰ and the freshwater species died out. Between 1976 and 1985, the salinity increased from 14‰ to 22‰, but with little change in the restricted biota. As the salinity increased further after 1985, the fauna has become dominated by a few hypo-osmotic regulators such as the copepod, *Calanipedia aquaedulcis and bivalves.*

With the fall in level other environmental factors have also come into play. The input of nutrients has declined as the river flows were reduced. The availability of light for benthic plants has greatly increased, while the ratio of sandy substrate to muddy substrate has declined markedly as the more sandy inshore areas have dried out. This led to various changes in the biota, following the chemical changes.

CHANGES BETWEEN 1958 AND 1985

Plants

Husainova (1958a and b) described only 12 spp. of higher plants, 67 spp. of phytoplankton and 26 spp. in the benthos, but more recent work has raised the list to over 300 species and subspecies. (Zenkievich, 1963; Pichkily, 1970; El'muratov, 1981). Almost all the higher plants of the macrobenthos are of freshwater origin except for the sea grasses, *Zostera* and *Ruppia.*

Phytoplankton

Although there was disagreement between the earlier explorers as to the variety of species present in the Aral Sea in the earlier part of the century, all observers agree that the flora was impoverished both in diversity and abundance (Karpevich, 1975; Zenkievich, 1963; Yablonskaya and Lukonina, 1962; El'muratov, 1981). The main groups present were the Bacillariophyta, the Dynophyta, the Chlorophyta and the Cyanophyta. The number of species declined as the salinity increased from the brackish waters of the estuaries to the more saline central regions. In the latter regions only the Bacillariophyta were common. In some years, only *Actinocyclus ehrenbergii* var. *crassa* was present in noticeable amounts. The biomass of the plankton ranged from 0.5 to 2.6 $\mathrm{g\,m^{-3}}$.

During the early stages of the recent regression, the fall in nutrients and the increase in salinity which followed the reduction in the inflow of fresh water, led to great changes in the plant associations. The major changes were a rapid replacement of freshwater and oligohaline species by mesohaline and halophilic species of marine origin together with a corresponding loss of diversity (Rusakova, 1995; Pichkily, 1981; El'muratov, 1981).

Phytobenthos

Before the recent regression, extensive reed beds had developed in the shallow coastal regions where the salinity was low. Apart from dense growths of semi-aquatic plants, Berwald (1964) recorded potamogetons (*Potamogeton perfoliatus*, *P. lusens* and *P. natens*), myriophyllums and ceratophyllums on the extensive coastal flats. Carp eggs were commonly found attached to the potamogetons (Karpevich, 1975). Sea grass was abundant on the muddy sands in the north-western regions of the Large Aral Sea. Other common bottom plants included the alga, *Vaucheria*, which formed 13% of the total biomass, *Cladophora* (Chlorophyta) and *Polysiphonia* (Rhodophyta). In coastal areas, various species of Charophyta were dominant and formed three quarters of the benthic biomass which was estimated at 10 million tonnes (Berwald, 1964). Of this, 90% was contributed by the phytobenthos with a mean biomass of 80–100 $\mathrm{g\,m^{-2}}$. The phytobenthos, therefore, dominated the nutrient cycle and as the phytobenthos contributed so much of the biomass, detritus feeders predominated over plankton feeders in the food chains.

Hydrological investigations have shown an increase in the transparency of the water indicative of a decrease in biomass (Aladin and Kotov, 1989; Seas of the USSR, 1990). In July 1980, the primary productivity at the majority of 28 stations was lower than in 1960 (Aladin and Kotov, 1989; Tab. IV). Between 1976 and 1980, several observers recorded a relative decrease in dissolved oxygen in the upper waters compared with earlier observations, particularly in the areas off the river mouths. These observations are also consistent with a fall in photosynthesis (Seas of the USSR, 1990). Altogether, the data suggest that the increase in salinity from 8–10‰ to 13–20‰, and the decrease in nutrient input, led to a change in species content and a decrease in primary production. The phytobenthos accounted for 80 to 90% of the primary production (Karpevich, 1975; Novozhilova, 1973).

The recent fall in water level has dried the coastal flats and what had previously been the sandy inshore areas of lake bottom, while mud, which had previously formed the bottom of the deeper areas of the Aral, now predominates in the shallow waters along the south, east and north coasts. The rapid and complete loss of the original shallows and the degradation of the estuaries have led to the extinction of the macrophytes and the Charophyta. Since the early eighties, the macrophytes have been replaced by sea grass (*Zostera* and *Ruppia*), green filamentous algae and benthic Bacillariophyta, which can tolerate large changes in salinity.

Animals

No complete faunal list is available for the quasistable period that existed before 1960. Some taxonomic groups were not examined in detail and other workers confined themselves to the more saline open waters, ignoring the rich fauna of the brackish estuaries (Husainova, 1958b; Zenkievich, 1963). Changes in taxonomy further complicate the issue. However, 195 free-living invertebrates, 71 parasites and 20 species of fishes were described (Yablonskaya, 1960, 1964; Dogel and Bychovsky, 1934; Nikolsky, 1940). According to Yablonskaya, among the free-living invertebrates, 17% were Caspian species, 18%

