Oceanology, Vol. 42, No. 1, 2002, pp. 91–98. Translated from Okeanologiya, Vol. 42, No. 1, 2002, pp. 98–105.

MARINE BIOLOGY

Productivity of the Aral Sea Benthic Communities

A. A. Filippov

Zoological Institute, Russian Academy of Sciences, St. Petersburg, Russia

Received March 23, 2000

Abstract—The productivity of the Aral Sea benthic assemblages in 1990 and the dynamics from 1950 to 1990 were estimated. In 1990, the marine macrobenthos was characterized by a high abundance of benthic organisms and high productivity of the benthic assemblages. In the coastal zone of the Small Aral Sea, the average biomass was found to be 2.4 times those in the Large Aral Sea and the destruction, production, and ration were 3 times greater than those in the Large Aral Sea. Over the last 40 years, the average values of abundance, biomass, and production of the benthic organisms of the Aral Sea have increased 4–9 times and, despite a more than twofold reduction in the area, the overall stock of zoobenthos grew almost fivefold. The total macrozoobenthos production increased approximately 2.3 times. The Small Aral Sea, which in 1990 was characterized by a high productivity of benthic communities and relatively stabile hydrological regime, has good prospects for fishery development.

INTRODUCTION

The decrease in size of the Aral Sea and the increase in salinity observed since the 1960s have caused a radical reconstruction of the whole ecosystem of the sea. By the beginning of the 1980s, the initial aquatic biocoenoses consisting mainly of fresh- and brackish-water species, had completely degraded. The majority of the autochthonous species are no longer encountered in the sea, whereas the acclimatized euryhaline invertebrates of marine origin have taken the leading positions in the benthic assemblages [1, 6, 18, 22, 23, 31]. Along with the invertebrates, the abundance of the acclimatized fishes, in particular, flounder (Z. Ermakhanov, personal communication) began growing. The stabilization of the water level and salinity in the northern part of the Aral Sea (Small Aral Sea) in the 1990s created conditions for the formation of high-production communities and commercial fishing recommencement.

In the 1990s, a program for the conservation and rehabilitation of the Aral Sea natural resources and fishery recommencement was developed by national and international organizations [29, 31]. For these conservation measures, an assessment of the current state and main tendencies in the sea ecosystem evolution (estimation of the commercial fish potential forage reserve, in particular) is required. The objective of this paper is to study the production characteristics of the Aral Sea benthic communities and to assess their dynamics within the period of the salinity decrease and water level fall.

MATERIALS AND METHODS

In the 1990s, benthic assemblages at eight locations of the Aral Sea northern area were studied (Fig. 1). As there were no vessels able to operate in the open sea, the studies were carried out mainly within the coastal zone. For sampling at depths over 3 m, a small Petersen grab was used; in shallower areas, a rod pneumatic sampler was mainly applied for sampling. In every area studied, 3–12 stations were selected; in each of them, 5 bottom samples were usually collected (Table 1). A total of 585 quantitative samples of the macrozoobenthos was taken. The material collected was processed using standard methods.

The values of the invertebrate biomass and abundance were averaged over each of the areas studied; the data were used for the calculation of the elements of the biotic balance. The values of the daily metabolic expenses, production, and the mass species ration were calculated by the physiological method [26] considering the parameters presented in the literature (Table 2). The food assimilation index was taken as 0.6 for nonpredatory species and 0.8 for predators [4]. The total production of a community was calculated according to the following equation:

$$P_t = P_{np} + P_p - A_p,$$

where P_t is the total production of a macrozoobenthos community; P_{np} is the production of nonpredatory species; P_p is the production of predators; and A_p is assimilation in the predatory zoobenthos [4]. The efficiency of the food utilization in the macrozoobenthos production was estimated with the coefficient K_1, calculated by the following formula:

$$K_1 = P/C,$$

where P is the production of the macrozoobenthos community and C is the total ration of the bottom invertebrates [12]. It was considered in the calculations that 50% of the ration of crabs and chironomid larvae from the *Procladius* and *Cryptochironomus* genera were

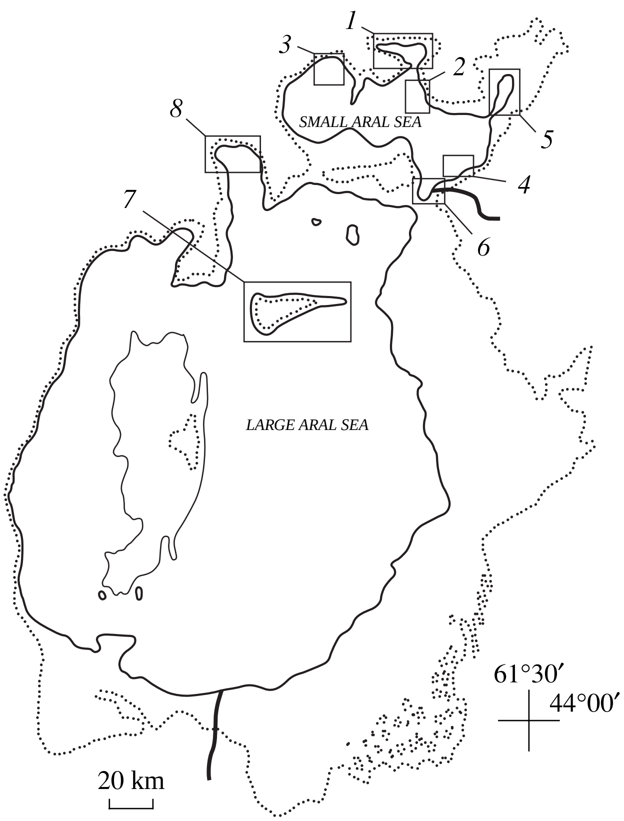

Fig. 1. Areas of the Aral Sea studies in the 1990s: *1*—Butakov bay; *2*—area of the Tastyubek Peninsula; *3*—Shevchenko Bay; *4*—area of Bugun' village; *5*—Bol'shoi Sarycheganak Bay; *6*—Berg Strait; *7*—area of Barsakel'mes Island; *8*—Tshche-Bas Bay. Dotted line—the coastline in 1960.

covered by predation within the macrozoobenthic community. Polychaetes were considered to be detritofages, as no invertebrate species able to be a food source for their predatoriness had been preserved in the macrobenthic communities by the moment of the expansion of polychaetes over the sea.

RESULTS

Within the benthic assemblages of all the sites studied, the same groups of invertebrates were encountered: bivalves *Abra ovata* and *Cerastoderma isthmicum*, gastropods *Caspiohydrobia* spp., and polychaetes *Nereis diversicolor.* In addition to them, in the Large Aral Sea, benthic crabs *Rhithropanopeus harrisii tridentatus* were indicated. These were found in the grab samples only in the Bay of Tshche-Bas, though visually they were noted within the coastal waters of Barsakel'mes Island.

The sites studied were characterized by high abundances of the bottom invertebrates (Table 3). The values of the benthos abundance and biomass in the Small Aral Sea, as a rule, were higher than those in the Large Aral Sea. Both the species composition and the ratio of main taxa in the macrozoobenthos were very similar at most of the sites studied. Practically everywhere, the bivalves *A. ovata* and *C. isthmicum* were dominants in the biomass; while the snails *Caspiohydrobia spp.* prevailed mostly in the abundance.

The high values of the abundance and biomass of bottom invertebrates determined the high intensity of the production and destruction processes in the bottom biocoenoses (Table 4). As a result of the monotony in the community structure, the distributions of the functional characteristics were found to be similar to the abundance distributions. The maximum values of the destruction rate, production, and rations of the benthic organisms per unit area were found in the Small Aral Sea, in which they were approximately three times greater than in the Large Aral Sea (Table 4).

Among the sites studied, the regions of the Berg Strait and Bol'shoi Sarycheganak Bay were the most distinguished with regard to the bottom community structure. In the first region, the bivalves, which usually dominate in the macrobenthic communities, were extremely small in number. The biomass was mainly formed by polychaetes, and the total abundance of the organisms was very low. In the shallow part of the strait directly adjoining the Syr-Daria River mouth, the bivalves were entirely absent and the benthos was exclusively represented by polychaetes. The bottom community of Bol'shoi Sarycheganak Bay was in many respects similar: the total density and biomass of the benthos was low, while the abundance of polychaetes was comparably high and the bivalve settlements were poorly developed (Table 3, Fig. 2).

According to the distribution of the relative abundance values, the bivalves (mainly *A. ovata*) made the biggest contribution to the processes of the organic matter transformation in the macrozoobenthic communities over the entire water area studied. Due to the high gastropod production and the absence of the carnivorous crab *R. harrisii* in the Small Aral Sea, the difference in the functional indexes between the Large and Small Aral seas was found to be even more considerable than that in the average abundance values.

Unlike most of the other areas of the sea, in Bol'shoi Sarycheganak Bay and the former Berg Strait, the main part of the production was formed by polychaetes (Fig. 3). In these areas, the calculated values of the production of benthic assemblages were the smallest for the entire sea (Table 4).