TABLE IV Primary production and decomposition in the northern Aral Sea 1989–1994

District	*Season date*	*Daily values* *Primary production*			*Decomposition*	*A/D ratio*	*DAN*	*Author*
		A opt	*A*	*P*	*D*			
$mg\ Cl^{-1}$	$mg\ C\ m^{-2}$	$mg\ C\ m^{-2}$	$mg\ C\ m^{-2}$				$mg\ C\ mg^{-1}\ Cl_a$	
Near Barsekelmes	0.7–0.8 1980	2.7–324.6	34.3–649.2	–	–	–	30	Aladin, Kotov, 1989
	07.1989	177	166.5*		151.5	1.1	–	Dobrinin *et al.*, 1990**
Butakov Bay	09.1990	300	310–650*	–	–	–	–	Dobrinin, Koroliova, 1991**
	09.1992	332	830	abs	1117	0.7	–	Orlova, 1993
Syrdar'ya	05.1992	1440	–	–	–	–	–	Orlova, 1993
	05.1993	0–476	0–47.6	abs	900–8400	near 0	0–15	Orlova, 1995
Syrdar'ya mouth	05.1992	134	93.8	abs	128	0.7	–	Orlova, 1995
	05.1993	208	135.2	abs	176.9	0.8	14	Orlova, 1995
pre-mouth Bay	05.1992	401	521	68	434	1.2	–	Orlova, 1995
	05.1993	336	470.4	abs	603.4	0.8	–	Orlova, 1995
Shevchenko Bay	09.1992	323	646	545	101	6.4	–	Orlova, 1993
Tsche-Bas Bay	09.1992	84–581	252–872	48–746	204–126	1.2–6.9	–	Orlova, 1993
The Bay near	05.1993	4289–883	2534–222	2313–95	221–127	11.5–1.7	372–175	Orlova, 1993
s. Bugun	05.1993	3215–324	114*	abs	287	0.4	25–29	Orlova, 1993

TABLE IV (Continued)

District	*Season date*	Daily values						
		Primary production			*Decomposition*	*A/D ratio*	*DAN*	*Author*
		A opt	*A*	*P*	*D*			
$mg\ Cl^{-1}$	$mg\ C\ m^{-2}$	$mg\ C\ m^{-2}$	$mg\ C\ m^{-2}$				$mg\ C\ mg^{-1}\ Cl_a$	
Tastubeck core	09.1993	3054–3696	1525–4850	131–814	1462–3747	1.–1.3	20–370	Orlova, Rusakova, 1995
	09.1993	1416–2000	3501–6419*	abs.–2202	4110–5110	0.5–1.5	–	Orlova, Rusakova, 1995
Sarychaganack Bay	06.1994	62–1496	15–1025	abs–169	367–1095	0.01–1.46	0.36–8	Orlova, unpubl. data
	06.1994	440–880	132–528*	abs–176	220–352	0.6–1.5	20–51	
	06.1994	545–1496	352–1232*	abs–660	528–572	0.7–2.15	12–31	Filippov *et al.* (in press)

* Integral values were been measured by curves of vertical distribution of primary production values without ** by formula $A = A$ opt$^{*}S$ (S-transparency).
** Radiocarbon method was been used for determination of primary production, obtained value is between total and net.
A – total value of daily primary production.
A opt – total value in optimal light conditions.
P – net value of daily primary production ($P = A - D$).
D – daily value of decomposition.
DAN – Daily Assimilation number (DAN = A opt C^{-1} Cl_a).

were of inland freshwater or of brackish water origin, and 5% were of marine origin. Some divided the fishes into three groups, 45% were described as Aral-Caspian in origin, most of the remainder were of northern Siberian freshwater origin (Nikolsky, 1940). The largest proportion of both invertebrates and fishes in the Aral Sea are of freshwater origin.

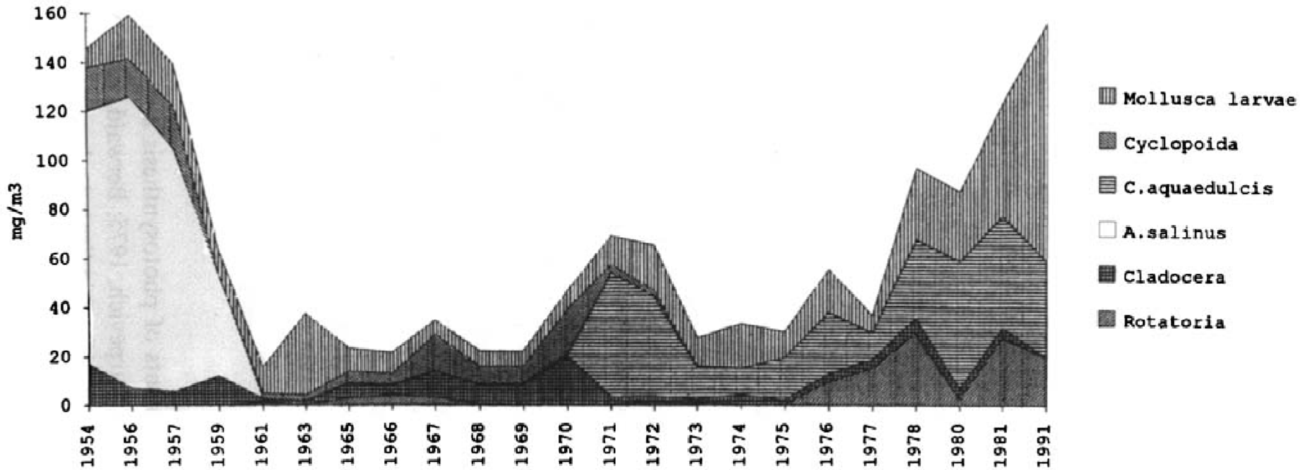
Zooplankton

The first expeditions to study the zooplankton were those of Berg in 1900–1902 and 1906 (Berg, 1908), of Meisner (1908) and Zernov (1903), which provided data on the distribution of species in relation to salinity. Further expeditions followed in the 1920s (Karzinkin, 1924; Virketis, 1927) but these earlier workers were only concerned with the composition of the fauna.

Investigations of relative abundance, biomass and seasonal variation, only began in the 1930s (Behning, 1934, 1935; Lukonina, 1960). In the late 1950s and early 1960s, sudden changes in the composition of the zooplankton species and the biomass occurred as a result of misguided efforts to acclimatise new species to the Aral Sea (Kortunova and Lukonina, 1970; Figs. 3 and 4). At the same time the salinity began to increase as a result of the expansion of irrigation in the basins of the rivers feeding the sea. The concomitant changes in zooplankton were described by Andreev during the 1960s and 1970s (Andreev, 1989). In the 1980s, Aladin described the summer plankton around Barsakelmes Island and in some of the hypersaline lagoons (Aladin, 1989, 1990) but information on the plankton of the open sea was not available.