DISCUSSION

The data obtained were mainly characteristic of the Aral Sea coastal zone. Apparently, they differ considerably from the sea average values of the macrobenthos abundance and production. Thus, the results of the occasional studies in the open parts of the sea at the beginning of the 1990s [5] showed that the Large and

Table 1. Characteristics of the sampling locations

Area	Month, year	Depth, m	Salinity, ‰	Number of samples
Small Aral Sea				
Butakov Bay	September 1990	1.0–3.2	38–41	40
–	September 1997	1.0–3.5	36	45
Tastyubek Peninsula area	September 1991	1.0–6.0	26	45
–	September 1993	1.5–8.5	18–20	60
Shevchenko Bay	September 1992	1.5–8.0	23–25	90
Bugun' village area	May 1993	1.5–8.0	19–25	65
Bol'shoi Sarycheganak Bay	June 1994	0.5–1.7	21–26	30
Berg Strait				
Syr-Daria River mouth area	May 1992	0.8–4.0	13–25	40
–	May 1993	1.5–4.0	15–25	10
Large Aral Sea				
Barsakel'mes Island area	May 1990	0.5–4.5	30	35
–	May 1991	1.0–5.0	35	60
Tshche-Bas Bay	October 1992	1.0–6.0	41	20
–	June 1993	1.6–6.0	41	45

Table 2. Indexes of dependence of the metabolic rate on the body weight ($R = aW^b$, where R is the respiration, ml O h^{-1}, and W is the average weight of animals, g) and the coefficients of efficiency of food assimilation for the body growth (K_2), used for calculations of the biotic balance

Taxa	Indexes		Source	K_2	Source
	a	b			
Crustaceans	0.125	0.759	[19]	0.20	[19]
Oligochaeta	0.105	0.750	[13]	0.30	[13]
Polychaeta	0.186	0.810	[13]	0.26	[21]
Chironomidae	0.091	0.747	[20]	0.50	[7]
Trichoptera	0.368	0.818	[11]	0.56	[11]
Bivalvia	0.079	0.750	[3]	0.26	[21]
Gastropoda	0.126	0.750	[9]	0.26	[21]

Small Aral Seas had no essential differences in mean quantitative characteristics of the macrozoobenthos. As was stated, the considerable distinction between the Large and Small Aral Seas in the coastal zone bottom invertebrate abundances could result from the features of the vertical distribution of the macrozoobenthos in these parts of the Aral Sea. As we showed earlier [22], the highest biomass of the benthos was formed in the deeper parts of the Large Aral Sea compared to the Small Aral Sea. Thus, in the Small Aral Sea, the depth range studied covered the zone of the highest biomass, while in the Large Aral Sea it did not. Evidently, this is the main explanation for the essential differences in the macrozoobenthos density and production in the parts of the Aral Sea mentioned.

The depression of the bottom community registered in the area of the Syr-Daria delta (the former Berg Strait) was observed before the beginning of the salinity growth in the Aral Sea [14]. Obviously, it was related to the instability if the environmental characteristics and frequent appearance of conditions unfavorable to mollusks. Thus, during our observations in the area studied,

Table 3. Average density (N, ind. m^{-2}) and biomass (B, g m^{-2}) of the main groups of bottom invertebrates in the Aral Sea areas studied in 1990–1997

Area (year)	*A. ovata*		*C. isthmicum*		*Caspiohydrobia* spp.		*N. diversicolor*		*R. harrisii*		Total	
	N	*B*	*N*	*B*	*N*	*B*	*N*	*B*	*N*	*B*	*N*	*B*
Small Aral Sea												
Butakov Bay (1990)	14310	338.75	304	105.69	8507	30.89	1328	26.11	–	–	24449	501.45
Butakov Bay (1997)	17294	410.16	172	159.98	22608	61.17	2218	15.31	–	–	42292	646.62
Tastyubek Peninsula area (1991)	7145	268.30	602	270.42	18302	40.12	779	3.56	–	–	26828	582.41
Tastyubek Peninsula area (1993)	12547	365.11	478	109.49	7539	17.08	2053	10.16	–	–	22616	501.84
Shevchenko Bay	9353	284.27	952	149.59	27803	43.40	1065	6.05	–	–	39173	483.30
Bugun’ village area	5604	192.15	273	66.72	10774	15.53	785	4.01	–	–	17435	278.41
Bol’shoi Sarycheganak Bay	3264	51.48	994	14.17	2704	11.24	3195	28.52	–	–	10157	105.41
Average	9931	272.89	539	125.15	14034	31.35	1632	13.39	–	–	26136	442.78
Berg Strait												
Syr-Daria mouth area (1992)	1383	27.03	19	6.35	1896	6.16	2489	21.46	–	–	5787	61.01
Syr-Daria mouth area (1993)	800	55.20	0	0.00	1916	8.24	770	23.40	–	–	3486	86.84
Average	1092	41.12	10	3.18	1906	7.20	1630	22.43	–	–	4637	73.93
Large Aral Sea												
Barsakelmes Island area (1990)	1798	65.93	28	14.75	389	1.35	452	10.31	0	0.00	2667	92.34
Barsakelmes Island area (1991)	1079	102.47	24	19.32	286	0.88	258	3.26	0	0.00	1647	125.93
Tshche-Bas Bay (1992)	4237	99.28	87	102.12	874	1.73	1870	11.93	42	6.86	7111	221.92
Tshche-Bas Bay (1993)	4420	156.09	79	146.76	729	2.22	1379	19.20	63	1.55	6670	325.82
Average	2884	105.94	55	70.74	570	1.55	990	11.18	26	2.10	4524	191.50

an essential desalination (Table 1) and elevated contents of suspended matter in the water (up to 19 g/m^3 [17]) was observed. Earlier, it has also been shown that this region was characterized by a considerable seasonal and annual variability of the hydrological regime [8].