Primary Production

Earlier direct measurements of photosynthesis and indirect estimates of primary production (Karpevich, 1975; Berwald, 1964; Yablonskaya and Lukonina, 1962; Tab. IV) all indicated a low rate or productivity, 50–55 mg C m^{-3} day^{-1}, over most of both the Large and Small Aral Seas, indicative of oligotrophic conditions. Around the river mouths the productivity was higher, 275–650 mg C m^{-3} day^{-1}, corresponding mg/m3


160
140
120
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mg/m3
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1975
1976
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1978
1980
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Mollusca larvae
Cyclopoida
C.aquaedulcis
A.salinus
Cladocera
Rotatoria

FIGURE

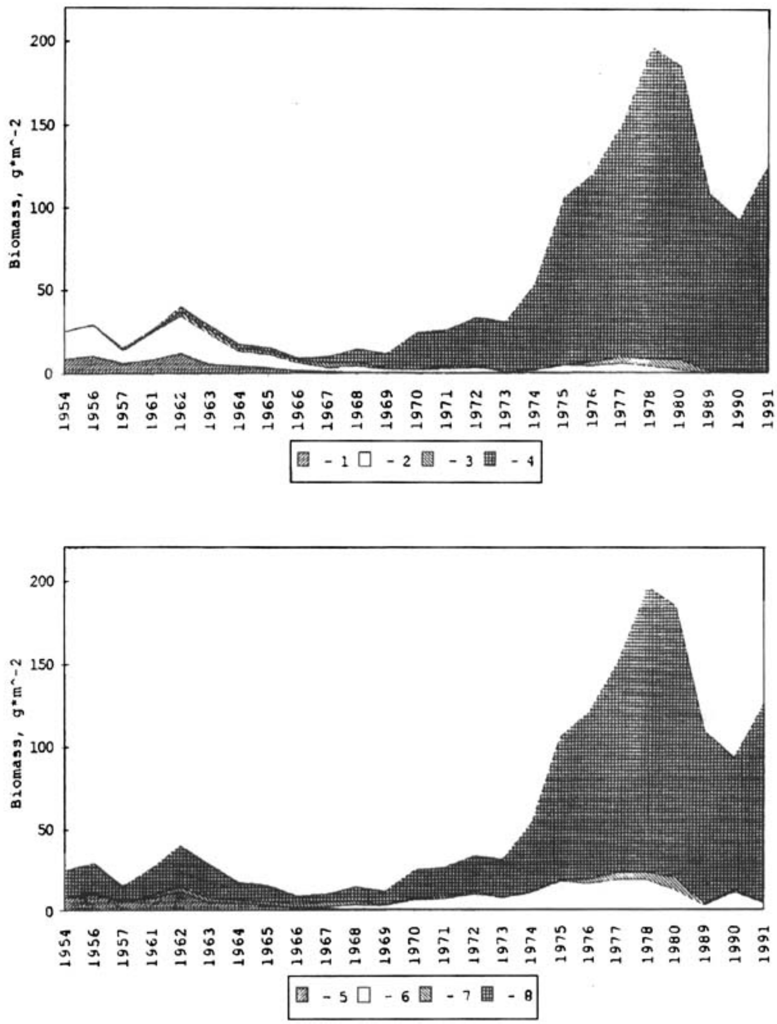

FIGURE 4 Changes in the composition and biomass of the macrobenthos in the Aral Sea between 1954 and 1991. 1 – fresh water species; 2 – brackish water species; 3 – hyperhaline species; 4 – marine species; 5 – Chironomidae; 6 – Polychaeta; 7 – Gastropoda; 8 – Bivalvia: 1954–1989 – according to Andreeva, 1989; 1989 – from: Andreev *et al.*, 1990; 1990–1991 – our data.

to mesotrophic conditions. The daily values of mineralization in the water column usually exceeded the rate of primary production by 1.5 to 2 times, so the zooplankton was maintained both by the allochthonous organic matter and the decomposition of the phytobenthos. The main causes of the low productivity were the limited input of nutrients from the rivers and the low turnover of nutrients in the ecosystem. Before the recent regression, the concentration of soluble phosphorus ranged from 1 to 4.2 $\mu g\,l^{-1}$ at the surface and fell to zero at depth (Yablonskaya and Lukonina, 1962). However, at the beginning of the regression from 1961 to 1977, the input of phosphorus increased as the result of the use of fertilizers under the irrigation and cotton growing programme. The reduction of the areas occupied by macrophytes also increased the rate of turnover, and today the phosphorus content of the water, in summer, lies between 14 and 30 $\mu g\,l^{-1}$ (Zizarin, 1991; Seas of the USSR, 1990; or in Tab. I).

Karpevich (1975) predicted that the phytoplankton production should increase following these changes. However no measurements of photosynthesis have been found for the nineteen seventies or eighties

Zoobenthos

Some information on the bivalves and gastropods of the zoobenthos was collected as long ago as the middle of the nineteenth century, and later workers added to the faunal lists (Berg, 1908; Husainova, 1951; Butakov, 1853). In the middle of 20th century the benthic faunal list included 44 species belonging to 16 families and 6 different classes. More recent investigations added 21 more species of gastropods (Starobogatov and Andreeva, 1981; Andreeva, 1987). Most of the Aral benthic fauna was of freshwater origin, including 10 species of oligochaetes and 27 insect larvae. The Caspian species include 2 zebra mussels, 2 bivalves (*Hypanis*), the gastropod *Theodoxus pallasi*, the amphipod *Gammarus aralensis* and three introduced species of *Mysis*. Species of marine origin include two species of *Cerastoderma*, and four introductions, the polychaete *Nereis diversicolor*, the prawn *Palaemon elegans*, the crab *Rhithropanopeus harrisii* and the bivalve *Syndosmya segmentum*. Gastropods of the genus *Caspiohydrobia* do not fit into any of the three categories above as they are believed to have evolved in saline lakes in the arid zone of central Asia (Andreeva, 1989). Quantitative studies of the benthos only began in the 1930s (Behning, 1934, 1935; Husainova, 1951, 1958b; Yablonskaya, 1960; Andreev and

Andreeva, 1979). Between 1930 and 1957, the number of benthic species was small and the density of the biomass was low, averaging 22 g m^{-2}. Bivalves of brackish water origin accounted for 67% of the biomass while insect larvae, mainly chironomids, contributed a further 32%. Worms and molluscs of marine origin contributed little (Yablonskaya *et al.*, 1974).