The instability of the environmental conditions also was the most probable reason for the formation of the specific structural and functional features of the Bol’shoi Sarycheganak Bay biocoenoses. Due to the fall of the Aral Sea level, from 1987 to 1992, the bay was separated from the sea and its salinity was considerably increased. As a result, the initial aquatic communities of the bay completely degraded [24]. Our studies in this area were carried out two years after the reestablishment of the connection with the Small Aral Sea and the basin of the bay had been refilled with water again. Apparently, within the period of observation, the bay biocoenoses continued to develope.This explains the essential distinctions of the macrozoobenthos community structure from those in the other parts of the sea.

It is interesting to note that the benthic communities of the Berg Strait and Bol’shoi Sarycheganak Bay are very similar to the Caspian biocoenoses in the newly flooded land areas under a rise in the sea level [15]. Evidently, the above-mentioned structural features, expressed in the mass development of the nereis and comparatively low share of the bivalves in the total macrozoobenthos biomass, are characteristic of the Aral and Caspian biocoenoses under unfavorable conditions or at the early stage of succession.

The analysis of the data on the dynamics of the Aral Sea benthic assemblages in the second half of the 20th century [5, 6, 22] showed that, despite an almost tenfold decrease in the macrozoobenthos fauna, its productivity over the last 40 years has essentially

Table 4. Mean values of the oxygen consumption rate (R), production (P), and ration (C) of macrozoobenthos in the Aral Sea areas studied in 1990–1997 (kcal m^{-2} day^{-1})

Area (year)	*A. ovata*			*C. isthmicum*			*Caspiohydrobia* sp.			*N. diversicolor*			*R. harrisii*			Total		
	R	P	C	R	P	C	R	P	C	R	P	C	R	P	C	R	P	C
Small Aral Sea																		
Butakov Bay (1990)	7.96	2.80	17.92	1.27	0.45	2.86	1.85	0.65	4.17	1.20	0.42	2.69	–	–	–	12.27	4.31	27.64
Butakov Bay (1997)	9.63	3.38	21.69	1.50	0.53	3.38	3.94	1.38	8.88	0.85	0.30	1.93	–	–	–	15.93	5.60	35.87
Tastyubek Peninsula area (1991)	5.62	1.97	12.65	3.04	1.07	6.86	2.72	0.96	6.14	0.21	0.08	0.48	–	–	–	11.60	4.08	26.13
Tastyubek Peninsula area (1993)	8.15	2.86	18.35	1.46	0.51	3.28	1.15	0.40	2.59	0.60	0.21	1.36	–	–	–	11.36	3.99	25.58
Shevchenko Bay	6.27	2.20	14.13	2.19	0.77	4.93	3.21	1.13	7.23	0.35	0.12	0.79	–	–	–	12.02	4.22	27.08
Bugun’ village area	4.11	1.45	9.27	0.87	0.31	1.97	1.17	0.41	2.64	0.24	0.08	0.53	–	–	–	6.40	2.25	14.41
Bol’shoi Sarycheganak Bay	1.34	0.47	3.01	0.38	0.13	0.85	0.65	0.23	1.47	1.52	0.53	3.42	–	–	–	3.88	1.36	8.75
Average	6.15	2.16	13.86	1.53	0.54	3.45	2.10	0.74	4.73	0.71	0.25	1.60	–	–	–	10.49	3.69	23.64
Berg Strait																		
Syr-Daria River mouth area (1992)	0.67	0.23	1.50	0.08	0.03	0.17	0.38	0.13	0.85	1.15	0.40	2.59	–	–	–	2.27	0.80	5.11
Syr-Daria River mouth area (1993)	0.99	0.35	2.24	0.00	0.00	0.00	0.47	0.17	1.07	0.99	0.35	2.22	–	–	–	2.45	0.86	5.52
Average	0.83	0.29	1.87	0.04	0.01	0.09	0.43	0.15	0.96	1.07	0.38	2.40	–	–	–	2.36	0.83	5.32
Large Aral Sea																		
Barsakel’mes Island area (1990)	1.39	0.49	3.13	0.16	0.06	0.36	0.08	0.03	0.18	0.46	0.16	1.03	0.00	0.00	0.00	2.09	0.73	4.70
Barsakel’mes Island area (1991)	1.70	0.60	3.83	0.19	0.07	0.42	0.05	0.02	0.12	0.16	0.06	0.37	0.00	0.00	0.00	2.11	0.74	4.74
Tshche-Bas Bay (1992)	2.34	0.82	5.27	0.90	0.32	2.04	0.12	0.04	0.27	0.68	0.24	1.52	0.15	0.04	0.32	4.19	1.36	9.26
Tshche-Bas Bay (1993)	3.32	1.17	7.47	1.16	0.41	2.61	0.14	0.05	0.31	0.94	0.33	2.11	0.06	0.01	0.11	5.61	1.93	12.57
Average	2.19	0.77	4.92	0.60	0.21	1.36	0.10	0.03	0.22	0.56	0.20	1.26	0.05	0.01	0.11	3.50	1.19	7.82