With the increase of salinity between 1960 and 1980, the freshwater species were lost from the Aral Sea, except in estuarine areas (Fig. 4; Karpevich, 1975; Aladin and Kotov, 1989; Mordukhai-Boltovskoi, 1972; Andreev and Andreeva, 1981; Husainova, 1968, 1971; Andreeva, 1981, 1983, 1989; Yablonskaya *et al.*, 1974; Gavrilov, 1970; Markova and Proskurina, 1974; Proskurina, 1979; Andreeva and Andreev, 1987). At the same time the euryhaline natives and some of the introduced marine species proliferated and the benthic biomass rose to 196 g m^{-2} by 1980, 8.5 times the earlier level (Fig. 4). In the middle 1980s, the salinity rose above 23‰ and the diversity of species, particularly ostracods, decreased rapidly but without significant change in the biomass with a total at 207 g m^{-2} (Aladin, 1989).

Fishes

Before the increase in salinity, 12 of the 20 species of fishes were of commercial importance (Aladin, 1991; Nikolsky, 1940). The total catch was about 44,000 tonnes annually, about a quarter of the Caspian catch. Most of the catch were benthivorous fishes (Karpevich, 1975). Surface feeders were limited by the shortage of plankton and bottom feeders by the limited spawning and feeding areas available for young fish.

Between 1927 and 1956, many new species were introduced into the Aral Sea in attempts to increase the commercial catch. *Atherina mochon*, several species of goby and a pipefish, *Syngnathus nigrolineatus caspius*, all of which were introduced inadvertently, were the most successful. Unsuccessful introductions included several fishes from the river Amur, two species of sturgeon, *Acipenser stellatus* and *A. nudiventris*, the herring *Clupea harengus*, and two mullets, *Mugil auratus* and *M. saliens*. The only intentional successful introductions were a flounder, *Pleuronectes flesus*, from the Sea of Azov and *Ophiocephalus argus* from Lake Balkhash (Lim and Markova, 1981). As a result of these introductions the number of fish species rose to 34, but by 1963 the fishing did not improve. By 1971, when the salinity had risen to 12‰, the first signs of spawning failure became evident. When the salinity reached 14‰ by the middle 1970s, young fish were no longer in evidence and by 1980 the fisheries had collapsed, except in the estuaries. The only fishes to be found in the northern Aral today are the flounder, some gobies, *Atherina*, the herring and some sticklebacks (Aladin and Kotov, 1989).

Bacterioplankton

The first account of the microbiology of the Aral was published by Novozhilova (1973), based on work carried out between 1965 and 1968, when the salinity had already begun to increase. Bacteria were most abundant in the north and west of the Small Aral Sea where counts ranged between 166×10^6 and 234×10^6 cells ml^{-1} and the biomass was between 0.033 and 0.047 mg ml^{-1}. The population in more open regions was lower. Rod-like bacteria were rare except in bottom waters (Novozhiklova, 1973; Adijatova and Novozhilova, 1967). Growth was slow, averaging one division each day (Adijatova, 1969).

CURRENT SITUATION: CHANGES SINCE 1985

Since 1985 investigations of many aspects of the fauna and flora of the Aral Sea have been reviewed, particularly with regard to the effects of salinity gradients on the distributions of plants and animals, and effects the changes of water level on primary productivity and decomposition (Dobrinin *et al.*, 1990). Unfortunately the investigations have had to be confined mainly to the coastal waters.

PLANTS

Phytoplankton

The diversity of species is still high and the flora generally resembles that of the Caspian Sea. A variety of brackish and freshwater species are still found but euryhaline species are dominant. These include

Actinocyclus ehrenbergii, *Exuviella cordata*, *Cyclotella caspia*, *Diploneis smithii*, *Navicula digitoradiata*, *Pleurosigma angulatum*, *Oocystis solitaria*, *Merismopedia punctata*, *M. tenuissima*, *Pseudoanaboena galatea* (Aladin *et al.*, 1995; Rusakova, 1995; Pichkily, 1981; El'muratov, 1981; Orlova and Rusakova, 1995). Since 1985, many species of Cyanophyta and Chlorophyta, previously common, have disappeared and the phytoplankton has become more monotonous, consisting mainly of Bacillariophyta, Chlorophyta and Dynophyta of marine or brackish origin (Rusakova, 1995; Pichkily, 1981; El'muratov, 1981; Dobrinin *et al.*, 1990; Dobrinin and Koroliova, 1991). Since 1990, 243 species and subspecies of algae have been identified. These include 115 species of Bacillariophyta, 115 of Chlorophyta, 29 Cyanophyta, 28 Dynophyta, two Chrysophyta, two Euglenophyta and one Xantophyta. There are considerable differences in the distribution of the species depending on the area studied.

In coastal lagoons, both in the Large Aral Sea and the Small Aral Sea, the dominant species are diatoms of marine origin, particularly *Chaetoceras wighamii*, *Actinocyclus ehrenbergii* and the brackish water Pyrophyta, which were previously of minor importance. Everywhere the greatest diversity occurs among the Bacillariophyta. The Pyrophyta are found in the regions of highest salinity while the Chlorophyta and Cyanophyta are most abundant in brackish areas, particularly around the estuary of the Syrdar'ya. The data suggests that the density of the phytoplankton may have increased in some central areas since the beginning of the change from less than $1\,g\,m^{-3}$ up to $7\,g\,m^{-3}$ (Tab. VIII). In the recently flooded Sarychaganak Bay, the biomass in June 1994 was only $1\,g\,m^{-3}$, but still three times the level in 1960 (Yablonskaya, 1964).

Primary Production

The present level of productivity in the Aral Sea is comparable to that in a mesotrophic lake (Tab. IV; Aladin *et al.*, 1995; Dobrinin *et al.*, 1990; Orlova and Rusakova, 1995; Dobrinin and Koroliova, 1991; Orlova, 1993, 1995; Filippov *et al.*, 1998). Photosynthesis was highest in the upper waters where the light was brightest and content of chlorophyll "a" concentration higher but decomposition was less dependent on depth (Fig. 5). There is considerable regional variation

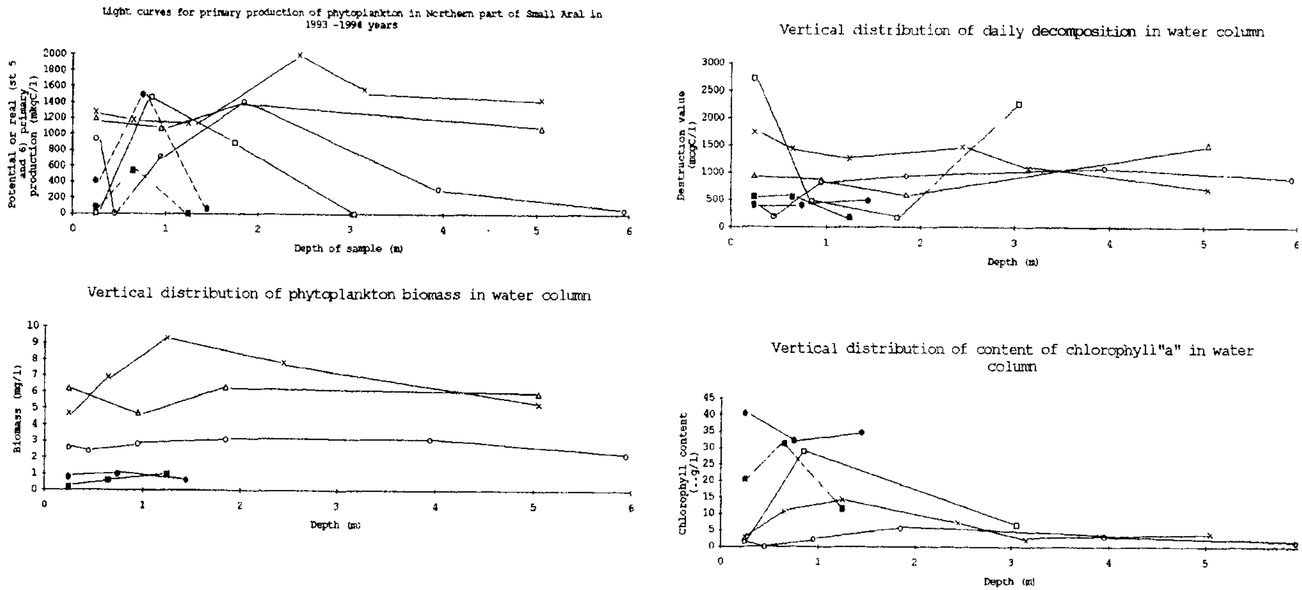

FIGURE 5 Changes in the characteristics of the plankton in the Aral Sea with depth (empty quadrats – near Bugun' 1.06.93; empty triangles – near Tastubeck core, st. 4, 12.09.93; crosses – the same, st. 4, 13.09.93; empty rings – the same, st. 5, 13.09.93; filled quadrats – Sarychaganak Bay, st. 6, 25.06.94; filled rings – the same, st. 7, 25.07.94).

in the rates of production and breakdown (Tab. IV). Off the mouth of the Syrdar'ya, in favourable light conditions (*A* opt.), productivity is high but it was still less than the rate of decomposition (Novozhilova, 1973). Productivity in the estuary was particularly erratic as a result of the disturbances caused by the work on the remedial dam during 1992 and 1993. In most of the areas studied, the productivity was highest near the shore, where the temperature was higher and nutrients were evidently available from the sediments. Detailed investigation of the newly flooded Sarychaganak Bay (Fig. 2) in 1994 showed that productivity was high in inshore regions (Tabs. IV and V) but is highest where in the areas covered by the sea grasses, *Zostera noltei* and *Ruppia cirrosa*. Shallow regions with surf action and areas without macrophytes have an intermediate level of productivity.

CURRENT CONTRIBUTION OF PLANKTONIC AND BENTHIC COMMUNITIES TO PRIMARY PRODUCTION AND AEROBIC DECOMPOSITION

Oxygen production and consumption have been measured in bottom cores (Orlova, 1993, 1995; Filippov *et al.*, 1998; Assman, 1953; Hayes and McAulay, 1959; Romanenko and Kuznetzov, 1972). For technical reasons, it was only possible to make both measurements where the water column was well lighted. Elsewhere, only decomposition rates were measured. Even in these conditions, which favoured the development of benthic macrophytes, the productivity in the water exceeded the benthic productivity (Tab. V). In the open waters, most photosynthesis and breakdown took place in the plankton. Only in the estuary of the Syrdar'ya and in nearby waters, does the benthic contribution match that of the plankton. The situation in the Sarychaganak Bay is exceptional. Here sea grass covers a third of the bay and in the coastal lagoons, together with filamentous green algae, it covers two thirds of the bottom. The biomass is highest here, reaching 4000 $g\,m^{-2}$, while the total plankton does not exceed 1 $g\,m^{-3}$ (Filippov *et al.*, 1998). It is clear that the changes during the last 30 years have greatly altered the processes of photosynthesis and decomposition in the Aral Sea.