Table 5. Total stocks of the invertebrates and intensity of the organic matter transformation in the Aral Sea macrozoobentos community

Area	Per 1 m^2				For all the sea				
	B_{av}	R_{av}	P_{av}	C_{av}	All the sea	B_{tot}	R_{tot}	P_{tot}	C_{tot}
	1954–1957				1954–1957				
All the sea	22.16	0.57	0.32	1.48	64110	1421	36.25	20.75	94.94
	1992				1992				
All the sea	203.92	3.94	1.38	8.86	34330	7000	135.12	47.47	304.31
Large Aral Sea	200.80	3.90	1.37	8.78	31500	6325	122.76	43.13	276.49
Small Aral Sea	238.60	4.36	1.53	9.83	2830	675	12.35	4.34	27.82

Note: The sea area is calculated from [28], km^2; B_{av}—average biomass, g m^{-2}; R_{av}, P_{av}, and C_{av}—average values of the respiration rate, production, and ration, respectively, kcal 10^9 day^{-1}; B_{tot}—total stock, kt; R_{tot}, P_{tot}, and C_{tot} are the respective total values.

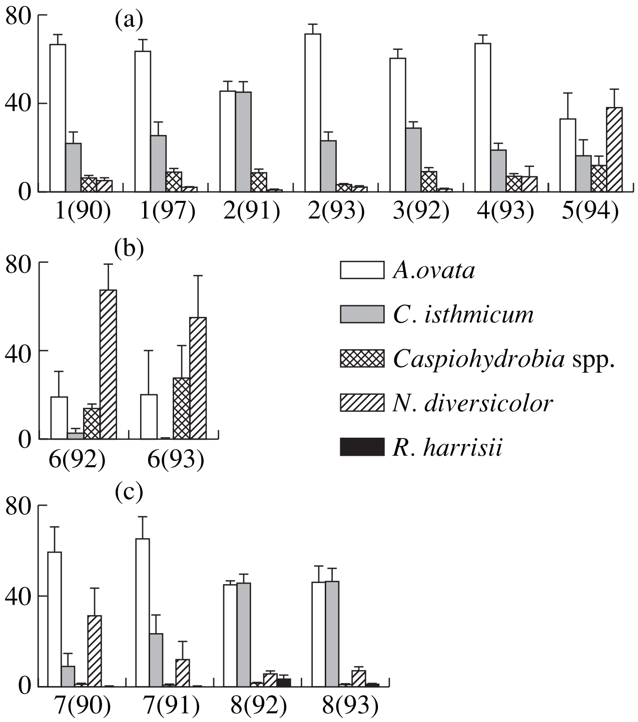

Fig. 2. Relative biomass of the main groups of macrozoobenthos in the Aral Sea areas studied in the period 1990–1997. (a) Small Aral Sea; (b) Berg Strait; (c) Large Aral Sea; *x*-axis—area studied (see Fig. 1 for legend); *y*-axis—percentage of the total macrozoobenthos biomass; vertical bars—errors in mean values.