TABLE V Comparative contributions of the plankton and benthos to primary production and decomposition in the Aral Sea 1992–1994

District	*St.*	*Season date*	*Plankton*		*Benthos*		*Whole values*		*Contribution of plankton to:*	
			Ap *mg C* m^{-2}	*Dp* *mg C* m^{-2}	*Ab* *mg C* m^{-2}	*Db* *mg C* m^{-2}	*Aw* *mg C* m^{-2}	*Dw* *mg C* m^{-2}	*Aw* *% of whole value*	*Dw*
Butakov Bay	1	05.1992	830	1117	22	280	852	1397	97	80
Syrdar'ya	1*	05.1993		900		59		959		94
	3*	05.1993		8400		79		8479		99
Syrdar'ya mouth	1*	05.1992		128		337		465		28
	1*	05.1993		176.9		177		353.9		50
	R1	05.1992	521	434	363	264	884	698	59	62
Syrdar'ya estuary	R2	05.1992	250	714	230	145	489	859	51	83
	R1	05.1993	470.4	603.4	753	597	1223.4	1200.4	38	50
Shevchenko Bay	1	09.1992	646	101	53	349	699	450	92	22
Tsche-Bas Bay	1	09.1992	872	126	13	158	885	284	99	44
The Bay near	1*	05.1993	4289	793	2534	221	6823	1014	63	78
Bugun'	2**	05.1993	883	563	222	127	1105	690	80	82
	4*	05.1993		261		287		548		48
Tastubeck	1**	09.1993	1525	1462	34	129	1559	1591	98	92
	2**	09.1993	4805	3747	164	637	4969	4384	97	85
	4*	09.1993		4217		850.52		5067.5		83
	4*	09.1993		4110		620		4730		87
	5*	09.1993		5101		775.28		5876.3		87
Sarychaganack	1**	06.1994	537	37	3471	2741	4008	2778	13	1
Bay	2**	06.1994	1023	889	1321	3275	2344	4164	44	21
	4**	06.1994	132	220	992	827	1124	1047	12	21
	6	06.1994	352	528	691	405	1043	933	34	57
	7	06.1994	1232	572	5452	6019	6657	6591	19	9

** Stations in temporary bodies of water.

* – stations, where transparency was less than depth. It was possible to determine only the total decomposition at these sites.

A, *D* as in previous table.

Whole values – are a sum of data for planktonic and benthic communities ($Aw = Ap + Ab$); ($Dw = Dp + Dw$).

ANIMALS

Zooplankton

A few species of zooplankton now form more than 90% of the animal biomass. The main components are still copepods and the larvae of bivalves but, whereas the commonest copepod was the continental *Arctodiaptomus salinus*, it is now the marine *Calanipedia aquaedulcis* and the larvae of *Dreissena* and *Hypanis* have been replaced by those of *Syndosyma segmentum* and *Cerastoderma isthmicum* (Andreev *et al.*, 1992). At times, the molluscan larvae are more abundant than the crustaceans and can form up to 98% of the plankton. A common but less abundant component of the plankton are rotifers of the genus *Synchaeta*, particularly *S. vorax*. The copepod, *Halicyclops rotundipedes aralanensis*, is also widely distributed but is not usually common. Only in the Small Aral Sea except of Berg's Strait and in Butakov Bay is the once characteristic Aral cladoceran, *Podonevadne camtonyx*, still found (Fig. 4). Although the plankton in both parts of the Aral are generally similar, the lower salinity in the Small Aral Sea allows a wider diversity of species. In the Large Aral Sea, and in the more saline Butakov Bay in the Small Aral Sea, molluscan larvae are more common than crustacean larvae in the spring, but at the end of the spawning season, crustaceans predominate.

In the Small Aral Sea, the biomass and abundance vary with season and conditions but biomasses range from 22 mg m^{-3}, and 2800 ind. m^{-3} and in Shevchenko Bay in the autumn to 437 mg m^{-3} and 203, 300 ind. m^{-3} on the east coast in May. The most fertile region of the Small Aral Sea are the waters around the mouths of the Syrdar'ya. Here the inflow of fresh water forms a stable salinity gradient and provides a continuous supply of organic detritus. In May 1992, the zooplankton density reached 244,000 ind. m^3 and the biomass 705 mg m^3, but in 1993 a similar sample contained only 50,600 ind. m^{-3} and a biomass of 109 mg m^{-3}. The gradients in this area are steep and the distributions are very patchy. This area was always one of the most fertile areas in the Aral Sea (Lukonina, 1960; Andreev, 1989, 1991). The zooplankton density is also high a little further south in the channel on the site of Berg's Strait. In the absence of bivalves on the bottom, the plankton is dominated by copepods, particularly *Calanipedia aquaedulcis*.

In the spring of 1993, after Berg's Strait had been dammed, the water level rose more than a metre, flooding the Bolshoi-Sarychaganak Gulf which had been reduced to a saline lagoon. It now contains a substantial body of water connected to the Small Aral Sea by a narrow strait. Following the flooding, a rich fauna developed, probably due to the release of nutrients from the terrestrial plants that had grown on the dry sea bed (Kuznetsov *et al.*, 1993; Orlova, 1995). In May 1993, the biomass was nearly ten times higher than in the open sea, but the fauna declined in the autumn and remained low in the following spring. Phytoplankton was poor and larval molluscs replaced the crustaceans which had predominated the previous year (Tab. VI). The cycle of plankton in the gulf, since it was refilled, resembles that in many new reservoirs.

Species diversity in the Aral has declined. Of the eight species of rotifers once found, two have disappeared (Andreev, 1989, 1991) and of the five species of cladocerans, four have been lost and the survivor, *P. camptonyx*, occurs only in the Small Aral Sea (Aladin, 1989; Andreev *et al.*, 1992; Aladin *et al.*, 1993). Only two of the five copepods are now found, although *Calanipedia aquaedulcis* is abundant (Aladin *et al.*, 1995; Andreev, 1991). Species diversity in the meroplankton was less affected during the 1980s, although the macrozoobenthos was unchanged (Filippov, 1991, 1993a, 1994; Andreev, 1991). At this time, nearly all the Caspian species disappeared from the Large Aral Sea as the salinity exceeded 23–25‰, which appears to be critical for these species (Plotnikov *et al.*, 1991; Dobrinin and Koroliova, 1991; Aladin, 1991b; Hammer, 1986), but Caspian species still survive in the slightly less saline Small Sea. The only survivors in the Large Sea are the recently introduced marine species and a few halophiles which originated in saline lakes. In all, only one fifth of the original fauna remains. Conditions in the Large Aral are now comparatively stable but the fauna in the Small Aral Sea is in danger as the salinity there is close to, or at, the critical level of 23–25‰ above which the Caspian component cannot survive.