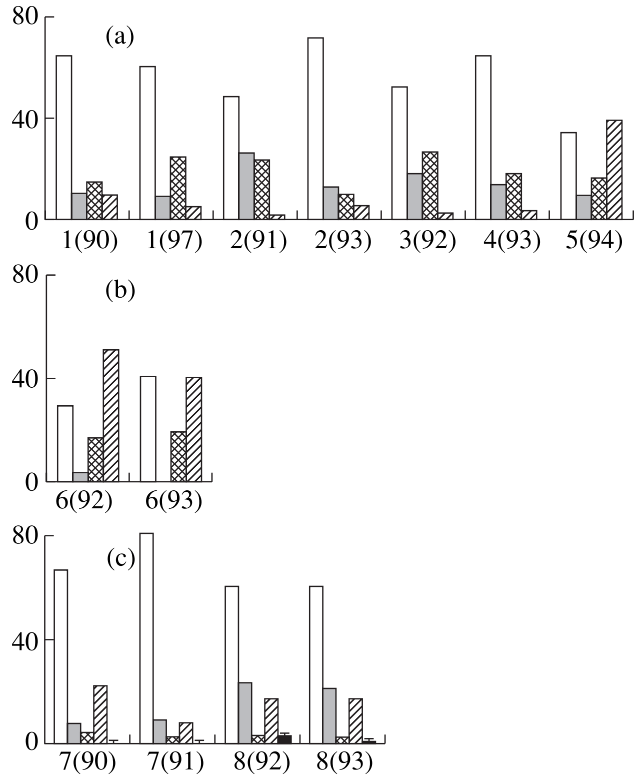

Fig. 3. Relative production of the main groups of macrozoobenthos in the Aral Sea areas studied in the period 1990–1997; *y*-axis—percentage of the total macrozoobenthos production; see Fig. 2 for other symbols.

increased. In comparison to the years 1954–1957, the average biomass of the benthic organisms increased more than ninefold (Table 5). According to our calculation of the biotic balance, the intensity of the organic matter destruction and bottom invertebrate rations grew approximately 6–7 times. Over the period of the observations, the production of the benthic assemblages per unit area increased by a factor of 4.2. The lower growth in the production as compared to the destruction and ration values was related to the drop in the efficiency of the food usage for the increase of the biocoenosis biomass (Fig. 4) because of the changes in the zoobenthos species composition. Thus, while before the salination the major part of the biomass was formed by chironomids, in the modern Aral Sea benthic assemblages their niche is occupied by polychaetes. Polychaetes are not as effective as chironomids in using the assimilated food for biomass accumulation (Table 2). In addition, the bivalves, which are not characterized by a high growth rate and high K_2 values, clearly increased their role in the total benthos biomass (from 60 to 97%).

When comparing the rates of the organic matter transformation in the Aral Sea in the 1950s and 1990s, it should be considered that all the estimations of the biotic balance indexes were carried out for a standard temperature of 20°C. Meanwhile, the decrease in the average depth of the sea and reduction of its area during the modern regression have led to a fast heating of the near-bottom water layers in the spring and growth in the maximal water temperature in the summer [8]. Taking into account the dependence of physiological processes on temperature, we can suggest that the actual productivity of the benthic assemblages was even higher than that suggested by our estimations.

However, the reason for the growth of the bottom biota abundance and production under the conditions of the radical reduction of the riverine runoff and the respective decrease in the amount of nutrients supplied with the riverine waters still seems unclear. Usually, the absence of grazing by fishes and the presence of salinity conditions favorable for the every haline species are offered as the explanation of this situation [1, 2, 6]. We may also assume that the enhancement of the trophic status of the reservoir provided the basis for the growth in the productivity of the benthic assemblages. The instrumental measurements of the primary production of the Aral Sea waters carried out in the 1990s [16] brought evidence of the essential growth of the primary production rate in comparison to the 1960s. Moreover, the hydrochemical data [8, 25] indicated a considerable increase in the nutrient content in the Aral waters. From our point of view, there are several reasons for such a

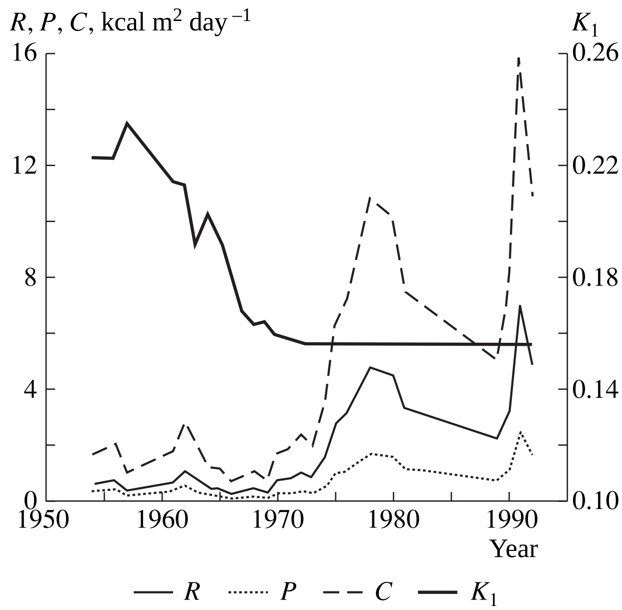

Fig. 4. Dynamics of the bottom invertebrate destruction (R), production (P), and ration (C) and efficiency of food utilization for biomass accumulation (K_1) in the Aral Sea macrozoobenthos communities in the years1954–1992. Calculated from [5, 6].

situation. It might result from the washing out of the nutrients buried in the sediments due to the sea level fall and the increase in the nutrient (and other salts) concentrations in the water column induced by evaporation of the major part of the water. Among other explanations, there are also cessation of the regular nutrient removal by commercial fishery, acceleration of the nutrient turnover because of the macrophyte degradation, and the decrease in the water depths, which resulted in the rise in the summer temperatures and intensification of the wave stirring of the near-bottom water layers.

Due to the considerable contraction of the sea area from the 1950s to the 1990s, an analysis of the long-term dynamics of the total stock and production of the benthic organisms in the reservoir is a matter of special interest. According to our estimations (Table 5), despite the twofold decrease in the sea area over the above-mentioned period, the total stock of the benthic organisms became almost 5 times as great. Meanwhile, a 3- to 4-fold growth in the total organic matter destruction and an almost identical increase in the bottom invertebrate rations was observed. The overall rate of the secondary production also increased by a factor of 2.3.

Thus, in the 1980s–1990s, the Aral Sea has turned into a highly productive reservoir. This was supported by the formation of the hydrological and hydrochemical conditions favorable for the present-day inhabitants of the Aral Sea. Despite the contraction of the sea area, the food stock for benthopfageous fishes considerably increased. The high productivity of the Aral Sea benthic assemblages makes this reservoir a perspective object for commercial fishing. Above all, this refers to the Small Aral Sea, in which the stabilization of the hydrological regime and the water level creates favorable conditions for the functioning of the biocoenoses.

ACKNOWLEDGMENTS

This study was supported by UNESCO and the Russian Academy of Sciences (Department for General Biology and the Young Scientists Commission).

REFERENCES

1. Aladin, N.V., Plotnikov, I.S., and Filippov, A.A., Changes in the Aral Sea Ecosystem Resulting from the Anthropogenic Impact, *Gidrobiol. zh.*, 1992, vol. 28, no. 2, pp. 3–11.
2. Aladin, N.V. and Kotov, S.V., Natural Condition of the Aral Sea Ecosystem and its Response to the Anthropogenic Impact, *Tr. Zool. Inst. Akad. Nauk SSSR*, 1989, vol. 199, pp. 4–25.
3. Alimov, A.F., Intensity of Metabolism in the Poikilothermal Aquatic Animals, *Obshchie osnovy izucheniya presnovodnykh ekosistem* (General Foundations of the Studies of Freshwater Ecosystems), Leningrad: Nauka, 1979, pp. 5–20.
4. Alimov, A.F., *Vvedenie v produktsionnuyu gidrobiologiyu* (Introduction to Productional Hydrobiology), Leningrad: Gidrometeoizdat, 1989.
5. Andreev, N.I., *Gidrofauna Aral'skogo morya v usloviyakh ekologicheskogo krizisa* (Hydrofauna of the Aral Sea under the Conditions of an Ecological Crisis), Omsk: Omsk. Pedagogich. universitet, 1999.
6. Andreeva, S.I., Macrozoobenthos of the Aral Sea at the Initial Stage of Its Salination, *Tr. Zool. Inst. Akad. Nauk SSSR*, 1989, vol. 199, pp. 53–82.
7. Balushkina, E.V., *Funktsional'noe znachenie lichinok khironomid v kontinental'nykh vodoemakh* (Functional Significance of the Midge Larvae in Inland Water Basins), Leningrad: Nauka, 1987.
8. Bortnik, V.N. and Chistyaeva, S.P., Eds., The Aral Sea, *Gidrometeorologiya i gidrokhimiya morei SSSR* (Hydrometeorology and Hydrochemistry of the Seas of the USSR), Leningrad: Gidrometeoizdat, 1990, vol. 7.
9. Vinberg, G.G. and Belyatskaya, Yu.S., Relation of the Metabolic Intensity to the Body Weight for Freshwater Gastrpoda Mollusks, *Zool. Zh.*, 1959, vol. 38, no. 8, pp. 1146–1151.
10. Golubkov, S.M., Dependence of the Oxygen Consumption Rate on the Body Weight for the Aquatic Larvae of Insects, *Gidrobiol. zh.*, 1986, vol. 22, no. 4, pp. 78–87.
11. Golubkov, S.M., Functional Ecology of the Larvae of Amphibiotic Insects, *Doctoral (Biol.) Dissertation*, St. Petersburg, 1999.
12. Ivlev, V.S., On the Energy Transformation at the Growth of Invertebrates, *Byull. Mosk. O-va ispyt. prirody, Otd. biol.*, 1938, vol. 47, no. 4, pp. 267–277.
13. Kamlyuk, L.V., Energy Exchange in the Free-Living Flat and Segmented Worms and the Factors Controlling It, *Zhurn.obshch.biol.*, 1974, vol. 35, no. 6, pp. 874–885.
14. Karpevich, A.F., Condition of the Fodder Base in the Southern Seas after the Regulation of the Riverine Run-

off, *Tr. soveshchanii Ikhtiol. komissii* (Trans. of the Workshop of the Ichtyological Commission), Akad. Nauk SSSR, 1953, no. 1, pp. 124–150.