Zoobenthos

During the 1980s data are largely confined to the waters around Barsakelmes Island, where species diversity declined markedly. In

TABLE VI Density (N ind. $10^3\,m^{-3}$) and biomass (B mg m^{-3}) of zooplankton in the Aral Sea 1992–1994

	Place	*Season*	*Rotifers*		*Crustaceans*		*Larval molluscs*		*Total*	
			N	*B*	*N*	*B*	*N*	*B*	*N*	*B*
Large Sea	Tsche-Bas gulf	IX-92	1.4	2.4	8.5	36.6	0.2	0.4	10.0	39.4
	Northern coast	IX-93	0.1	0.2	4.4	18.6	0.1	0.3	4.6	19.3
	Eastern coast	V-93	0.8	1.4	45.6	100.7	23.8	52.9	70.0	155.0
	Shevchenko Gulf	IX-92	2.8	5.0	2.6	7.7	0.0	0.0	5.0	12.7
	Mouth of Syrdar'ya	V-92	0.6	1.1	172.2	547.9	70.9	156.1	243.7	705.0
		V-93	0.4	0.8	31.7	68.2	18.2	40.0	50.6	109.0
Small Sea	Berg's Strait	V-92	0.0	0.1	60.0	158.7	3.3	7.2	63.3	166.0
	Butakov Bay	V-92	4.6	8.3	9.3	29.6	43.2	95.1	57.2	132.9
	Bolshoy Sarychaganak	V-93	1.5	2.7	304.4	649.5	33.3	73.2	304.8	725.4
	Bolshoy Sarychaganak	IX-93	0.4	0.8	27.0	94.1	0.5	0.0	27.9	95.6
	Bolshoy Sarychaganak	VI-94	0.7	1.3	29.9	62.5	14.6	32.0	45.2	95.8
	Bolshoy Sarychaganak	IX-94	0.8	1.5	1.7	5.3	0.2	0.4	2.7	7.1

1984, only two bivalves, *Syndosmya segmentum* and *Cerastoderma isthmicum*, two genera of gastropods, *Casiohydrobia* spp. and *Theodoxus pallasi*, and one polychaete *Nereis diversicolor*, one crab, *Rhithropanopeus harrisii*, and four ostracods were found. By 1990, *Theodoxus* had gone and only one species of ostracod remained (Aladin, 1989). At the same time the biomass declined from 207 to $121\,g\,m^{-2}$. Such changes appear to have been widespread (Andreev and Andreeva, 1991; Filippov, 1991). In 1989, a more extensive survey showed that of the benthic community only bivalves, gastropods of genus *Casiohydrobia*, the polychaete, the shrimp and the crab survived. Chironomid larvae were extremely rare and the biomass of the Large Aral Sea zoobenthos was $108\,g\,m^{-2}$, while that of the Small Sea was $247\,g\,m^{-2}$ (Andreev *et al.*, 1990). The greater fertility is due partly to the higher rate of primary production.

Since 1990, the Zoological Institute of the Russian Academy of Sciences at St. Petersburg has monitored the fauna of the Aral Sea, particularly the macrobenthos (Aladin and Kotov, 1989; Filippov, 1991, 1993a and b). These surveys have shown that there was little change in either sea between 1990 and 1993, although the salinity of the Large Sea increased from 27‰ to 41‰ during this time. The fauna is now extremely monotonous with the same few species almost everywhere. Berg's Strait remains unusual, bivalves are rare, while *Nereis* contributes most of the low biomass. The fauna is uniform even though the salinity ranges from 20‰ to 40‰. For a while, after the Sarychaganak Bay was refilled, the fauna there remained limited but it has now recovered (Tab. VII).

Bacterioplankton

The bacterioplankton have only been studied extensively since 1989 (Sulalina and Smurov, 1993a, b). Densities range from 0.7 to 2.4×10^6 cells ml^{-1}, while the biomass ranged from $0.41\,\mu g\,l^{-1}$ to $1.22\,mg\,l^{-1}$, higher than before the regression began (Novozhilova, 1973). The concentration of heterotrophs was 92 to 380 cells ml^{-3}. Bacterial production in the spring of 1992 was 0.05 to $0.44\,\mu g\,l^{-1}$ each day, but the ratio of production to biomass was low, −0.05 to $0.46\,\mu g\,m^{-3}$. Rod-like bacteria are most abundant, cocci form no more

TABLE VII Density (N, ind. m^{-3}) and biomass (B, gm^{-2}) of the zoobenthos in the Aral Sea 1990–1993

Site	*S. segmentum*		*C. isthmicum*		*Caspiohydrobia*		*N. diversicolor*		*R. harrisii*		*Total*	
(year)	*N*	*B*	*N*	*B*	*N*	*B*	*N*	*B*	*N*	*B*	*N*	*B*
					Small Sea							
Butakov Bay	14310	338.75	304	105.69	8507	30.89	1328	26.11	–	–	24449	501.45
Tastubek core	7145	268.30	602	270.42	18302	40.12	779	3.56	–	–	26828	582.41
Shevchenko Bay	9353	284.27	952	149.59	27803	43.40	1065	6.05	–	–	39173	483.30
Near Bugun	5604	192.15	273	66.72	10774	15.53	785	4.01	–	–	17435	278.41
Sarychaganak Bay	3264	51.48	994	14.17	2704	11.24	3195	28.52	–	–	10157	105.41
Pre-mouth area (92)	1383	27.03	19	6.35	1896	6.16	2489	21.46	–	–	5787	61.01
Pre-mouth area (93)	800	55.20	0	0.00	1916	8.24	770	23.40	–	–	3486	86.84
					Large Sea							
Tsche-Bas Bay (92)	4237	99.28	87	102.12	874	1.73	1870	11.93	42	6.86	7111	221.92
Tsche-Bas Bay (93)	4420	156.09	79	146.76	729	2.22	1379	19.20	63	1.55	6670	325.82

TABLE VIII Phytoplankton abundance in the Aral Sea 1990–1994, (N - density); (B - biomass)