15. Latypov, Yu.Ya., Gul'bin, V.V., and Yakovlev, Yu.M., The Caspian Sea-Level Rise and Its Impact on the Coastal Communities, *Biol. Morya*, 1995, no. 21(4), pp. 281–285.
16. Orlova, M.I., Materials to the General Estimation of the Production–Destruction Processes in the Coastal Zone of the Northern Part of the Aral Sea. Vol. 1. Results of the Field Observations and Experiments of 1992, *Tr. Zool. Inst. Akad. Nauk SSSR*, 1993, vol. 250, pp. 21–37.
17. Orlova, M.I., Materials to the General Estimation of the Production–Destruction Processes in the Coastal Zone of the Northern Part of the Aral Sea. Vol. 2. On Some Peculiar Features of the Ecosystem Functioning in the Syr-Darya River Delta Region and on the Shoals of the Adjacent Sea Bay, *Tr. Zool. In-ta Ross. Akad. Nauk*, 1995, vol. 262, pp. 47–64.
18. Plotnikov, I.S., Zooplankton of the Aral Sea (Small Aral Sea) under the Conditions of Stabilizing Its Regime, *Tr. Zool. Inst. Akad. Nauk SSSR,* 1994, vol. 262, pp. 33–44.
19. Sushchenya, L.M., *Intensivnost' dykhaniya rakoobraznykh* (Respiration Intensity of Crustaceans), Kiev: Nauk. Dumka, 1972.
20. Toderash, I.K., Energy Balance of Midge Larvae, *Obshchie osnovy izucheniya presnovodnykh ekosistem* (General Foundations of the Studies of Freshwater Ecosystems), Leningrad: Nauka, 1979, pp. 31–42.
21. Umnov, A.A. and Alimov, A.F., Relation of the Production to the Total Energy Flux through a Population, *Obshchie osnovy izucheniya presnovodnykh ekosistem* (General Foundations of the Studies of Freshwater Ecosystems), Leningrad: Nauka, 1979, pp. 133–139.
22. Filippov, A.A., Macrozoobenthos of the Coastal Zone in the Northern Part of the Aral Sea under the Present-Day Polyhaline Conditions: Abundance, Biomass, and Spatial Distribution, *Tr. Zool. Inst. Akad. Nauk SSSR*, 1995, vol. 262, pp. 103–166.
23. Filippov, A.A., On the Salinity Resistance of the benthic organisms of the Aral Sea, *Tr. Zool. Inst. Akad. Nauk SSSR*, 1995, vol. 262, pp. 65–102.
24. Filippov, A.A., Orlova, M.I., Rusakova, O.M., *et al.*, Plankton and Benthos of Bol'shoi Sarycheganak Bay (Aral Sea), *Gidrobiol. zh.*, 1998, no. 4, pp. 15–32.
25. Tsytsarin, A.G., Present-Day Condition of the Elements of the Hydrological Regime of the Aral Sea, *Tr. Gos. Okeanogr. Institute.*, 1991, vol. 183, pp. 72–91.
26. Shushkina, E.A., Physiological Technique for Calculations of the Production of Species Populations, *Metody opredeleniya produktsii vodnykh zhivotnykh* (Methods for Determination of the Production of Aquatic Animals), Minsk: Vysheishaya Shkola, 1968, pp. 126–135.
27. Yablonskaya, E.A., Present-Day Condition of the Zoobenthos of the Aral Sea, *Tr. Vses. Nauch.-Issled. Inst. Rybol. Okeanogr.*, 1960, vol. 43, no. 1, pp. 115–149.
28. Bortnik, V.N., Kuksa, V.I., and Tsytsarin, A.G., Present Status and Possible Future of the Aral Sea, *Post-Soviet Geography*, 1992, vol. 33, no. 5, pp. 315–323.
29. *Ecological Research and Monitoring of the Aral Sea Deltas. A Basis for Restoration*, UNESCO Aral Sea Project, 1992–1996 Final Scientific Report, Paris: UNESCO, 1998.
30. Orlova, M.I., Aladin, N.V., Filippov, A.A., *et al.*, Living Associations of the Northern Part of the Aral Sea in 1993–1995, *Ecological Research and Monitoring of the Aral Sea Deltas. A Basis for Restoration*, UNESCO Aral Sea Project, 1992–1996 Final Scientific Report. Paris: UNESCO, 1998, pp. 95–139.
31. *Sustainable Use of Natural Resources of Central Asia*, Yashenko, R., Kosali, T., Pachikin, K., *et al.*, Eds., Proc. Int. Sci. Conf., Almaty, Sept. 9–11, 1997, Almaty: Tethys, 1998.