District and season	*Depth (m)*		*Number (min.cells m^{-3}), biomass ($g\ m^{-3}$)* *Cyanophyta*	*Dynophyta*	*Bacillariophyta*	*Chlorophyta*	*Total*	*Authors*
Barsakelmes island	1–1.5v	N	480–4872	60–132	52–486	0–68	536–5490	Dobrynin *et al.*, 1990
(July 1989)		B	no data	no data	no data	no data	no data	
Butakov Bay (Sept. 1990)	1.5–3	N	16–2360	16–160	4–144	4–68	44–2676	Dobrynin and Koroliova, 1991
		B	near 0–0.071	0.087–1.763	near 0–2.695	near 0–0.12	0.14–3.75	
Butakov Bay (Sept. 1991)	data	N	0–64	8–16	28–486	0–4	36–570	Koroliova, 1993
		B	0–0.004	0.08–0.38	0.006–0.239	0–0.0002	0.086–0.653	
Tastubeck (Sept. 1993)	5	N	168–1100	412–1053	252–332	5–10	837–2495	Orlova and Rusakova, 1995
		B	0.0045–0.033	3.89–4.34	2.09–2.91	0.0003–0.002	5.985–7.285	
Sarychaganack Bay (June 1994)	1.2–1.4	N	30–786	2–8	153–504	0	445–1149	Filippov *et al.* (in press)
		B	0.0003–0.112	0.011–0.079	0.188–0.902	0	0.201–0.991	

than 10% of the total and spherical filamentous and spiral bacteria are also found.

DISCUSSION AND CONCLUSIONS

During the prehistoric period the salinity and volume of the Aral Sea were determined by the inflow of fresh water, which in turn was determined by climatic conditions. More recently, the inflow has been determined largely by human activity, particularly by efforts to irrigate the lands around the rivers supplying water to the Aral Sea. The twentieth century is not the first time that the Aral Sea has been deprived of water but the new factors in the present crisis are the chemical contamination of the water by defoliants, pesticides and fertilizers, and the introduction of alien marine species, a few of which can tolerate the elevated salinities better than the native fauna.

PRODUCERS

The changes in salinity and water levels have brought about substantial changes in the primary producers. Except in the immediate area of the river mouths, freshwater species have been replaced by euryhaline or hyperhaline species which can resist both high and variable salinities. After declining during the 1970s and 1980s, as the salinity passed a critical level, both the biomass and species diversity of the planktonic microalgae are increasing again. In contrast, the diversity of the macrophytes and their biomass have been reduced but it may take some considerable time for the macrophytes to adapt to the changes in the depth of water and consequently in the light regime, and to the changes in shoreline, bottom sediments and nutrients.

At the present time, the rates of primary production, both by plankton and benthos are high. Whereas the water was only 55 to 76% saturated with oxygen in the summer in the 1980s, in recent years the water has been 90% saturated (Aladin *et al.*, 1993; Seas of the USSR, 1990). In most areas the phytoplankton are the major primary producers but in recently flooded regions, the benthos makes an important contribution.

CONSUMERS

New communities of both zooplankton and zoobenthos have developed, characterized by extremely low and stable species diversity, capable of surviving in high and fluctuating salinities. The zoobenthos, particularly in the Small Aral Sea, has a high density, perhaps dependent on the input of organic matter form the Syrdar'ya. The zooplankton is noteworthy for the paucity of species but the high density of crustaceans and rotifers. With the virtual elimination of the freshwater and Caspian species, salinity has ceased to be a major environmental factor controlling the distribution of animals. More important factors now are depth, transparency, wind and wave action, and the details of local topography. The recently reflooded Sarychaganak Bay is of special interest as the biota there have not yet reached equilibrium.

FUTURE DEVELOPMENTS

Attempts to conserve the northern or Small Aral Sea have been underway for several years but the future is still uncertain. There are at least three possible future developments. If the attempts to maintain a dam across Berg's Strait are unsuccessful, the sea will continue to dessicate. In this case, the oligo- and meso-haline species will be lost and only the halophilic species will survive, as is now the case in some temporary coastal lagoons, where the salinity reaches 40‰. The available data (Plotnikov *et al.*, 1991; Filippov, 1994; Aladin, 1995) suggests that some organisms of marine origin will survive up to salinities of 60 to 70‰. In higher salinities, the marine species would be replaced by hyperhaline species, ultimately of freshwater origin, which have developed the ability to hypo-osmoregulate, such as chironomids and ephydrids now found in some lagoons. It is possible that some species of *Caspiohydrobia* might survive in salinities up to 100 – 110‰. Even most halophilic species would be lost if the salinity rose to 200‰ (Tseeb, 1982; Hammer, 1986; Timms *et al.*, 1986).

The second possibility is that the water level will be maintained at about its present level with the existing fauna and flora. If sufficient resources become available to control both the water input to the Small Aral Sea and the outflow into the Large Aral Sea, it would be possible to increase the volume of water and to regulate the salinity (Mordukai-Boltovskoi, 1960). Relicts of the earlier fauna and fauna still survive in refuges in the delta. If the salinity was reduced below 15–17‰ these survivors would begin to recolonize the open waters but a full restoration of the brackish and freshwater flora and fauna, and the elimination of most of the most of the alien marine species would probably need a salinity of 10‰ or less.

The third possibility is that the water level will be maintained at about its present level with the existing fauna and flora. If sufficient resources become available to control both the water input in the Small Aral Sea and the outflow into the Large Aral Sea, it would be possible to increase the volume of water and to regulate the salinity. It would then be possible, utilising both the Small Aral Sea and the delta of the Syrdar'ya, to restore the wide range of conditions, and their associated flora and fauna, which existed previously (Filippov, 1994; Karpevich, 1975; Zenkievich, 1963; Kravtsova, 1989; Kchlebovich *et al.*, 1989; Tseeb, 1982; Husainova, 1959; Mordukhai-Boltovskoi, 1972). Relicts of the earlier fauna and fauna still survive in refuges in the delta. If the salinity was reduced below 15–17‰ alien marine species these survivors would begin to recolonize the open waters but a full restoration of the brackish and freshwater flora and fauna, and the elimination of most of the alien marine species, would probably need a salinity of 10‰ or less.

The future of these ecosystems require further work and study in the latter time since restoration.

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